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Electric vehicle conversion based on distance, speed and cost requirements

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Abstract

The improvement of environmental awareness emerges issues on new technology leading to environmentally friendly technology. One of the said technologies is electric vehicle (EV) technology. EV brings zero emission concepts as the positive result of electric motor propulsion system. Zero emission concepts in this term can be applied not only in a built-in EV but also in converting a fossil fueled vehicle into its electric version. Considering financial curb and the available choices of new vehicles, vehicle conversion becomes an effective investment alternative in line with vehicle utility purpose. Just like EVs, the electric vehicle conversion performance requirements depend on few targets which are trip distance, speed and cost. The electric vehicle conversion based on daily trip distance can be designed according to the required battery capacity. The capacity of the battery divided by the average of energy consumption of each kilometer can be used to predict the range distance from fully to low charged of EV batteries. Speed target depends on the electric motor power used. When more speed is needed then more power is needed from electric motor. The electric motor power affects voltage and current specification required. Hence, affects the battery specifications. Increasing the battery voltage can increase the electric motor power, instead reduces the battery maximum current. One of the problems of electric vehicle conversion is the cost. Cost target is the boundaries that appear in addition to technical limits. Optimization of the mileage and speed can be affected by the cost target. The cost effectiveness is also an impact on the determination of EV conversion performance requirements based on the trip distance and speed. About 20-50% of EV conversion cost is the battery. It depends on battery type used. Therefore when requirement of EV conversion is based on cost it is better to start with determining the battery then the required drive components.

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Keywords: electric car conversion; trip distance; speed; cost

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1. Introduction

The improvement of environmental awareness emerges issues on new technology leading to environmentally friendly technology. One of the said technologies is electric vehicle (EV) technology. EV brings zero emission concepts as the positive result of electric motor propulsion system. Zero emission concepts in this term can be applied not only in a built-in EV but also in converting a fossil fueled vehicle into its electric version. Considering financial curb and the available choices of new vehicles, vehicle conversion becomes an effective investment alternative in line with vehicle utility purpose.

The policy to use alternative energy source other than oil has been a big subject in developed country as a mission to lessen oil dependency and as an effort to reduce the cost of energy. President Obama, as the example, releases a memorandum on cutting oil dependency as much as 30% for government vehicles, thus based on that memo, the General Services Administration (GSA) created a pilot project to implement the EV and its technology to government vehicles [1]. The same thing is also done by the government of China, by mandating that 30% of government vehicles should use alternative energy. The vehicles would cover electric, plug in hybrid and fuel cell vehicles. For this reason, China targets 5 million units of EV will be available on the road in 2020 [2].

The choice to convert a vehicle has been done by several communities as well as governments. Electric Vehicle of America (EVA) states that the impact of electric vehicle conversion includes maintenance cost savings which embrace costs born for tune up, engine replacement, exhaust improvement, and engine cooling system repair. To sum up, advantages of electric vehicle conversion are the following:

- Used vehicle recycling
- Decreasing air pollution level
- Eliminating the need to replace lubricant
- Erasing the obligation to use water cooling system
- Enabling user to conduct most vehicle maintenance independently [3].

Indonesian Institute of Sciences (LIPI) has done a conversion to its operational vehicle. Retrofitted in 2009, the vehicle is now still works well on the given electric propulsion system. The conversion was conducted to a 1994 Toyota Kijang Super in Fig. 1, a seven passenger car with 1500 cc engine using carburetor fuel system. The built concept was performance similarities of the vehicle when using gasoline and using electricity. Therefore, power and torque of the electric motor became the main priority to be fulfilled in that electric vehicle conversion system. The specification of the converted car is:

