

High-Performance Compact Traction System of Fuel Cell Hybrid Powered Test Railway Vehicle



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RTRI has been developing an energy-efficient fuel cell hybrid powered railway vehicle with low carbon-dioxide emissions in an effort to address global environmental issues. We have examined the possibility of replacing DMUs with fuel cell hybrid powered railway vehicles. In 2019 we downsized and improved the performance of the fuel cell hybrid powered railway vehicle's traction system, seeking to replace not only DMUs but also part of EMUs. This development has made it possible to install all the equipment for running underfloor, achieve high acceleration performance equivalent to an EMU, and secure sufficient cabin space. This article explains the development of the fuel cell powered hybrid test vehicle.

Introduction

In recent years, driving systems of automobile have been rapidly shifting from conventional gasoline engines to electric motor and gasoline engine hybrid systems to reduce carbon footprint and energy consumption. While Japanese railway vehicles have been mainly EMUs in urban areas, mostly DMUs are running in

rural, non-electrified areas. This is because the ground facilities for DMUs are simple and less expensive compared to electric power supply facilities. However, due to the urgent necessity to conserve the global environment, DMUs have been replaced either with hybrid diesel vehicles driven by both electric motor and diesel engine or with battery vehicles. These vehicles have their drawbacks and advantages

in terms of environmental impacts and cruising distance. Since 2001, RTRI has been developing a fuel cell hybrid powered test railway vehicle satisfying both requirements. This article describes our development to downsize and improve the performance of the driving system of the fuel cell hybrid powered test railway vehicle, targeting replacement of not only DMUs but also part of EMUs.

Fuel cell

Among several types of fuel cells, the polymer electrolyte fuel cell, which is called PEFC, is used for railway vehicles. This fuel cell generates electricity by reacting hydrogen as fuel with oxygen in the air. This type of fuel cell has the advantages that it has shorter start-up time compared to other fuel cells, higher energy efficiency than diesel engines, and that it is a clean device as it emits only water when it generates electrical power.

Fuel cell hybrid powered railway vehicle

The hybrid powered railway vehicle combines a fuel cell and a battery for its power source and use electricity efficiently to drive (*Traction system of a fuel cell hybrid powered test railway vehicle*). During accelerating, both the fuel cell and the battery provide electricity to motors. During coasting, the fuel cell charges the battery, and during braking, regenerated power and the fuel cell charge the battery.

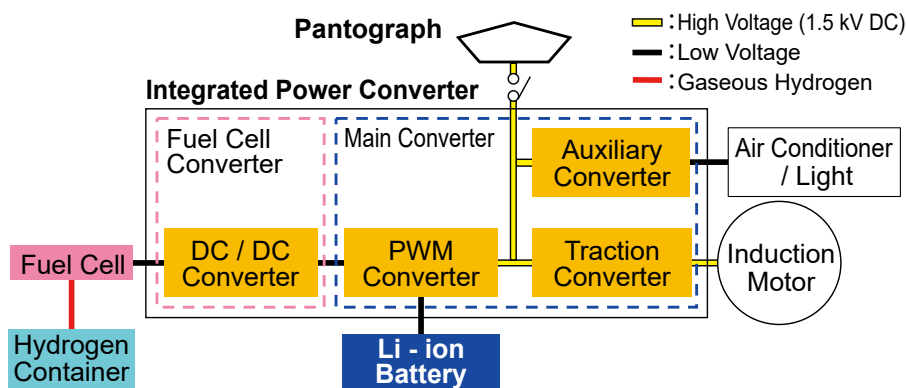
Downsizing and improving performance

In the initial stage of developing the fuel cell hybrid powered test railway vehicle, RTRI focused on research and development for using fuel cells as a part of traction systems for railway vehicles and has continued running tests for more than 10 years. However, the performance of the fuel cell and the battery was limited. Also, the equipment for running was large and was placed in the cabin. Due to the size and performance, sufficient space for passengers was not available and the acceleration performance remained at the level of the old-type DMU (0.4 m/s^2). To address these challenges as the next step, RTRI started to develop a vehicle which has sufficient cabin space and enough acceleration performance equivalent to an EMU (0.7 m/s^2 or higher). If vehicles with these performances are developed, we can replace DMUs running on non-electrified lines with them and reduce CO_2 emissions. Furthermore, if vehicles running on electrified but lower-traffic

lines are replaced with the hybrid vehicles, the ground power supply facilities can be reduced, and maintenance cost can be cut without compromising the quality of passenger services such as travel time. The targets of research to attain this goal are explained in the following paragraphs.

