Korea Transportation Safety Authority
Korea Automobile Testing & Research Institute

Research on the system power of fuel cell electric vehicles

65st EVE IWG 11~12 October 2023

CONTENTS

Background

■ Currently, research and development of fuel cell electric vehicles is increasing and vehicle distribution is increasing.

■ The number of fuel cell electric vehicles will increase further because they are environmentally friendly and have increased mileage compared to electric vehicles.

■ However, UN GTR21 stipulates that it does not apply to FCEVs.

> II. Text of the GTR
> 2. Scope and application
> **2.2.This UN GTR does not apply to fuel cell vehicles.**

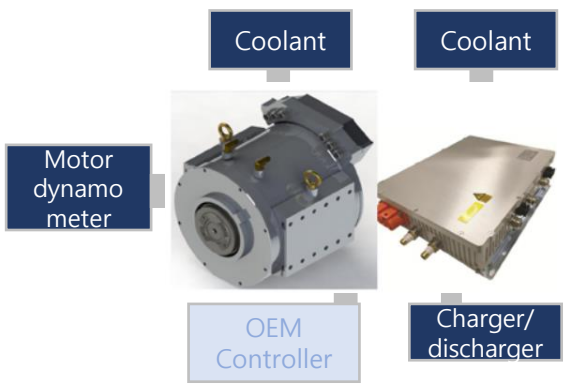
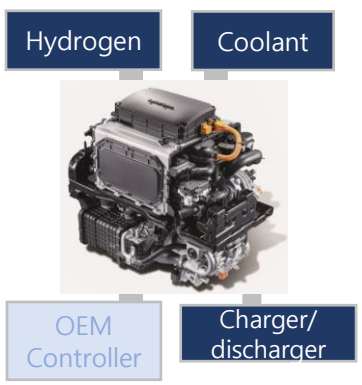
Background – Power Test(KMVSS 106)

◆ Currently, in KMVSS 106, methods for measuring the power of motors, fuel cells, and batteries for driving motors are separately specified to evaluate the power of vehicles. ◆ Motor power: harmonized with UN R85(same)

◆ Fuel cell power: specified to evaluate the peak power of fuel cell

◆ Battery(for driving the motor) power: specified to ensure that the power supplied to the motor is sufficient when the power evaluation of the motor is performed.

In order to check of available Motor(more precisely inverter) input power source

	Motor (Harmonized with UN R85)	Fuel cell (KMVSS)	Battery (KMVSS)
Conditions	25℃±5℃	20℃±10℃	25℃±5℃
DUT unit and testing equipment			
Test specifics	**Peak power** 1)Warm-up at 80% of peak power 2)Evaluation finished within 5min for all points **30min continuous power** -RPM should be within 90% of RPM at peak power	**Peak power** 1)Stepwise load increase starting from minimum load 2)1min measurement at peak power, result averaged 3)Repeated 3 times with 1hr rest	**Peak power** 1)SOC set 2)Rested for 8hrs 3)Discharged at peak power for the time interval provided by the supplier

*Test rig can have the same layout as the actual car **Reducer efficiency needs to be provided ***DUT: device under test

Background – Power Test(KMVSS 106) – GTR21

◆ However, it is appropriate to calculate the motor supply power of a fuel cell electric vehicle by adding up the fuel cell power, battery power, and loss.

◆ GTR21 does not yet consider fuel cell electric vehicles, but specifies the system power for this concept (taking into account power summation, losses and efficiency).