- 3 Phase inductive motor with maximum power of 52 HP, maximum torque of 156 Nm, and maximum rotation of 6500 rpm
- Space vector typed motor controller with maximum voltage of 96 VDC and maximum current of 550 A
- Deep cycle lead acid battery of 96 VDC 235 Ah, 135 minutes on 75 A
- Charger with approximate power of 2800 W, maximum current of 25 A
- DC-DC converter with maximum power of 400 W
- EHPS and electric vacuum pump
- Average distance per charge is 75 km

Fig. 1. Converted Toyota Kijang into one with electric motor propulsion

2. The concept methods

Concept needed in an EV conversion is the vehicle performance requirement. Performance requirement means demand of the vehicle users. Optimum value from investment of EV conversion becomes customable. There are three factors regarding with EV performance requirement, which are distance, speed and cost. Consequently EV conversion can be planned based on distance or speed. Furthermore, it would be a cost function which will affect the optimum values of distance and speed.

The concept starts with knowing the vehicle type that will be converted and understand each EV propulsion components. Heavier vehicles need more power than the lightweight ones. There are two major components that should be considers before doing EV conversion, i.e. the battery and the electric motors.

- The Battery;
  There are currently two battery types which can be used for EV conversion, i.e. Deep Cycle Lead Acid in either flooded or maintenance free forms, and Lithium. Second type battery is the best option, but the price is still too high.
- The Electric Motor;
  The electric motor related to propulsion technology and acquired total system efficiency. Conventional electric motor which is commonly used is Brush DC motor. This type electric motor is easy on speed controller design but have disadvantage due to presence of mechanical commutator, causing maintenance need if it worn out. The Induction motor have role to maintenance free feature. It designed without mechanical commutator, but designing the speed controller is more complicated, causing the presence of three sinusoidal waves to be feed to the electric motor. Efficiency of an induction motor is better than brush DC motor. New technology also bore the Brushless DC (BLDC) electric motor or Permanent Magnet Synchronous Motors (PMSM). Certain manufactures claiming that their electric motor product is the highest in efficiency, but the other comments that need more development for this type electric motor.

The batteries and electric motors in market made up of many brands and specifications. The combination of these two components will determine the best option of distance, speed and cost which expected.

3. EV conversion concept discussion

3.1. Distance

Distance concept for EV conversion is its daily distance. EV is more suitably utilized a city daily commuting vehicle, like when people go back and forth from their houses to offices. A survey carried out by General Motor in early 90s indicates:

- The majority of people do not travel far when driving
- More than 40% of the whole travels are below 5 miles (8 km)
- Only 8% people travels beyond 25 miles (40 km)
- Almost 85% drivers travel below 75 miles (120 km) every day.

Performance design based on distance depends on battery capacity, vehicle weight, wind resistance and driving style. If wind resistance is deemed insignificant and driving style can be conditioned, only battery capacity and vehicle weight that would have effects on vehicle distance design. Generally a converted vehicle with battery voltage of 120 VDC will be able to travel as far as 75 miles (120 km) per charge when vehicle weight can be made less than 3000 pounds (1360 kg) [4]. To obtain distance prediction electricity energy consumption per kilometer should be assumed. This assumption would differ for each vehicle, based on its type in Table 1.

Table 1. Electricity energy consumption based on vehicle types [5]

Vehicle types	Energy consumption (kWh/km)
Passenger car	0.20
Truck (freight)	0.80
Bus	0.80
Motorcycle	0.03

Battery capacity can be calculated from specification sheet issued by battery manufacturers. That capacity was acquired by multiplying battery voltage with Ah value of the battery.

$$Capacity(Wh) = battery\ voltage\ x\ Ah\ x\ number\ of\ battery \quad (1)$$

Distance prediction is achieved from dividing battery capacity with electrical energy consumption for every kilometer.

$$Trip\ distance(km) = \frac{Capacity\ (Wh)}{Energy\ Consumption\ \left(\frac{Wh}{km}\right)} \quad (2)$$

