

Evaluation of Vehicle Performances of an Electric Bus in Service

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Abstract

Reduction of pollutants in exhaust gas from engine vehicles remains as an important issue on the protection of the environment. Developments of treatment devices, such as catalyst, have contributed to reducing pollutants in exhaust gas significantly. Nevertheless, reducing pollutants in exhaust gas to zero is impossible. Electric vehicles demonstrate an environmental compatibility by the feature that they do not emit exhaust gas from their own.

Providing performances of heavy duty electric vehicles which include charging to users will be important as steps to clarify the positions of such vehicles in markets. Light weight electric vehicles are already available in markets. On the other hand, heavy duty electric vehicles are not predominant yet. Short range and long charging time are major disadvantages. Nevertheless, there are still possibilities, such as route buses and refuse collection vehicles [1], which heavy duty electric vehicles can cover. The performance of heavy duty electric vehicles which may be limited in comparison with light weight electric vehicles should be informed to help the users to deploy such vehicles to their applications properly.

In this paper, measured results of vehicle performances of an electric bus in services will be reported focusing on factors which give impacts on electric energy consumption. The electric bus accompanying dedicated charging system was developed to provide over 100 km drive length in day time. This electric bus provides 120 km service for all day time with supplemental charges between services. The charger was developed to adopt high voltage by a modified protocol of CHAdeMO standard [2]. In the final part, issues on the test methods of heavy duty electric vehicles will be discussed.

Keywords: electric vehicle, bus, energy consumption, Japan

1. Concept and specification of the electric bus

1.1 Concept of the electric bus

The electric bus accompanying dedicated charging system was developed to provide over 100 km drive length in day time. Figure 1 shows an example of frequency distribution of length between origins and destinations of route buses in commercial sites in Japan. This figure represents that the distribution has a peak below 15 km. However, at least 100 km of range of an electric bus is demanded from suggestions which were delivered by bus drivers' interviews. The range of 100 km will include not only commercial routes length but also length to commute from bus pools to regular commercial routes.

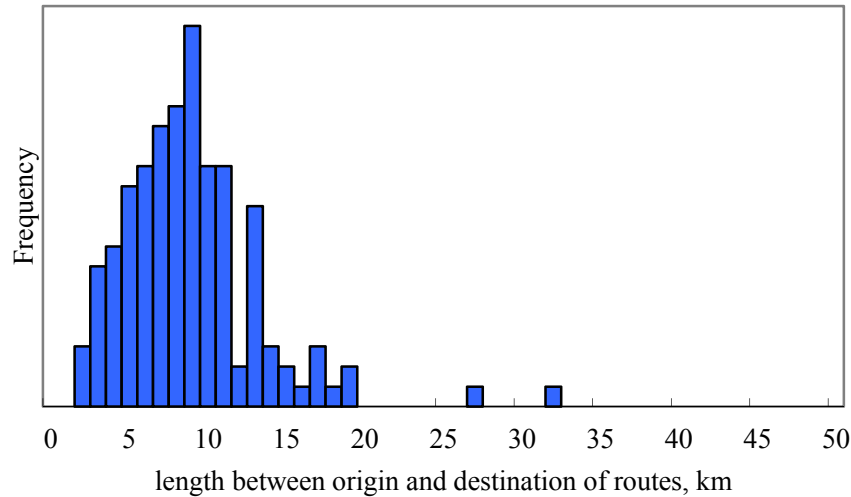


Figure 1: Frequency distribution of length between origins and destinations of route buses

On the other hand, electric buses with commercially available battery technologies provide limited range per charge. Route buses need to be designed to provide sufficient services for people who might have difficulties on traffic. For instance, low floor and kneeling functions which reduce gaps between the floor and ground level are quite common functions between routes buses as passenger-friendly technologies [3]. However, these functions may limit spaces to install large batteries. Providing 100 km of range under actual traffic conditions is very challenging to keep such passenger friendly technologies.