Calculation of power output of fuel cell and battery

Since a fuel cell has only limited output per volume and is very expensive, it is not reasonable for the fuel cell to provide all the necessary power of vehicle operation. Power consumption by conventional railway trains has a characteristic pattern. The trains use large power during acceleration, but the average power thorough entire running time is lower than the maximum power for acceleration (*Example of a conventional railway vehicle power usage*). Regenerative power during braking recovers a part of the power used for the acceleration. To take this characteristic into account, the fuel cell is designed to have the output equivalent to the average amount of power loss during running. Meanwhile, the battery output covers the difference between the power demand for running and the fuel cell output. This reduces the size and cost of the fuel cell. Under this design policy, we simulated a two-car trainset running over a short, flat section with the acceleration performance equivalent to an EMU (0.7 m/s^2) and examined the desirable output of equipment. Based upon the result of this research, we have determined fuel cell output to be 150 kW and battery output to be 540 kW and designed each equipment to be manufactured according to this specification.



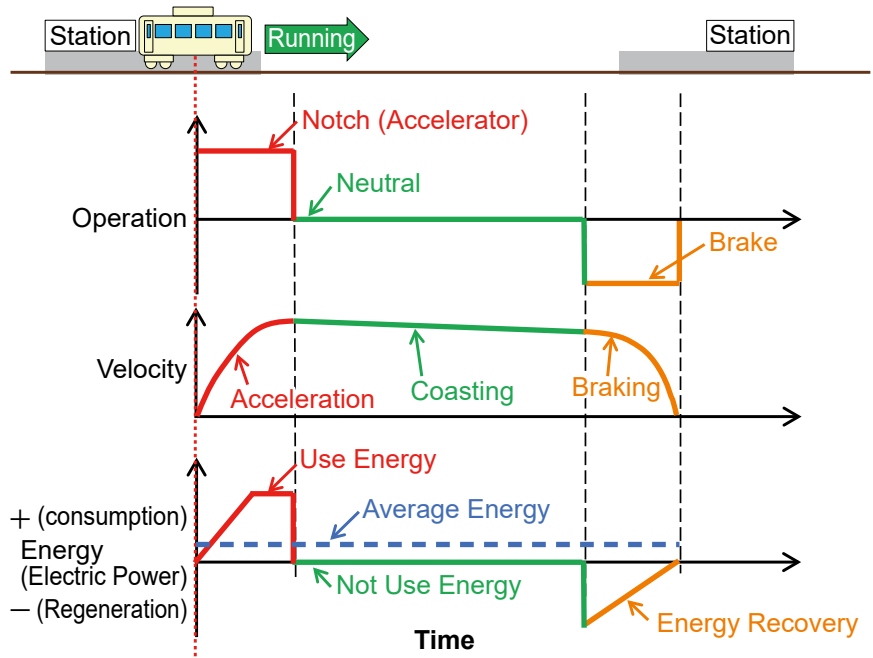
Traction system of a fuel cell hybrid powered test railway vehicle

Downsizing and improving performance of fuel cell

It was necessary to raise the output of the fuel cell 1.5 times higher than existing equipment and downsize them so they can be mounted to the underfloor of the vehicle. The fuel cell has many components including fuel cell stacks, device to take in air to react with hydrogen, and cooling device to dissipate heat from power generation. Therefore, in addition to raising power generation performance of the fuel cell stacks, we downsized the cooling device by making its design simpler. We have succeeded in increasing the output by 50% and reducing volume per output by 23% by downsizing peripheral equipment (*Comparison of fuel cell unit*). With these improvements, we developed a thinner fuel cell that can be mounted under a vehicle's floor.

Downsizing power converter

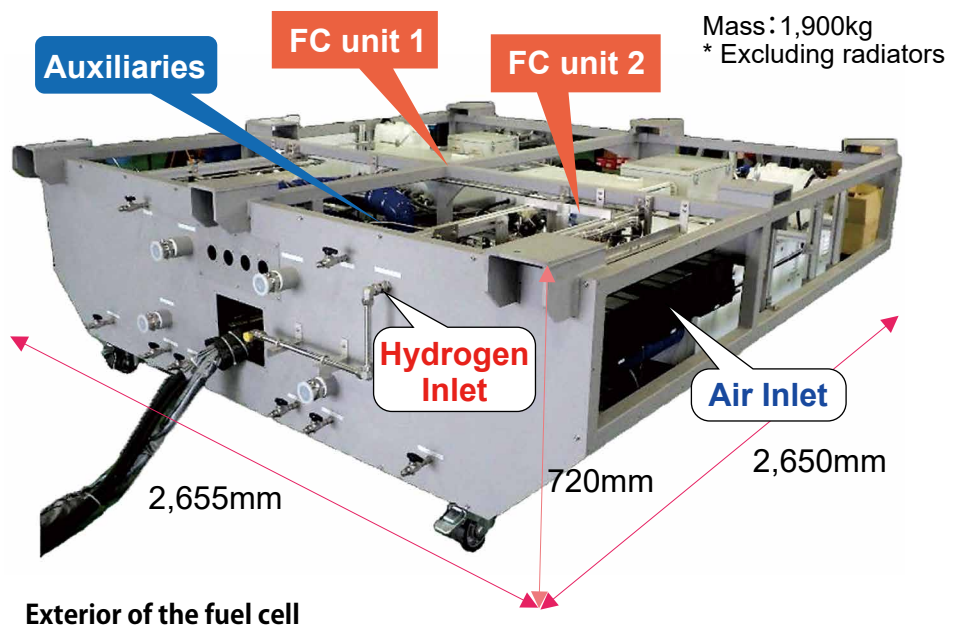
Traction system of a fuel cell hybrid powered test railway vehicle shows a schematic diagram of the power converter. Since the input voltage of the traction converter and auxiliary converter is set at 1500 V in this circuit, the voltage used in most DC-powered sections in Japan, the fuel cell railway vehicle can run as EMUs powered by an overhead power supply line without using the fuel cell. As the railway vehicle does not use hydrogen in the electrified sections, cruising distances in non-electrified sections can be extended. This circuit has a set of two fuel cells and a set of three batteries connected to each converter, so the railway vehicle can keep running even if one of the fuel cells or the batteries fails, thereby improving reliability. The number of overlapping components in this circuit has been reduced by integrating converters for traction, auxiliary power and