A passenger car which uses deep cycle type of lead acid battery with specification of 6 VDC 235 Ah and battery capacity of 1,410 Wh, if its battery total voltage is 96 VDC there will be 16 batteries of 6 VDC each. Therefore battery capacity of the vehicle would be 16 x 1,410 Wh = 22,560 Wh. Theoretically distance would be 22,560/200 = 112.8 km. In real application, that value will not be accomplished since battery capacity cannot be used until it is really empty. There will always a minimum energy stored in the battery, however the energy cannot move the vehicle. The minimum energy is energy that equivalent with tractive resistance of the vehicle. Explanation about tractive resistance will be elaborated in Speed Target section below.

$$Battery\ minimum\ power\ (W) = Tractive\ resistance\ (W) \quad (3)$$

Practically, only 70% of the battery capacity can be consumed before the battery starts to drop low. Accordingly, the realistic prediction of the distance would be 112.8 km x 0.70 = 78.96 km. In actual condition, distance traveled will reach around that value.

$$Probably\ trip\ distance\ (km) = Trip\ distance\ (km)\ x\ 0.70 \quad (4)$$

For other types of battery, like lithium-ion or lithium-polymer, the distance traveled might be farther. This can happen due to the energy density and power density of the lithium batteries which in fact higher than those of lead acid. Lithium-ion and lithium-polymer which have same capacity as lead acid will have smaller dimension and lighter weight. As a result, the energy consumption per kilometer will decline which happens from the decline of traction resistance due to weight reduction.

3.2. *Speed*

City roads, highly populated with vehicles, will not allow vehicles to run in high speed. Nevertheless some people demand their vehicles to have same speed before and after conversion. This is to guarantee a satisfaction in converting an EV.

Speed target relies on the performance of electric motor. The components of electric motor performance are determined by the employed propulsion system.

- Electric motor power, which is influenced by the ability of motor controller, which are battery voltage and maximum current.
- Electric motor torque, which depends on the maximum current produced by motor controller.
- Propulsion system efficiency, which depends on the type of electric motor used and the efficiency of motor controller.

Efficiency is also available on power transmission components of the vehicle, which are transmission, propeller shaft and differential. However in EV conversion the efficiency of power transmission component is regarded ideal or constant.

To find out the performance requirement in order to achieve the speed target, resistances work on a vehicle should be calculated. Those resistances are forces which prevent the vehicle from moving, which called Tractive Resistance. Tractive resistance consists of rolling resistance, air resistance, gradient resistance and inertia [6].

3.2.1. Rolling resistance (Frr)

Rolling resistance is force that prevents wheel from rolling from its idle position (speed = 0 km/h). Crr is rolling resistance coefficient, rolling resistance coefficient between wheel frontage and road surface. Wheel frontage pattern and type of road surface affect the coefficient. When vehicles run on asphalt road, Crr is 0.03 [7].

$$Frr = Crr\ x\ m\ x\ g \quad (5)$$

3.2.2. Air resistance (Fd)

Air resistance is force prevents vehicle to achieve a certain speed due to aerodynamic factor. In equation (6), v is vehicle speed. Wind speed (v_o) is not included in the calculation. If so, then v equals ($v \pm v_o$). v_o is positive when it is against the direction of the vehicle and negative when it is in the same way with the vehicle. A is vehicle surface area against the wind, which called frontal area. Cd is drag resistance. A times Cd (CdA) is drag area. For example, CdA for Jeep Cherokee is 12.81 and 6.85 for Honda Civic [8].

$$Fd = 0.5\ x\ \rho\ x\ v^2\ x\ A\ x\ Cd \quad (6)$$

3.2.3. Gradient resistance (Fg)

As an illustration, Fig. 2 shows vehicle in its position on a slope. Angle created between horizontal and the slope is θ. Several industrial vehicle manufacturers call the ability of the vehicle to run on a slope as Gradeability. Unit for gradeability is percent. Gradeability is calculated by multiplying tan θ with 100%. For speed target, ignoring gradient resistance (Fg = 0) is common since speed target is defined under the assumption that road is flat.