In order to check of available Motor(more precisely inverter) input power source

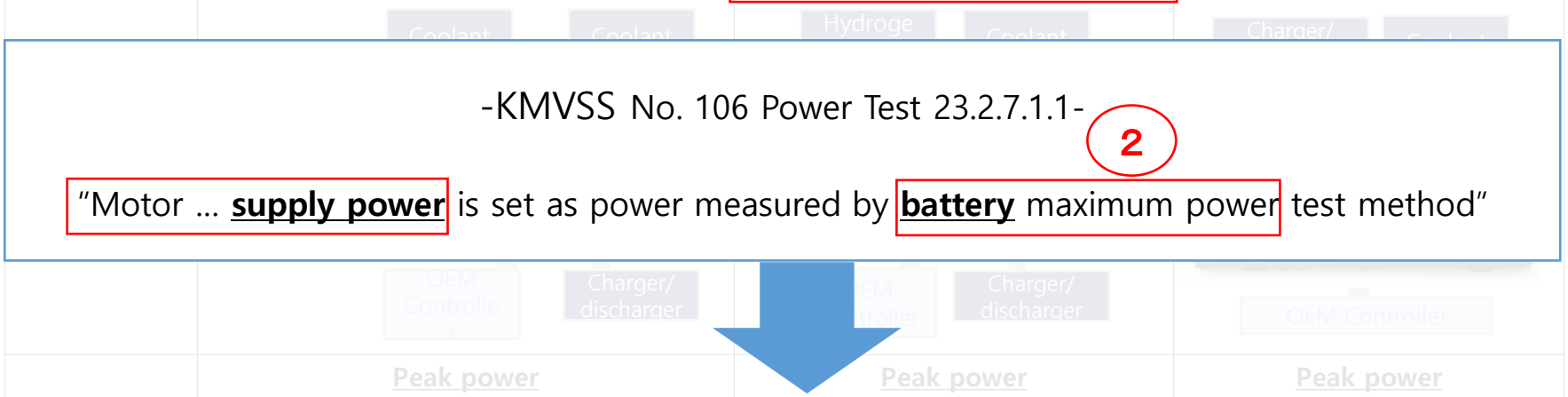
	Motor (Harmonized with UN R85)	Fuel cell (KMVSS)	Battery (KMVSS)
Conditions	25℃±5℃	20℃±10℃	25℃±5℃

1

-KMVSS No. 106 Power Test 23.2.7.1.1-

2

"Motor … **supply power** is set as power measured by **battery** maximum power test method"



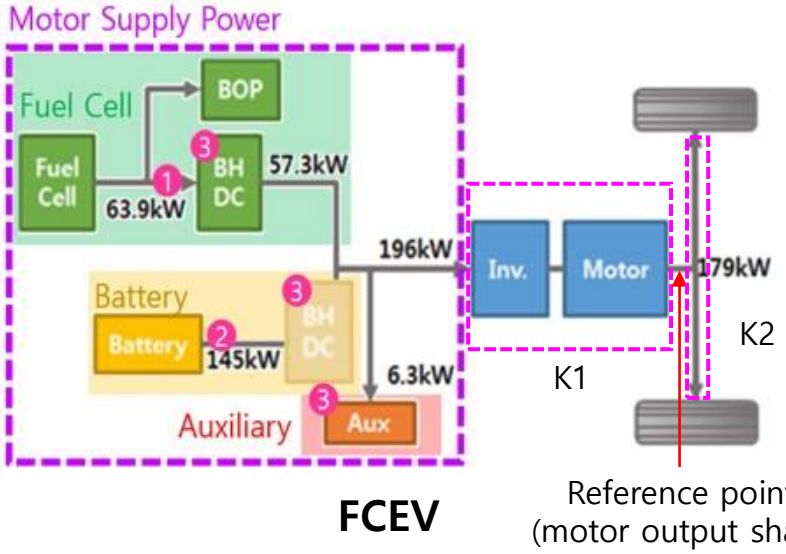
<Need for modification of supply power source for motor power test>

