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A Study on an Electric Power System Design of a Small Electric Vehicle

Hansub Sim*,#
*Gyeongnam National University of Science and Technology

소형 전기자동차의 전기동력시스템에 관한 연구

심한섭*,#
*경남과학기술대학교

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ABSTRACT

The electric power system design of the electric vehicle are required to improve the performance. The electric power system on the electric vehicle are consist of a battery, a pedal sensor, an electric motor and a controller. In this paper, Automotive manufacture's various electric vehicle models are investigated and analyzed. The mathematical models for the electric power system are studied, and then important variables are considered. Simulation and experimental test results show the model of the electric power system on the electric vehicle and design parameter decision are effective to the electric vehicle design.

Key Words : Electric Vehicle(전기자동차), Electric Power System(전기동력시스템), Modeling(모델링), Vehicle Design(자동차설계)

1. Introduction

Studies on electric vehicles that use electric energy as a power source have been continuously performed to protect the atmospheric environment from the exhaust gas of automobiles with an internal combustion engine that uses petroleum energy such as gasoline and diesel. Additionally, governments from several countries are implementing various programs to reduce the economic burden of consumers through support for the purchase of automobiles and tax reduction to commercialize and distribute electric vehicles. In addition, they have made efforts to expand the charging systems, which are essential for the distribution of electric vehicles. The greatest obstacle for the commercialization of electric vehicles is the performance related to the energy density and charge time of a battery that stores electric energy. The performance related to the energy density of the battery is the maximum distance that the electric vehicles can drive using the electric energy stored in the battery in the electric vehicle. It is possible to expand the capacity of the battery to increase the mileage by a single charge of the battery in the electric vehicle, but this expansion increases the

Corresponding Author: hansub@gntech.ac.kr
Tel: +82-55-751-3644

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weight and price of the vehicle. The increased weight decreases the running performance, and the increased price increases the purchase cost.

In addition to the general technology in existing automobiles with an internal combustion engine, additional studies on electric power systems for driving using electric energy are necessary to research and develop electric vehicles. Therefore, the electric power system, which determines the running performance of the electric vehicle, consists of a battery, a battery management system (BMS), a motor controller, and an electric motor. Optimized design and research are required for the electric power system.[1-3]

In this study, we analyze the performance of the power control system by studying the electric vehicle developed and sold by the automobile manufacturer. We also express various elements of the control system and their combination in a mathematical model by studying and modeling the electric power system of the small electric vehicle. Then, we determine the constraints and variables to understand the response characteristics of the system. Based on these results, it is possible to predict the main performance of the actual system and determine important performance variables. These performance variables and design values may be used to design the power control system.

2. Investigation and analysis of the electric power system

The electric motor power and a single-charge mileage of the electric vehicle are the most effective factors to determine the performance of the electric vehicle. Fig. 1 shows the electric motor power and mileage of an electric vehicle for riding, which was manufactured by an automobile manufacturer. The electric motor power of the electric vehicle is approximately 50~150 kW, and the single-charge maximum mileage is mainly 100~200 km. The electric motor power and mileage were significantly increased in a high-performance electric vehicle (Tesla). The electric motor power and single-charge mileage of a small electric vehicle, where one or two persons can board, are shown in Fig. 2. The electric motor power is approximately 60 kW or less, and the single-charge mileage is approximately 160 kW or less. Specifically, electric vehicles with a motor power of approximately 15 kW are classified into two mileage groups: 55-70 km and 100~120 km. When the electric motor power is 30-55 kW, the mileage is classified into 80 km and 140-160 km. These small electric vehicles are classified as near-field electric vehicles (NEV) and urban electric vehicles (UEV). These results will significantly help the determination of the motor power and battery capacity on development of electric vehicles.