Example of a conventional railway vehicle power usage

Comparison of fuel cell unit (Former one equals 1)

Items	Former Fuel Cell Unit	Downsizing Fuel Cell Unit
Output	1	1.5
Output per Volume	1	0.77



Exterior of the power converters



(a) Main converter



(b) Fuel cell converter

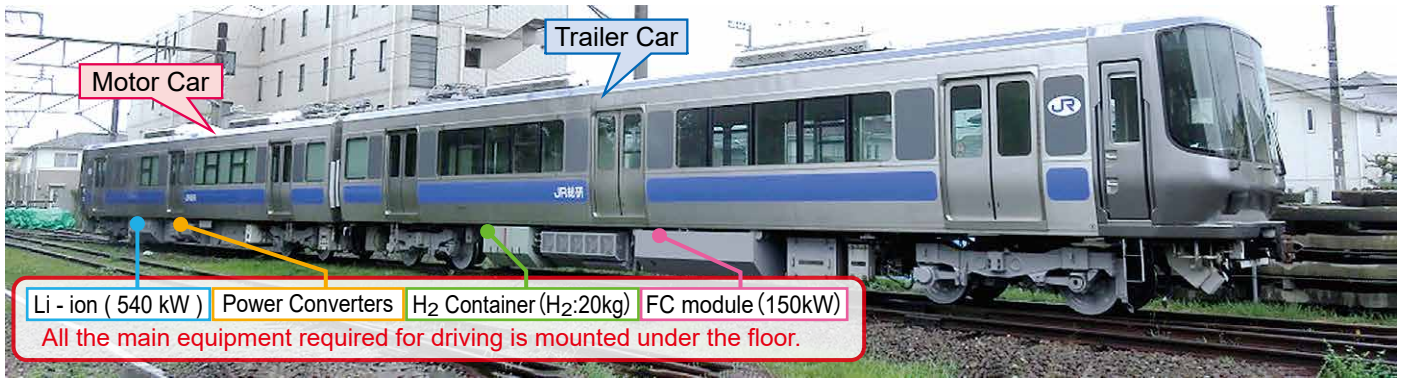
batteries, allowing a smaller main converter to be configured. Since the voltage of the fuel cell converter has been reduced by improving the circuit configuration and a low-loss SiC power device was used, the cooling device was downsized and smaller-sized circuit breakers were used. These improvements made downsizing the entire fuel cell converter possible. The volume and weight were reduced by 45% and 40% respectively compared to the previous power converter (*Comparison of power converters*).

Test vehicle and running test results

The traction system of the fuel cell hybrid test vehicle was downsized and its performance was improved. *Exterior of the fuel cell hybrid powered test railway vehicle* shows the improved test railway vehicle, and *Comparison of cabin* shows the cabins of the previous railway vehicle and the improved one. Tests to confirm running performance were conducted with this improved test railway vehicle

Comparison of power converters (Former one equals 1)

Items	Former Power Converters	Downsizing Power Converters
Volume	1	0.55
Weight	1	0.6



Exterior of the fuel cell hybrid powered test railway vehicle

on the 650-meter test track at RTRI. The test railway vehicle attained a starting acceleration of 0.81 m/s^2 (0.78 m/s^2 before slope adjustment), which confirms it has an acceleration performance equivalent to an EMU (A test result on the test track). Furthermore, as almost the same levels of battery SOC (State of charge) have been shown before and after the test running, we demonstrated that the energy used for running has been compensated by charging from the fuel cell as designed and the railway vehicle can run continuously.