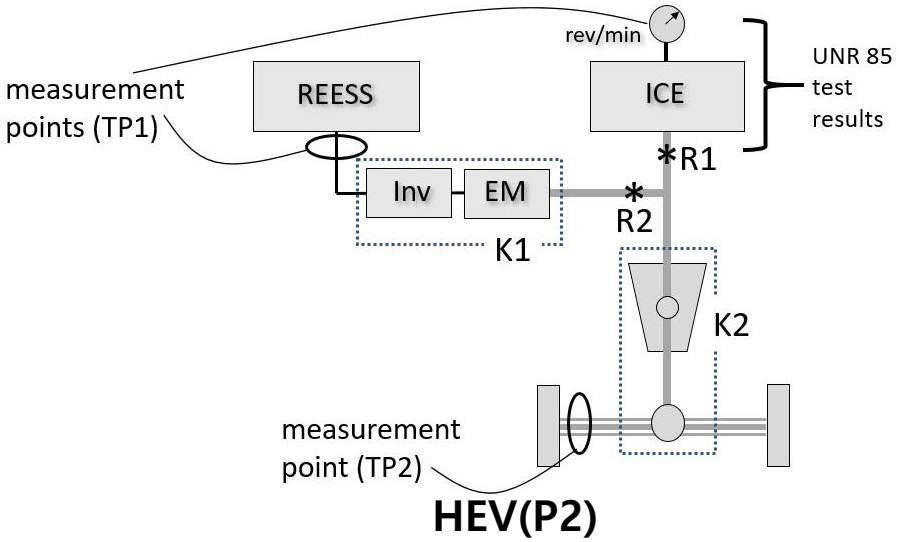
Battery power **only** → fuel cell + battery **combined** power + Vehicle **Loss**

*Test rig can have the same layout as the actual car **Reducer efficiency needs to be provided ***DUT: device under test

Background – Applicable to FCEVs?

■ Powertrain architecture comparison FCEV, HEV(P2)





■ Test method (System power point : Motor output mechanical power)

1) TP1 : Up stream (fuel cell/Battery → Motor Input) * K1 -> System power(Component loss considered)

2) TP2 : Down stream (Motor → axle shafts power) / K2 -> System power(Drive train loss considered)

In this study, we will check whether the system power of FCEVs can be defined using the concept of TP1/TP2 and propose adding FCEVs in the GTR 21.

*BOP: Balance of plant (BOP) is a term generally used in the context of power engineering to refer to all the supporting components and auxiliary systems of a power plant needed to deliver the energy, other than the generating unit itself.
- FPS(Fuel Processing System), APS(Air Processing System), TMS(Temperature Management System)… etc.

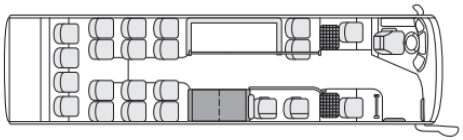
*BHDC: Bidirectional DC–DC converter

Test vehicle

■ Specification of test vehicle(**Hyundai_ELEC CITY_FCEV**)

