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450-kW Conductive Dynamic Charge System

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ABSTRACT: The widespread adoption of electric vehicles (EV) is key to reducing CO_2 emissions from vehicles in operation to zero. One example of an initiative furthering the realization of that aim is the introduction of a Dynamic Charging System that recharges EVs in operation directly from the electric road. This paper describes the results of testing Dynamic Charging System for conductive charging from the side applied to heavy-duty trucks.

KEY WORDS: electric vehicle, dynamic charge system, electric road system, social system, electricity-based society systems

1. INTRODUCTION

The reduction of CO_2 emissions as a measure to counter global warming has become an urgent task. Total global CO_2 emissions have risen to 36.75 billion tons. Of that, the amount of CO_2 emissions in the transportation sector, which includes motor vehicles, is 7.87 billion tons. That is 21.4% of total CO_2 emissions. Breaking down the figure for the transportation sector, the amount for motor vehicles, which combines private automobiles and freight trucks, is 5.88 billion tons. This comprises 74.8% of the amount for the transportation sector, which is discharging 16.0% of total global emissions [(1)].

In order to achieve zero CO_2 emissions in this transportation sector, it will be essential to introduce vehicles that do not use fossil fuels but operate entirely by motor, meaning electric vehicles (EVs) and fuel cell vehicles (FCVs). EVs, however, face a number of major issues even today. Of those, the main issues are (1) driving range; (2) quantity of batteries installed (securing resources for materials, assuring production volume, disposal, etc.); (3) charging (difficulties, time waiting while charging, charger congestion, support for ultra-rapid charging, measures to counter heat generation, etc.); (4) infrastructure installation (number of charger units, securing area for installation, etc.); and (5) deterioration of driving performance (increase in vehicle weight, driving to avoid running out of battery power, etc.), among others. Moreover, heavy-duty trucks require high power output, and their full electrification to run only on installed electric energy will require installation of high-capacity batteries. This indicates that the shift to EVs faces numerous issues and is not thought to be readily achievable.

For the present research, a dynamic charge system (DCS) that uses conductive charging from the side was devised and study of its application to passenger cars and race cars has been pursued (Fig.1) [(2-5)]. For the present research, attention has been further focused on resolution of issues with cargo vehicles, which account for a large part of CO_2 emissions from the transportation sector. While electrification of heavy-duty trucks to make them into EVs has not been considered readily achievable, application to such trucks has been advanced. The present report describes the design, prototyping, and road testing results for heavy-duty trucks for DCS use with conductive charging from the side.

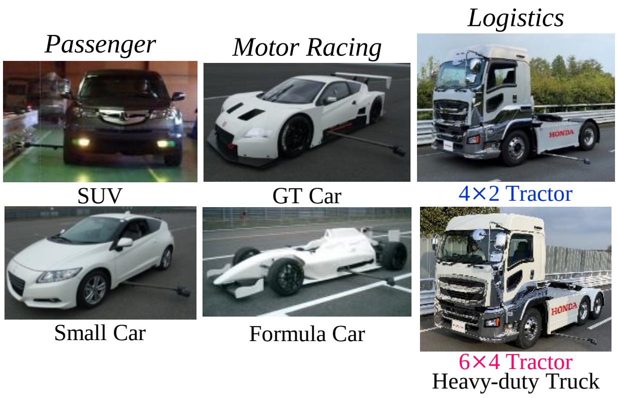


Fig.1 Dynamic Charge Electric Vehicles

2. Electric Road System (ERS)

Figure 2 shows the primary electric road system (ERS) [(6-8)]. The ERS is of two main types, one that provides charging while the vehicle is driving (dynamic charge) and the other that provides only a supply of power. In the case of the system that provides only a supply of power, the vehicle will be driving as a hybrid electric vehicle (HEV) when it is driving outside ERS power supply sections, so that engine operation will be needed. The dynamic charge system is the subject of the present research.