Supplemental charging could become a compromised solution which provides at least 100 km of range installing basic passenger friendly technologies. In order to deal with sufficient supplemental charging between services, a dedicated charging system was developed by components which were based on commercially available technologies. The charging power was increased up to 75kW with the components which were developed by modified components and protocols based on CHAdeMO standard.

1.2 Specification

The electric bus is the first electric bus to be obtained type approved under the Japanese type approval test. The specification of the electric bus is shown in Table 1. Photographs of the electric buses are displayed on Figure 2. The estimated range of the electric bus was 100km with JE05 (JE05 is a test cycle for Japanese approval test method of heavy duty vehicles [4]). However, the range under actual traffic stations usually shortened in comparison with the range obtained by measurement with specific test cycles (for example, NEDC [5]). Thus, the range of the electric bus will be shorted in the real world.

Table 1: Specification of the electric bus

Parameters	Value/
Number of passengers	67 (includes 1 driver)
Weight	11,560 kg
Maximum speed	85 km/h
Battery pack	621.6V / 150 Ah / 93.24 kWh
SOC(State Of Charge) window	10 – 90 %
In normal operation	
Usable electric energy In Normal operation	74.6 kWh
Estimated range (with JE05 mode)	100 km

The electric bus has the function of regeneration. The regenerative function could be used during breaks manually by the driver. The regenerative function cannot provide cooperative operation with mechanical break system of the electric bus.



Figure 2: Photographs of electric buses and map of operation sites

2. Method

2.1 Sites and routes where the electric buses were operated

The data of vehicle performances of the electric bus was acquired during services. The vehicle performances were measured on two different routes which were in Kitakyushu-city, Fukuoka prefecture and Satumasendai-city, Kagoshima prefecture. The features of both locations are shown in Table 2. In order to observe the electric energy consumption for auxiliary units, such as air conditioner, the data was acquired in winter season.

Table 2: Features of both locations

	Kitakyushu-city	Satumasendai-city
Period for data acquisition	9 days of Oct. Nov. (2014), A/C off of Cooler on Jan. (2015), Heater on	9 days of Nov. Dec. (2014) , A/C off of Cooler on Feb. (2015) , Heater on
Total length of a day	40 km	104 km
Duration of the route	35 minutes	30 minutes
Number of charging of a day	1	3
Variation in altitude in the route	45 m	15 m

2.2 Measured parameters

The measured parameters are listed on Table 3.

Table 3: Measured parameters

Parameters	Units
① Motor rotation	rpm
② Battery current	A
③ Battery voltage	V
④ Battery SOC(State Of Charge)	%
⑤ Battery temperature	°C
① Vehicle speed	km/h
② Altitude	m
③ Drive length	km

3. Results

3.1 Drive length of all day

120km drive length per day was delivered inserting several supplemental charges for short period between the services. The range per one time charge exceeded 120km. Figure 3 shows the variations of vehicle speed and electric parameters of the electric bus against time. The time table of the operation was specially arranged for the electric bus considering its performance. Vehicle performances, such as electric consumption, were reported. In the bottom of the figure, the drive length of all day service is represented. In this case, all periods between services were set around 60 minutes which allowed recovering the SOC up to the maximum level of the normal operation window. In each period, the SOC levels were recovered up to 90% within 30 minutes.