Conclusion

The fuel cell hybrid powered test railway vehicle features high energy efficiency and a low carbon footprint, and we can conclude that it is one embodiment of what a railway vehicle should be in the future. In the meantime, the hybrid powered railway vehicle still has a long way to go before it is introduced to revenue service. In addition to further development of the vehicle, laws and regulations are

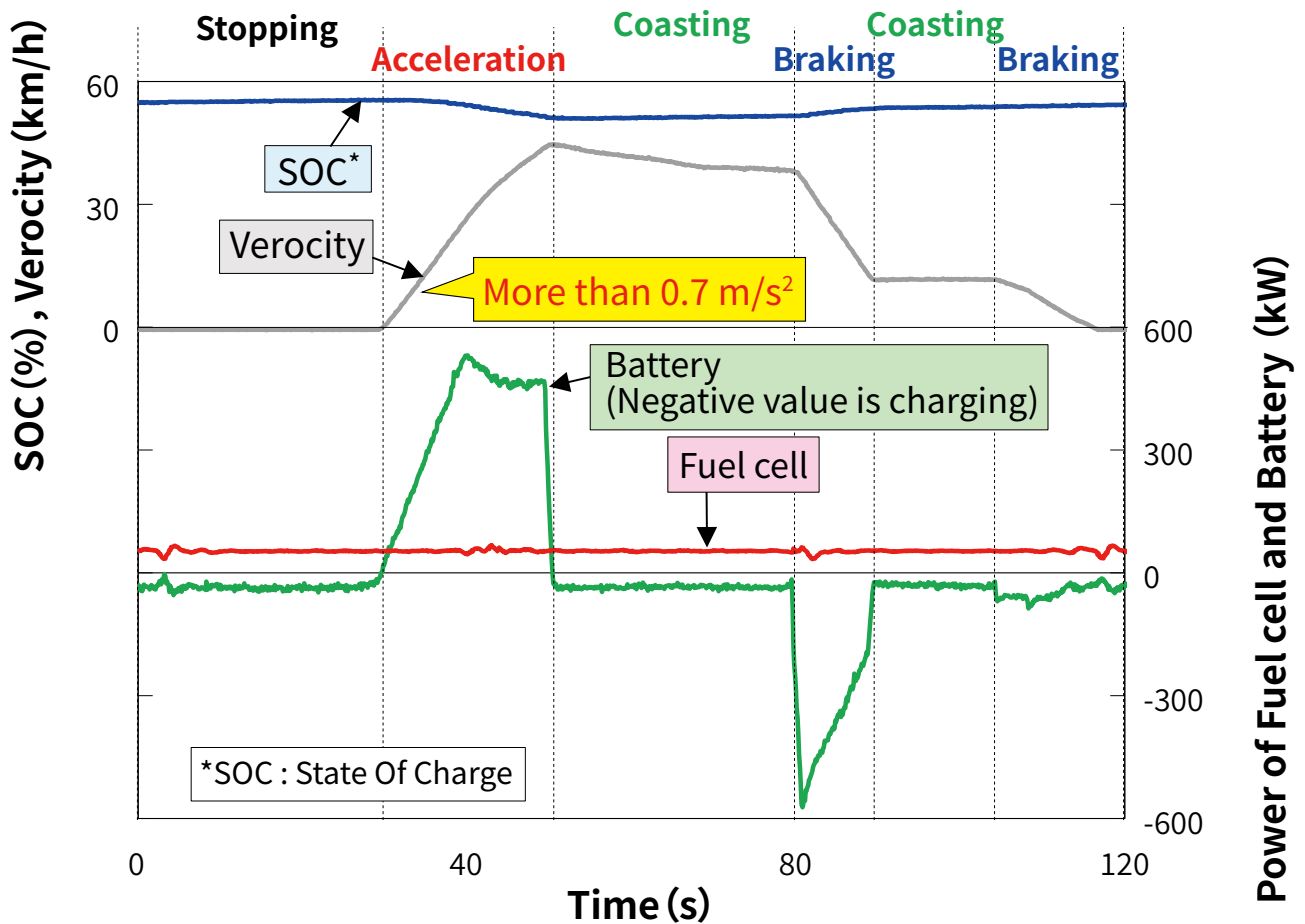


Before
(Equipment is mounted in the cabin)



After
(Secure the cabin space)

Comparison of cabin



A test result on the test track

required, such as a high-pressure gas security act that will enable railways to safely use high-pressure hydrogen gas. A hydrogen supply chain needs to be built as large amounts of hydrogen will be needed and the currently expensive cost of the fuel cell must be reduced. We expect that these issues will be solved as the energy source

for our society further shifts to hydrogen, and the fuel cell hybrid powered railway vehicle will be used widely. At the same time, we hope the hybrid powered railway vehicle we have introduced here which has a small-sized, high-performance traction system will help the social change.

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