The dynamic charge system was developed with attention to the perspectives of (1) the power to be supplied, (2) transmission efficiency, (3) safety (electromagnetic noise, foreign objects on the road surface, mixed operation on roads with motorcycles, etc.), (4) convenience (positioning, lane changing, etc.), (5) infrastructure installation and maintainability, and (6) cost and related matters. From those perspectives, a system of revolving point-contact from the side of the vehicle (roadside) was devised, which was judged most advantageous. The total electric power supplied to a vehicle while in motion (battery charging power plus motor driving power) was made 450 kW (600 A at 750 VDC or greater) to make it greater than the driving energy of the moving vehicle and also to fully enable charging the on-board batteries.

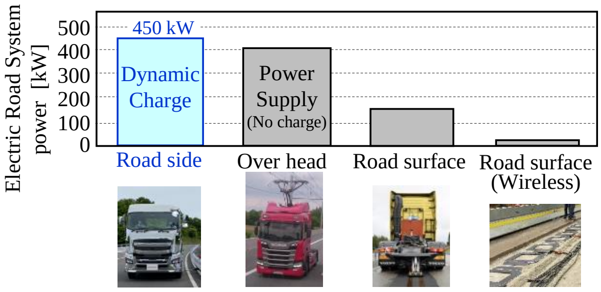


Fig. 2 Electric Road System Power Comparison

3. ERS with Conductive Charging from the Side

In order to resolve the issues described above, the present research has been furthering DCS development. The key points for DCS development are the supply of electric power, transmission efficiency, safety (electromagnetic noise, foreign objects on the road surface, mixed operation on roads with motorcycles, etc.), convenience (positioning, ease in changing lanes, etc.), infrastructure installation and maintainability, and cost and related matters. From this perspective, a system of revolving point-contact from the side of the vehicle judged most advantageous was adopted. The total electric power supplied to a vehicle while in motion (battery charging power plus motor driving power) was made 450 kW or more (600 A at 750 V DC or greater) to ensure it will be greater than the driving energy of the vehicle in motion and also be fully adequate for charging the on-board batteries Fig.3).

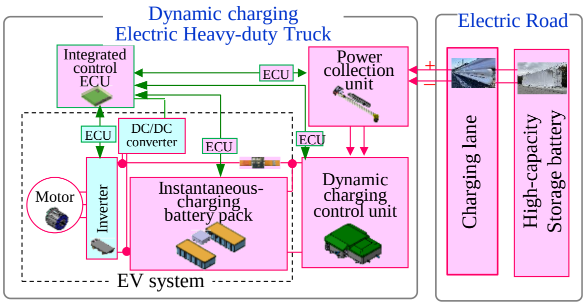


Fig.3 Dynamic Charge Control Block Diagram

3. System Overview

This system is made up of the DCS infrastructure and the dynamic charging electric heavy-duty truck (Fig.4). The DCS infrastructure is made up of high-capacity lead storage batteries and the dynamic charging lane (Fig.5, 6). The vehicle's side has the power collection arm, dynamic charging control unit (DCCU), instantaneous charging battery pack, and a typical EV system.

Fig.4 Dynamic Charge Electric Trucks

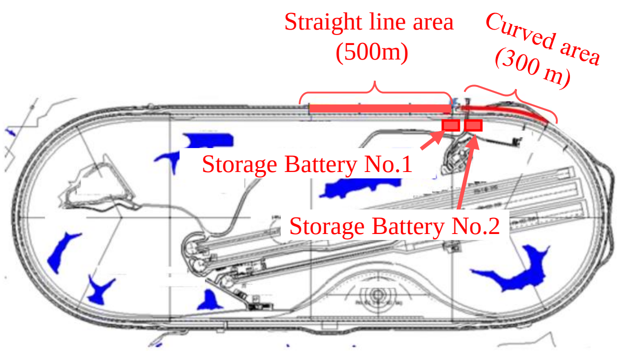


Fig.5 Dynamic Charge Test Course Layout

(a) Straight Lane

(b) Curved Lane

(c) Storage Battery
Fig.6 Evolved Version of Dynamic Charge Infrastructure

4. Charging Lane and Power Collection Mechanism

Figure 7 shows the charging lane, which charges the vehicle while it is driving. The charging lane is infrastructure that can share supply power to all types of vehicle, from passenger cars to heavy-duty vehicles.