$$Fg = m\ x\ g\ x\ sin\theta \tag{7}$$

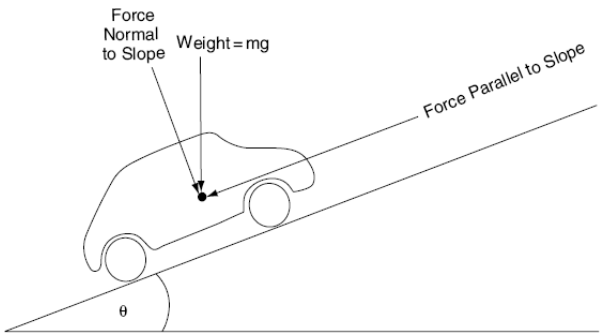

Fig. 2. Forces acting on a vehicle when driving on a gradient condition [6]

3.2.4. Inertia (Fi)

Inertia is force that inhibits the vehicle to reach a certain speed in a certain time. It is impossible for vehicle to achieve a certain speed from its idle position without acceleration. Therefore to get to certain speed, the vehicle should be able to perform acceleration. Acceleration is actually loads for the driving motor. For instance, a vehicle weighted 1,000 kg will need 10 seconds to reach a speed of 100 km/h (27.8 m/s) from its rest position.

$$Fi = m\ x\ a \tag{8}$$

All of those resistance components are to be added to get the value of tractive resistance. The values of wheel dimension, transmission ratio and differential affect the minimum power needed by the propulsion to move the vehicle.

$$Ftr = Frr + Fd + Fg + Fi \tag{9}$$

Another consequence of need for speed on EV conversion is the increase of power of electric motor. The increase of motor power will in turn increase the voltage. Increasing current to boost power is not a good approach. The enlarged current will raise the temperatures of the motor, cables and power electronic components. The best approach is adding the voltage of the battery. On equivalent battery capacity, voltage increase will decrease the value of Ah. For several kinds of battery, the shrink of Ah value relates to the shrink battery capability to generate its maximum current.

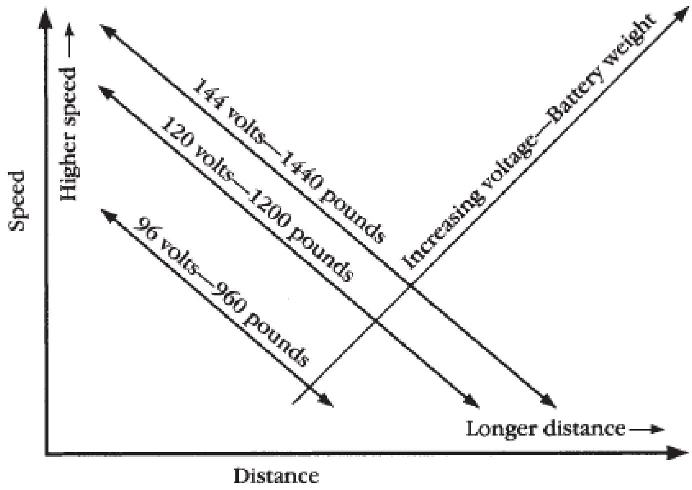

Fig. 3. The higher battery voltage, the higher the achieved speed will be [4]

3.3. *Cost*

The advantage of EV conversion is that there is no strict limitation in term of financing. Moreover, EV conversion is also a form of education tool for vehicle owner to freely decide his choice based on the amount of investment he would like to have. As shown in Fig. 3, battery voltage increase corresponds to distance and speed improvements although conversion cost will increase as well. Financing target is another restriction surfaces beside technical restrictions. Optimization of distance and speed can be influenced by financing target. Financing effectiveness is also the outcome of the performance requirement of EV conversion either based on distance or speed. Even some experts can demonstrate the financing of EV conversion based on voltage system needed for conversion.