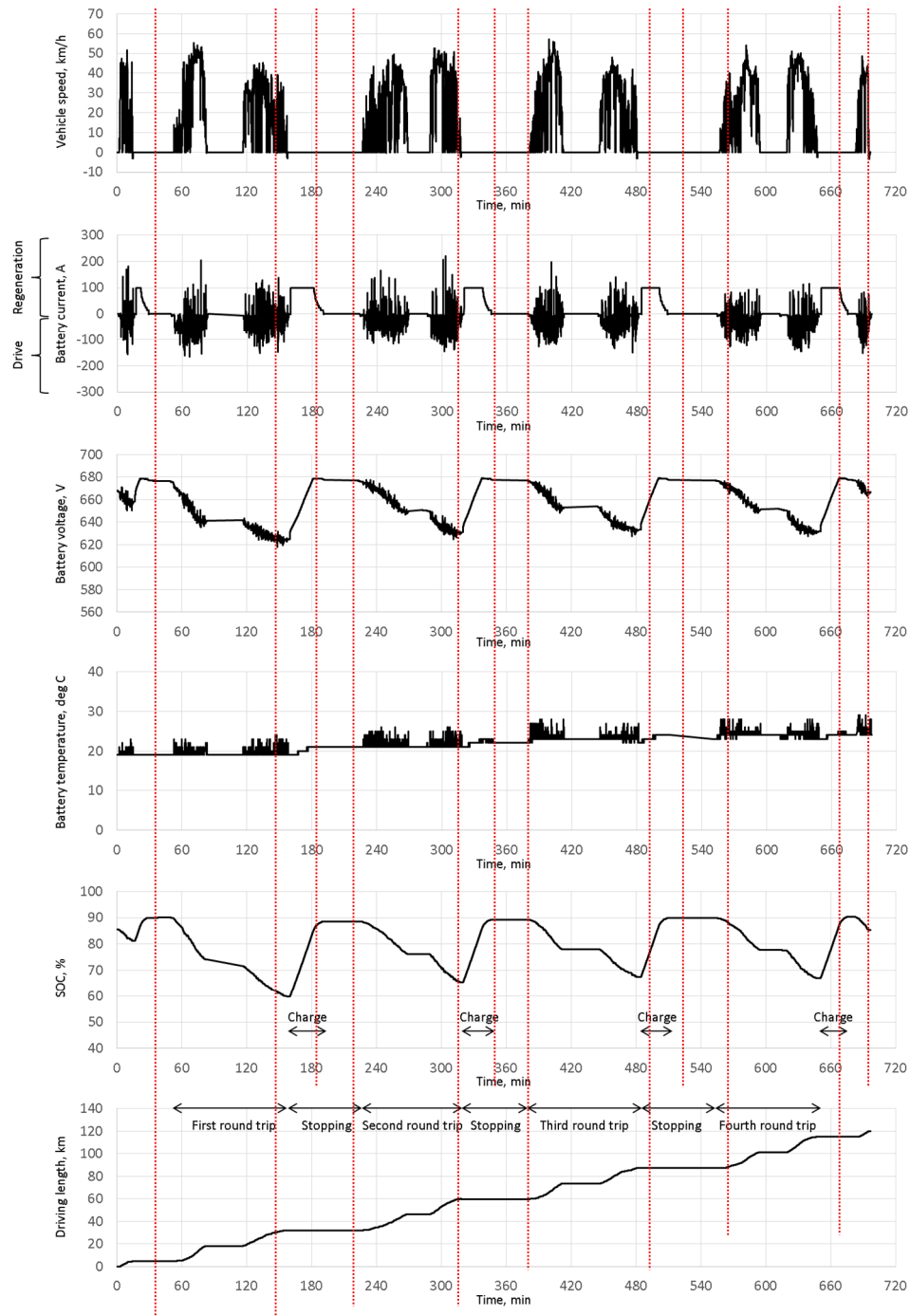


Figure 3: Variations of parameters and driving length for all day

3.2 Electric energy consumption

As the general tendency, it was found that the usage of air conditioner gave impact on electric energy consumption of the electric bus. The electric energy consumption of the electric buses in both Kitakyushu-city and Satumasendai-city was measured. The measured results of electric energy consumption were shown in Figure 4. The electric energy consumption was averaged over services in each route of the sites. Figure 4 shows that the electric buses with the air conditioner consumed more electric energy than those of the cases without the air conditioner. When the usage of the air conditioner is focused, the same tendency in each route was found that the electric energy consumption of heater was higher than that of cooler.