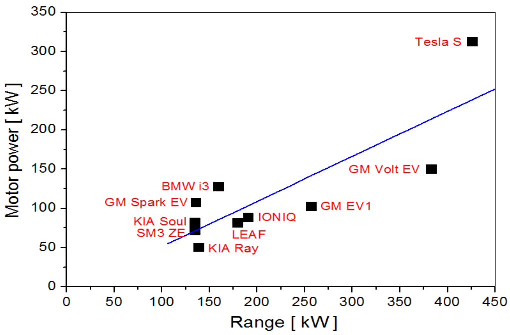

Fig. 1 Motor power vs. range on passenger EVs

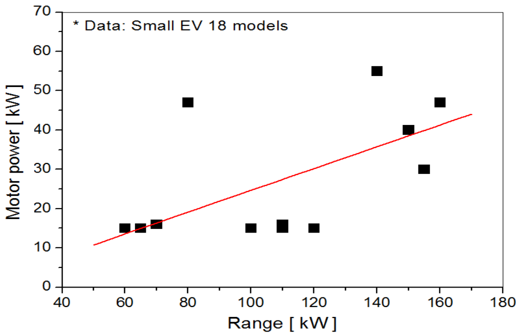

Fig. 2 Motor power vs. range on small EVs

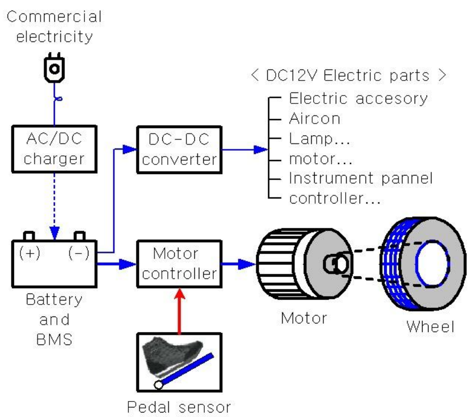

Fig. 3 Power control system of an electric vehicle

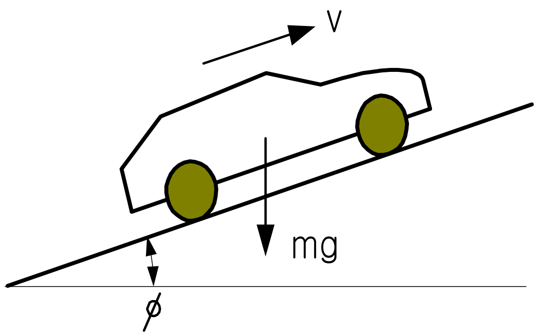

Fig. 4 An electric vehicle driving along a slope

3. Modeling of an electric power system

3.1 Configuration of the electric power control system

The power control system of a small electric vehicle consists of a battery, a motor controller, a motor and a pedal sensor, as shown in Fig. 3. The battery stores electrical energy and provides the energy required to drive the electric vehicle. The electric motor generates torque and rotates the wheel. The charger uses the commercial power to charge the battery. In addition, the DC 48 V must be converted to DC 12 V using a DC-DC converter to operate electrical units for DC 12 V parts.

3.2 Dynamic modeling

When an electrical vehicle drives on an inclined road as shown in Fig. 2, the resistance force on the vehicle is given by equation (1).[4]

$$F_t = F_{rr} + F_{air} + F_{hc} + F_{acc} \quad (1)$$

F_{rr} : rolling resistance force

F_{air} : aerodynamic drag force

F_{hc} : hill climbing force

F_{acc} : acceleration force

The driving resistance force (F_t) on the electric vehicle during driving is expressed by equation (2) for each element.

$$F_t = \mu_{rr} W + \frac{1}{2}\rho A C_d v^2 + W\sin\phi + \left(m + \frac{IG^2}{\eta_g r^2}\right) a \quad (2)$$

μ_{rr} : coefficient of rolling resistance

W : weight(=mg)

m : mass

g : gravity acceleration

ρ : air density

A : frontal area

C_d : drag coefficient

v : vehicle speed

ϕ : slope angle

I : inertia

G : gear ratio

η_g : gear efficiency

r : radius of a tyre

a : acceleration speed

Equation (2) indicates that the weight reduction factors that affect the running performance (W, A, I), aerodynamic design values (A, Cd), and rolling resistance of the tires should be decreased, and the power transmission efficiency(η_g) should be improved. When the electric vehicle drives on a flat road(ϕ=0), the gradient resistance does not work (F_{hc}= 0).