<Source : ELEC CITY_FCEV _ **HYUNDAI** >

Seat Layout



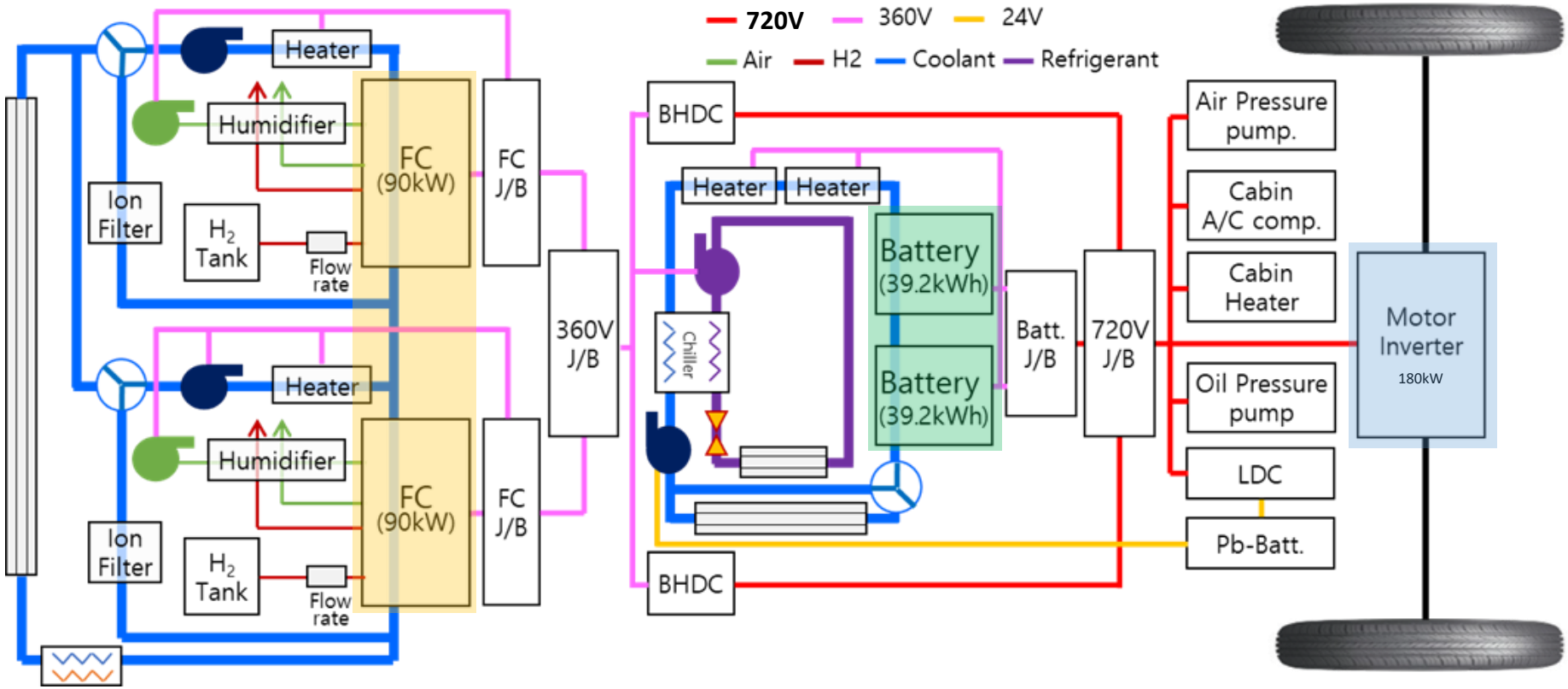
48(22+1+25)

ELEC CITY_FCEV spec.

Size(mm)		10,995x2,490x3,400
Weight(kg)		12,770
Fuel Cell(kW)		180(90 x 2ea)
Hydrogen Tank	**Volume(L)**	875L (175L x 5ea)
	Total Amount(kg)	34.5
	Charging pressure(bar)	700
Motor	**Type**	ZF Central motor
	Power(kW/rpm)	180/4000
Battery	**Type**	Lithium Ion Battery
	Capacity(kWh)	78.4(39.2 x 2ea)

Test vehicle powerplant

■ Powerplant composition



<Hyundai Elec City FCEV system composition>

Diagram summarizes the overall system power and heat management components of the vehicle.

*Humidifier: a device that supplies heat and moisture to the air through an internal humidifying membrane so that the air supplied to the fuel cell stack meets the requirements of the specifications. The heat and moisture of the exhaust air from the stack are transferred to the supply air of the stack, and the temperature and moisture of the air supplied to the stack are adjusted to suit the requirements of the stack.

Test Bed

■ Chassis dynamometer

- Vehicle max. power test
- **TP2 loss : Tire and Drive train (Axle)**
- **Motor Torque value is measured by CAN data**

<Vehicle chassis dynamometer test>

■ Hub dynamometer

- Motor and drive train max. power test
- **TP2 loss : Drive train only**
- **Motor Torque value is measured by sensor**