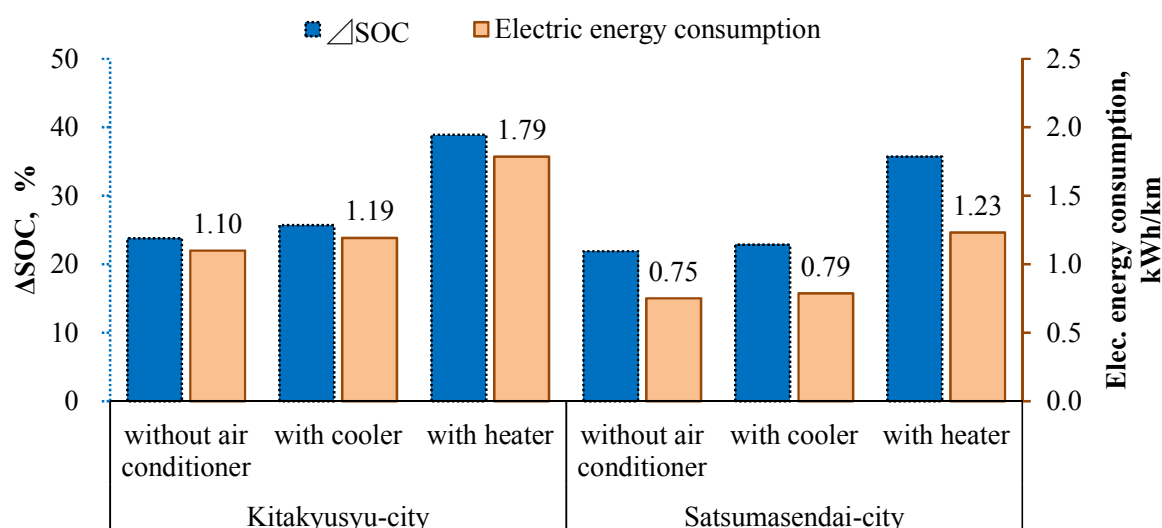


Figure 4: Electric energy consumption

The geographical features in each route also gave impact on electric energy consumption. The further analysis was conducted focusing on the difference of overall electric energy consumption between the sites. Table 2 shows the difference in the altitude of both sites. The service route in Kitakyushu-city has a larger difference of altitude than that in Satumasendai-city. In the service route of Kitakyushu-city, there is a bridge which has sufficient height to enable ships to go through under the bridge. A part of the service route connects to the bridge going through a long slope of 6%. Figure 5 displays the comparison of electric energy consumption between the slope part and plane part in routes. The blue plots show the electric energy consumption on the slope. The red plots represent the electric energy consumption on plane parts of routes in Satumasendai-city. The electric energy consumption on the slope was 3 times higher than that of plane roads.

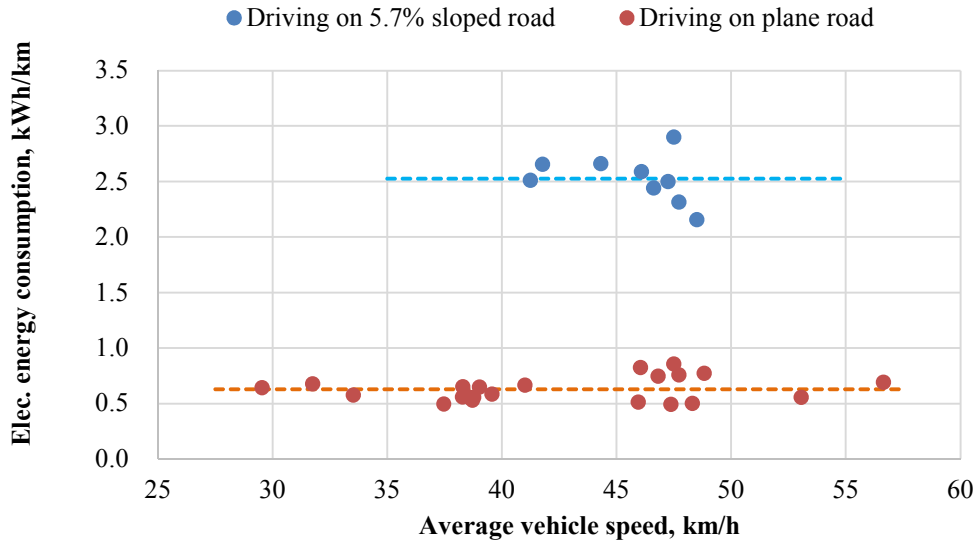


Figure 5: Comparison of electric energy consumption between slope and plane roads