The torque (T) generated in the electric motor is transmitted to the driving wheel by the power transmission device, and the driving force is equal to the running resistance (F_t) of the electric vehicle, as shown in equation(3).

$$\frac{G}{r}\eta_g T = F_t \quad (3)$$

Equations (2) and (3) show that when the electric vehicle accelerates on a flat road (φ=0), the speed and acceleration can be obtained from equation (4).

$$\frac{G}{r}\eta_g T = \mu_{rr} W + \frac{1}{2}\rho A C_d v^2 + (m + I\frac{G^2}{\eta_g r^2})a \quad (4)$$

3.2 Driving power

The power required to drive an electric vehicle is shown in equation (5). The electrical efficiency of the electric motor(η_e) and mechanical efficiency(η_m) of the power transmission device should be considered.[5-6]

$$P_{ideal} = \frac{F_t v}{\eta_e \eta_m} \quad (5)$$

η_e : electrical efficiency

η_m : mechanical efficiency(=η_g)

When the electric vehicle drives on a flat road at a constant speed, the required power is shown in equation (6). (φ=0, a=0, F_{hc}=0,F_{acc}=0)

$$P_{rr+air} = (\mu_{rr} W + \frac{1}{2}\rho A C_d v^2)\frac{v}{\eta_e \eta_m} \quad (6)$$

Equation (6) is a relational expression to determine the battery capacity of an electric vehicle. Moreover, it is necessary to consider the required power and remaining power for various electrical units.

4. Experiments and Result

4.1 Design and experiment of a small electric vehicle

The small electric vehicle of this study for one passenger was designed and produced based on the investigation and analysis of the research and development cases of automobile manufacturers, electric vehicle modeling and basic knowledge. Table 1 shows the main specifications of the self-produced test vehicle. Fig. 5 shows the components of the electric power system, and Fig. 6 is a photograph of the test vehicle. The vehicle weight is approximately 210 kgf, and the maximum speed was limited to 60 km/h. The power system is 48 V and has a 10-kW BLDC motor for driving. The motor torque is transmitted to the chain, and the reduction gear ratio is 4.75:1. The vehicle also has basic features such as steering, suspension, and brake system.

4.2 Results and discussion

Fig. 7 is the required power of the test electric vehicle at a constant speed according to equation (6). The power required at a constant speed (v=100 km/h) is approximately 12.5 kW. However, the capacity for driving the electric vehicle requires additional consideration of the operation of the accessory electrical equipment and the remaining power.

Fig. 8 shows the speed change, which was obtained by applying various variables (Table 1) of the test small electric vehicle to equation (4) and calculating equations (7) and (8). Experimental values of the manufacturer were used for the torque of the electric motor. The maximum speed of the test electric vehicle was limited to 60 km/h for safety issues.

$$\frac{dv}{dt} = 1.657772 - 001617\, v^2,\ (v_{EV} \le v_c) \quad (7)$$

$$\frac{dv}{dt} = 1.665772 - 0.054372 v + 0.001617 v^2,\ (v_{EV} > v_c) \quad (8)$$

The test electric vehicle accelerated to 60 km/h with maximum torque from 0 to 11.5 sec. Then, it maintained the speed limit (60 km/h) for safety by control program of the motor controller.