<Motor/Drive train bench hub dynamometer test>

Same test condition

- Motor Speed and Torque (CAN)
- Motor/Inverter coolant temp.
- Battery voltage

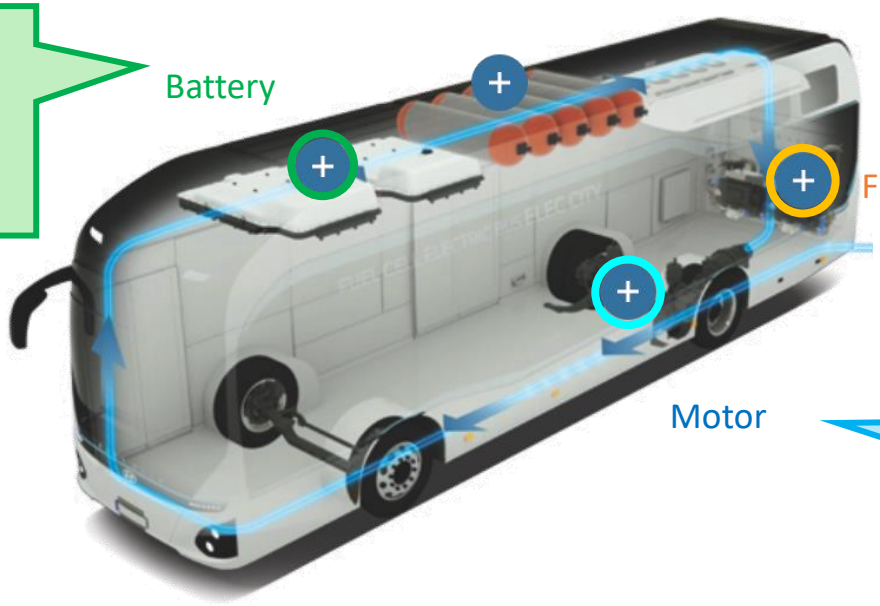
Chassis dynamometer

■ Measurement methods

- CAN data
- Measured by sensor if unavailable from CAN

- System voltage
- System current
- Temperature
- SOC
- etc

Battery



Fuel Cell

- System voltage
- System current
- Coolant temperature
- Coolant flow rate
- Air temperature
- Air pressure
- Hydrogen flow rate
- Hydrogen pressure
- etc