The electric energy consumption could be improved by installing cooperative regenerative break system. As already mentioned, the electric bus equipped a manual regenerative function only. The SOC of the battery could be recovered during going down the slope after the end of the bridge by regenerative function. The degree of recovering in SOC by manual regenerative function highly depends on drivers skills. To obtain stable quality in efficiency by regeneration during breaking, the introduction of cooperative regenerative break system will be effective.

3.3 Analysis on composing elements in total electric energy consumption

The baseline of electric energy consumption which was for auxiliary units was measured during zero speed periods in services. Figure 6 shows an example of electric power variation during a drive. The blue curve represents the vehicle speed. The baseline of electric energy consumption was estimated while the speed of the electric bus was zero. The baseline was estimated around 6.0 kW. The main item to consume 6.0 kW of electricity was estimated as the air compressor. For the further analysis of composing elements in the electric energy consumption, the lowest level of electric energy consumption during breaks was investigated.

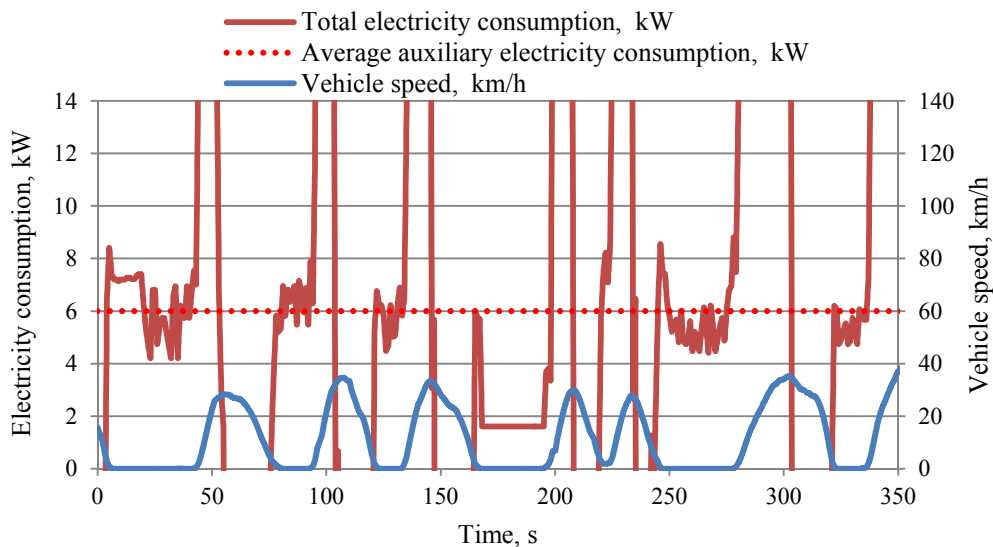


Figure 6: Electricity consumption focusing on the baseline during stopping

The electric energy consumption of the period in which the lowest level of electric energy consumption appeared in Figure 6 was extracted as Figure 7. During the period, the motor of the air compressor was stopped. From the results of Figure 7, the lowest level of electric energy consumption was estimated 1.5 kW. Thus, 4.5 kW was consumed by the air compressor. The peak power of compressing motor was 20 kW. This peak power appears at the start timing to drive the motor and normal power becomes around 1/4 of the peak power [6]. Thus, 4.5 kW for the air compressor is reasonable.