Figure 8 shows the charging lane structure, which has a normal guardrail as a base with trolley wires added on. The trolley wires are mounted on insulators with the plus (positive) side and minus (negative) side at a 90° angle from each other in a V configuration. A guide plate is also positioned to guide the roller of the power collection arm to the trolley wires. The structure has the surrounding area covered with a protective cover made of insulating resin.

The power collection mechanism simply pushes the power collection arm out from the side and presses it against the trolley wires, which are arranged in a V configuration. This centers the height of the arm so that the rollers contact the wires at the proper position. Power collection then takes place through rotating contact by the rollers arranged on the power collection arm, and electric power is transmitted to a high-voltage harness through brushes that contact the rollers. The power collection arm can move approximately 300 mm in the vertical direction and approximately 1,500 mm in the lateral direction. Electrical safety conforms to the Japan Association of Rolling Stock Industries (JRIS) standard.

Fig.7 Guardrail Type Dynamic Charge Lane

(a) Shoulder Side (b) Road Side

Fig.8 Dynamic Charge Lane Mechanism

5. Dynamic Charge Infrastructure Installation Method

This infrastructure is envisioned for installation on expressways and in local areas (areas exclusively for charging by municipalities).

For installation on expressways, a single section was defined as 50 km. This is close to the interval between service areas, and the total distance includes sections for vehicles to operate independently (normal EV driving) and sections for supplying power and charging to vehicles in motion.

When a heavy-duty EV truck is traveling at 80 km/h, it is envisioned as being supplied a charge for approximately 15 km within the 50-km section and operating independently for approximately 35 km. The ratio between power supply/charging operation and independent operation is 3:7 (30% of the operating sections is power supply/charging). In a single section, the battery charging capacity is approximately 89 kWh, and vehicles will continue driving while intermittent charging occurs.

6. Heavy-Duty Truck Prototype

The specifications of tractors that is the dynamic charge heavy-duty EV truck produced for this research are shown in Table 1. As shown in Table 1, the total vehicle weight envisioned when towing cargos are 40 ton and 60 ton. The tractor drive systems are 4×2 (four wheels and rear two-wheel drive) and 6×4 (six wheels and rear four-wheel drive). The tractor weights are 7.25 ton and 8.8 ton and the motor power output is 350 kW (476 PS). The capacity of the on-board batteries (when fully charged) is 100 kWh (maximum power 450 kW, maximum voltage 750 VDC, maximum current 600 A). The maximum vehicle speed is 80 km/h (limiter control to speed limits in Japan). The vehicle speed when being supplied a charge while in motion ranges from 7 km/h (creep speed) to 80 km/h (maximum speed). The maximum input power is 450 kW (maximum voltage 750 VDC, maximum current 600 A), and the charging distance (distance between trolley wires and vehicle) was set at 0.1 m to 1.6 m.

Figure 9 and Fig. 10 show the external view of the vehicle that were produced. Figure 9(a) and Fig. 10(a) show the power collection arm stored in the vehicle body (the state when in independent operation) and Fig. 9(b) and Fig. 10(b) show the state with the power collection arm opened out (the state during power supply/charging operation). As shown in Fig. 9(a) and Fig. 10(a), the power collection arm is located to fit inside the lower portion of the side of the vehicle body so as not to clash with the external appearance of the vehicle.

All of the power units shown in Fig. 3 are installed inside a frame under the floor of the vehicle, as shown in Fig. 11 (below than the upper surface of the tire). This made it possible to secure more space in the lower portion of the cabin and cockpit than in a conventional diesel engine vehicle.

As shown in Fig. 12, by comparison with the base vehicle equipped with a conventional diesel engine weighing 9.81 ton, the vehicle weight of the dynamic charge EV is 8.88 ton. This is a weight reduction of 0.93 ton.