- Conversion for voltage system of 48 VDC is USD 4,317
- Conversion for voltage system of 96 VDC is USD 4,917
- Conversion for voltage system of 144 VDC is USD 6,317 [9].

Those are prices examples applied in The United States. For Indonesia, some additional cost should be borne. Those conversion prices cover all basic components essential for conversion except the battery. Global Battery Indonesia releases a deep cycle lead acid price list normally used on golf cart. Those prices are ranging from two to three million rupiah, depends on battery type and capacity [10]. Some batteries have a progressive price reduction, however some others demands rising price. Fig. 4 show that National Research Council estimates that there will be a battery cost decline of more than 50% from current price in 2020 [11].

The fall of battery price can happen due to the growing demand of EV or Plug-in Hybrid Electric Vehicle (PHEV). As a result, battery manufacturers set a target to produce batteries up to several MWh per year.

In addition, the financing of EV conversion is also influenced by the technology of electric motor implemented. The technology used is connected with efficiency enhancement of the electric motor. The more efficient the motor, the cooler and more powerful it is, hence longer distance to travel. On the other hand, this condition results in higher cost. The average efficiency of 3 phase AC electric motor is 85%, higher than that of series wound DC motor which is 65%. However, 3 phase AC motor is more expensive than its series DC counterpart.

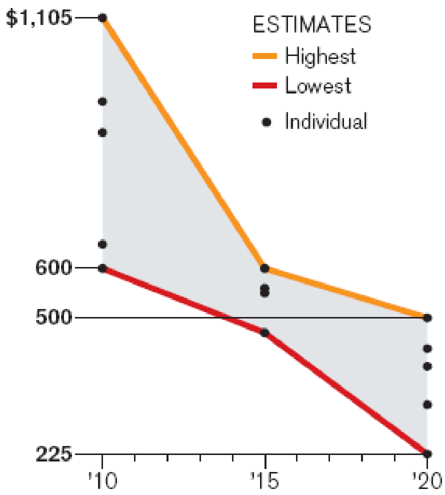

Fig. 4. Annual estimates of battery price per KWh

Furthermore, even when the voltage used is similar, which is 72 VDC, performance of EV conversion kits on conversions done using 3 phase AC motor and series DC motor would be different.

- Conversion kit for series DC motor with maximum power of 40 HP is $ 2,618 [12]
- Conversion kit for 3 phase AC inductive motor with maximum power of 48 HP is $ 3,220 [13]

Research on improving electric motor efficiency is done intensively. One of them is the application of synchronous motor using permanent magnet rotor for EV. Some call this type of motor as Brushless DC motor, which has the efficiency of 95%. This means, the longer the distance, the higher the performance and conversion cost will be.

4. Conclusion

As result, the best choice to decide EV conversion is based on how to choose performance requirement. If conversion is done based on distance, maximum speed should be set first, then the battery capacity. On the contrary, when conversion will be done based on speed, distance is not prioritized. When financing is the constraint then combination of distance, speed and optimum efficiency should be established. To get longer distance using same voltage system, battery capacity should be enlarged. This will keep electric motor in same performance; however its distance will rise. Higher speed can be obtained by using high performance electric motor, yielding voltage increase. To keep the battery capacity similar to avoid additional weight and space within the vehicle, battery with higher voltage and smaller Ah should be utilized. Battery cost reaches approximately 20-50% of EV conversion cost. As an example, for 144 volt system, the batteries using 6 volt in series, will need 24 batteries. The batteries would be priced around USD 3,360. If based on 144 volt conversion system, which price is USD 6,317, and using 6 volt batteries, total price will be USD 9,677. So the batteries price is 34% of the total cost of conversion. This variety is due to the kind of battery used. It depends on voltage, capacity and types of the battery. Therefore, when EV conversion is done based on financing, it is better to start with battery choice then the required drive component afterward.

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