Table 1 Technical specifications of the experimental electric vehicle

Dimension	L2.23m × W1.34m × H1.37m
Weight	210kg$_f$
Max. velocity	60km/h
Motor power	10kW, 48V BLDC motor
Transmission	chain-sprocket, gear ratio=4.75:1
Battery	DC48V
Wheel radius	265mm
Passenger	1-person

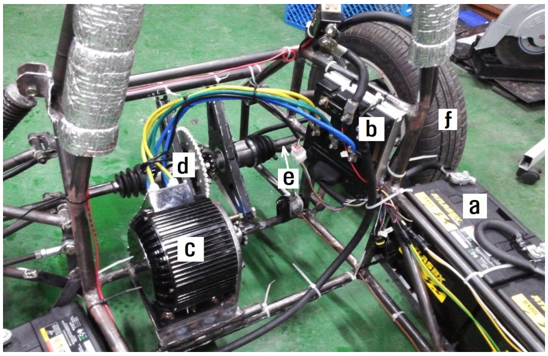

Fig. 5 Electric power system : (a) battery, (b) motor controller, (c) BLDC motor, (d) chain sprocket and differential gear, (e) drive shaft, (f) wheel

Fig. 6 Electric vehicle driving test on the test road

Fig. 9 shows the voltage drop of a battery during driving at a relatively constant speed (v=50~60 km/h). The initial battery voltage decreased from 49.7 V to 46.5 V after 1 hour of driving, and the decrease rate was approximately 0.05 V per minute.

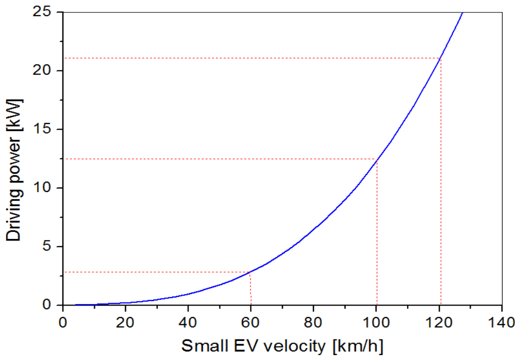

Fig. 7 Driving power at various speeds

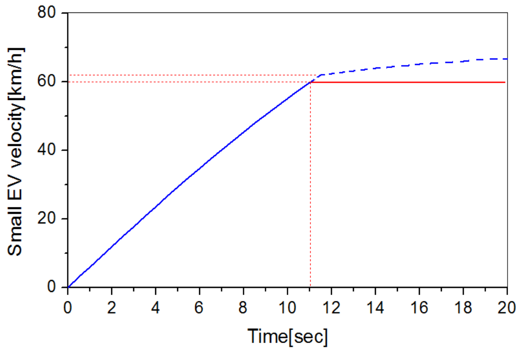

Fig. 8 Acceleration of the electric car

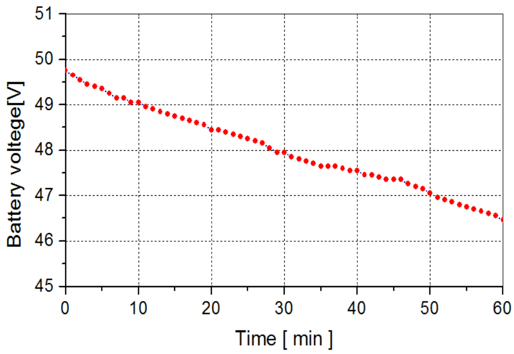

Fig. 9 Battery discharging test on driving test

4. Conclusion

The case study and analysis, modeling, design and performance test of the electric power system of the small electric vehicles led to the following conclusions.

1. The performance information, which includes the motor power and mileage of the electric vehicles developed by the automobile manufacturers, was analyzed. The information can be used as reference data such as the electric motor power, mileage, and battery capacity in the actual design.
2. A mathematical model of the electric power system of electric vehicles was examined, and a model to predict the required electric energy capacity was presented.
3. The design, production and performance test of the small electric vehicle confirm that the mathematical model and performance prediction of the electric power system and the design process of the vehicle based on the model and prediction are valid.

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