Table 1. Specification of Dynamic Charge Electric Heavy-duty Trucks

Drive system		4×2	6×4
(Total vehicle weight)		(45 ton)	(60 ton)
Tractor weight		7.25 ton	8.88 ton
Arm opening and closing time		2 sec.	1 sec.
Motor	Max. power	350 kW (476 PS)	
	Max. torque	3,500 N・m	
On-board battery	Max. capacity	100 kWh	
	Max. power	450 kW	
	Max. voltage	DC 750 V	
	Max. current	600 A	
Max. vehicle speed		80 km/h (Limiter)	
Dynamic charge	Vehicle speed	7 (Creep speed) - 80 km/h	
	Max. power	450 kW	
	Max. voltage	DC 750 V	
	Max. current	600 A	
Cruising distance	Highway	Infinite (km)	
	City	90 km	

(a) Arm Closed (b) Arm Open

Fig.9 Dynamic Charge Electric Truck (4× 2 Tractor)

(a) Arm Closed (b) Arm Open

Fig.10 Dynamic Charge Electric Truck (6× 4 Tractor)

Fig.11 Dynamic Charge Power Unit Layout (6×4 Tractor)

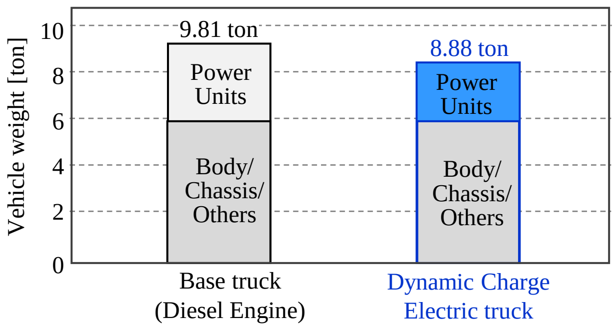


Fig.12 Comparison of Vehicle Weight (6×4 Tractor)

7. Road Testing Results

The results obtained by conducting road tests of dynamic charging using the expanded infrastructure and heavy-duty truck produced for the present research are described in the following.

The dynamic charge energy is voltage of 750 VDC and current of 600 A. The charging of on-board batteries is controlled by three modes: the constant current charge mode (CC mode), the constant power charge mode (CP mode), and the constant voltage charge mode (CV mode). The vehicle was supplied with electric power while in motion at speeds ranging from 7 km/h to 80 km/h.

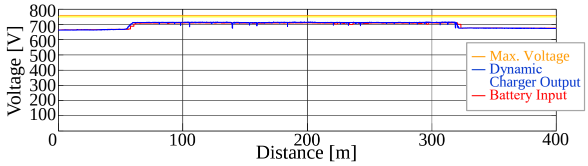
Road testing in the curved area charging lane shown in Fig. 13 and Fig. 14 was carried out with electric power of 450 kW (maximum voltage of 750 V, maximum current of 600 A). This report presents results obtained at vehicle speeds of 50 km/h and 80 km/h.

Figure 13 shows the results for implementation of dynamic charge at the vehicle speed of 50 km/h. Figure 16 shows the main parameters for charging, including the values for output to the vehicle from the dynamic charge control unit (DCCU) on the vehicle side when it has received electric power from the infrastructure, and the values for input to the on-board batteries. Figure 13(a) shows the voltage values, Fig. 13(b) the current values, Fig. 13(c) the electric power values, Fig. 13(d) the vehicle accelerator opening and motor torque, and Fig. 13(e) the vehicle speed.

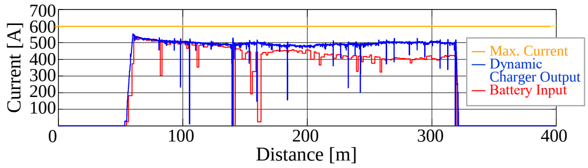
The difference between the DCCU output values in Figs. 13(a) to 13(c) and the on-board battery input values indicates the energy that is distributed from the DCCU directly to the drive motors that are in operation. The section following the distance of approximately 100 m in Fig. 13 is the uphill grade section. This confirmed the changing difference between the CCU output values and the on-board battery input values, and it successfully confirmed that control of the distribution of electric power received from the infrastructure is being appropriately implemented by the control system.

Figure 14 shows the results for implementation of dynamic charge at the vehicle speed of 80 km/h.