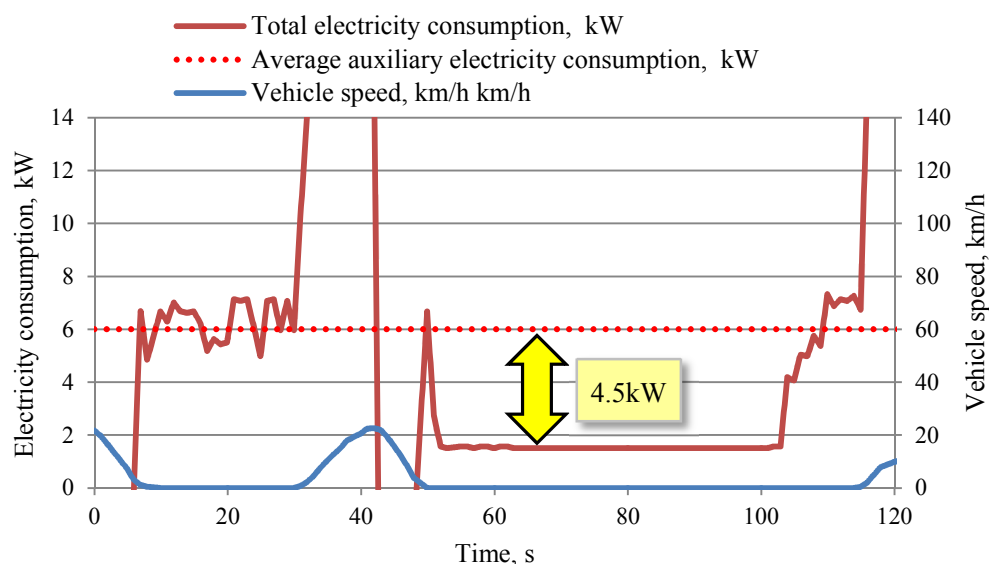


Figure 7: Least electricity consumption

4. Issues on type approval for heavy duty electric vehicles

In this part, issues on constructing test method for the type approval of heavy duty electric vehicles are discussed. In Japan, the test method for the type approval of light weight electric vehicles exists [7] [8]. However, the specific test method for the type approval of heavy duty electric vehicles has not been established. A major part of the test method for light weight electric vehicles can be applicable for the case of heavy duty electric vehicles because system configurations of them are the same. In this discussion, some specific issues which should be considered especially for heavy duty electric vehicles will be focused. The followings are different features between light weight and heavy duty electric vehicles.

- I. Range of heavy duty electric vehicles is quite limited in comparison with light weight electric vehicles.
- II. Heavy duty electric vehicles accompany off-vehicle dedicated charging systems. In contrast, light weight electric vehicles equip on-vehicle charging system.

When the test method for heavy duty electric vehicle will be discussed, the issues which come up from these features have to be overcome.

4.1 Issue on the short range

Due to the feature I, the charging speed which is not an obligation for light weight electric vehicles, will be necessary to be informed to users. When users deploy heavy duty electric vehicles, they have to consider charging schedule because it is necessary to get long drive length in operations. As the fact reported in this paper, supplemental charges between services were needed to obtain long distance for all day services. Any specific test method to measure charging speed for light weight electric vehicles has not been established. Thus, the test method might be produced newly.

4.2 Issue on measuring electric energy consumption including energy loss of chargers

Due to the feature II, the input power of the off-vehicle dedicated charging systems should be measured. It is necessary to keep the test method in the same line with the test method of light weight electric vehicles. For light weight electric vehicles, the input power of chargers should be measured considering the loss of the chargers. When the input power of the off-vehicle dedicated charging systems will be measured, examiners should take care of high voltage and current of the systems. The test method to provide the measurement procedure of such high voltage and current should comply with relevant legal cords.

5. Conclusion

The electric bus accompanying dedicated charging system which provides at least 100 km of range installing basic passenger-friendly technologies were proposed. This electric bus provided services with 120 km length in day time under the time table which was specially arranged for the electric bus. Vehicle performances, such as electric consumptions, were reported.

In addition, issues on constructing test method for the type approval of heavy duty electric vehicles are discussed. Providing charging speed and input power for charging will be helpful for users to consider the deployment of electric buses into commercial routes. The specific test method to measure these parameters are required.

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