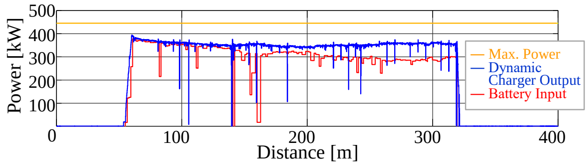
In contrast to the results at the vehicle speed of 50 km/h shown in Fig. 13, the results in Fig. 14(e) show the motor torque increasing as the vehicle speed increases. For this reason, the difference between the DCCU output values shown in Figs. 14(a) to 14(c) and the on-board battery input values also increases, which has confirmed that electric power distribution control is being appropriately implemented by the control system.



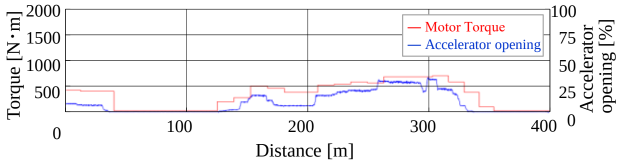
(a) Dynamic Charge Voltage



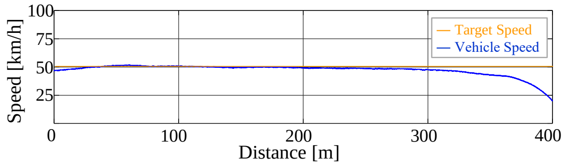
(b) Dynamic Charge Current



(c) Dynamic Charge Electric Power

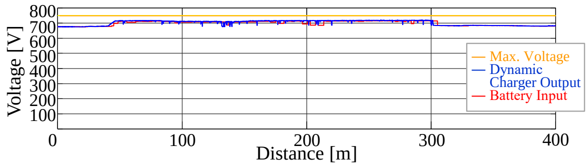


(d) Motor Torque and Accelerator Opening

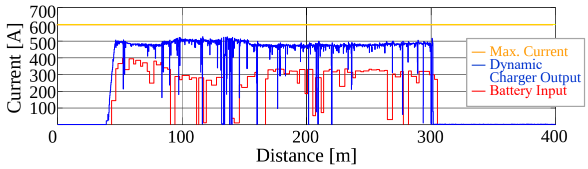


(e) Dynamic Charge Vehicle Speed

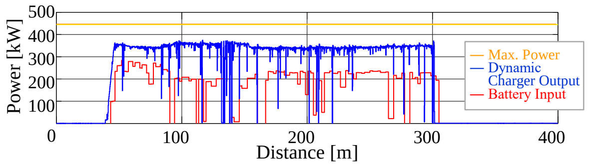
Fig.13 Results of 450-kW Dynamic Charge Test at 60 km/h



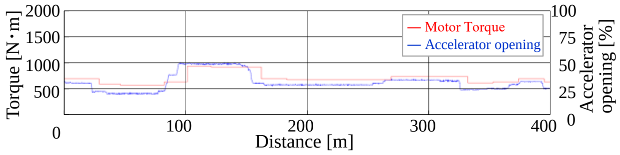
(a) Dynamic Charge Voltage



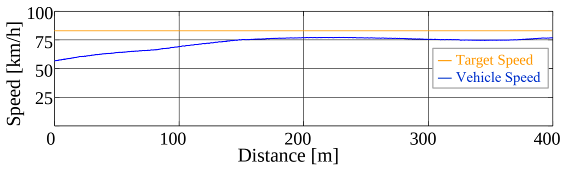
(b) Dynamic Charge Current



(c) Dynamic Charge Electric Power



(d) Motor Torque and Accelerator Opening



(e) Dynamic Charge Vehicle Speed

Fig.14 Results of 450-kW Dynamic Charge Test at 80 km/h

8. CONCLUSION

In this research, the DCS that supplies power conductively from the roadside was applied to heavy-duty trucks, which had been considered problematic for a shift to EV. Advances were also made in expanding infrastructure technology with installation on curves and slopes. Multiple storage batteries were also installed and verification tests were conducted with actual vehicles. As a result:

Going forward, the aim is to achieve early practical application of this system while continuing to investigate the charging of multiple vehicles, increasing reliability and safety, optimizing infrastructure installation, methods for supplying electric power, and other such matters, with a view to deployment in society.

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