Motor

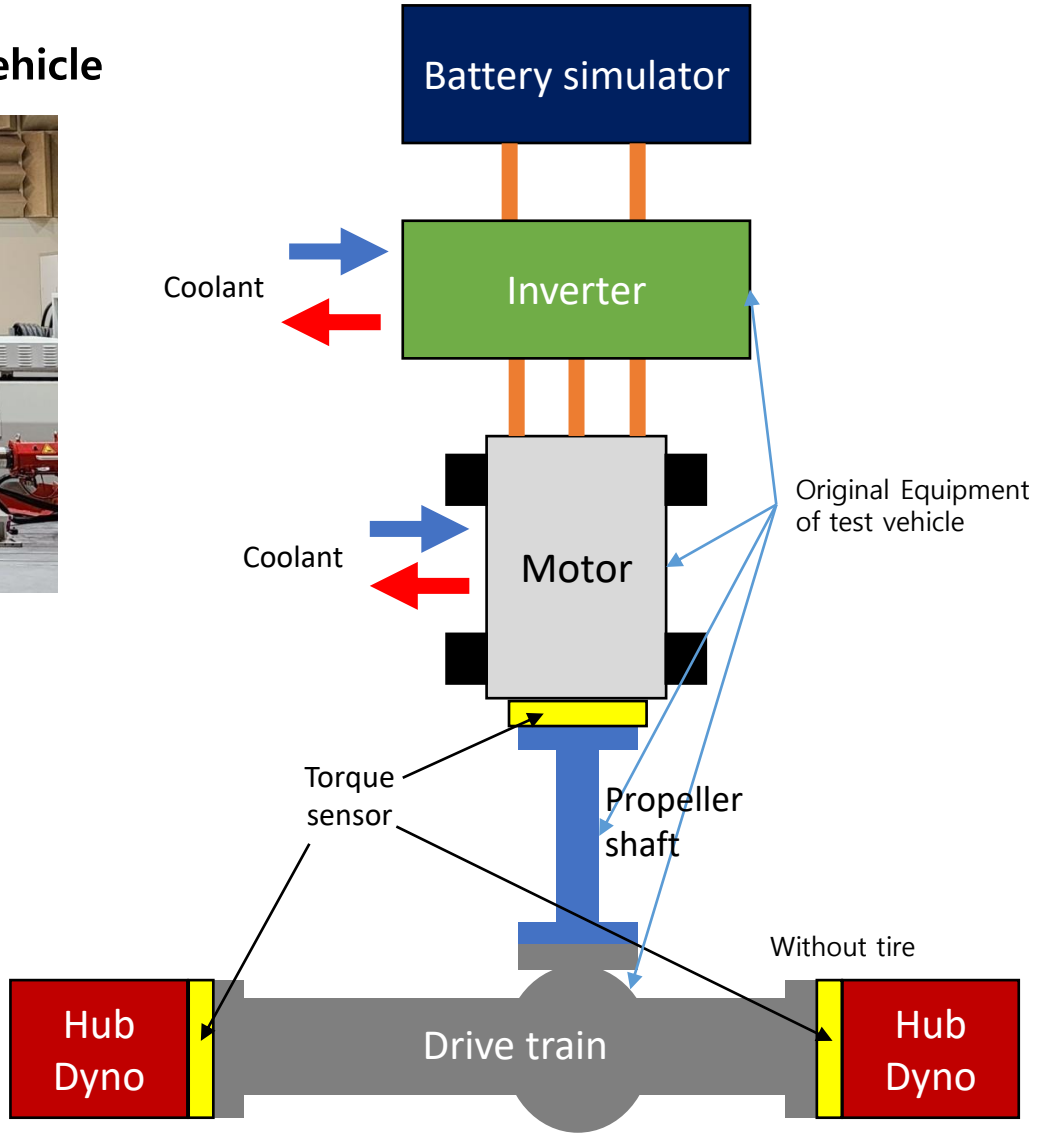
- Voltage
- Current
- Speed
- Torque
- etc

<Main measurement data>

Hub dynamometer

■ Hub Dynamometer for commercial vehicle

Category	No.	Data name	Qt'y	Method
Hub Dyno test	1	Motor speed	1	CAN
	2	Motor torque	1	
	3	Motor speed	1	Sensor
	4	Motor torque	1	
	5	Hub dyno speed R	1	
	6	Hub dyno toque R	1	
	7	Hub dyno speed L	1	
	8	Hub dyno toque L	1	
	9	Inverter coolant temp.	1	
	10	Motor coolant temp.	1	



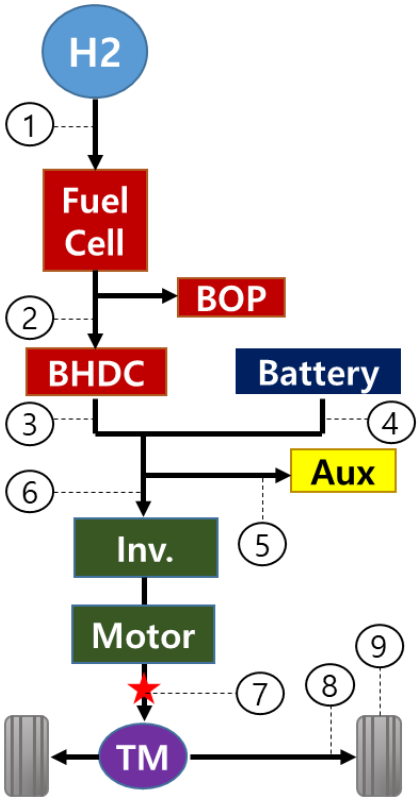
Test Condition

■ Test conditions

No.	Vehicle speed (Cont.)		APS	Test possibility
	Target	Actual		
1	10 km/h	-	100%	No (Tire slip)
2	20 km/h			
3	30 km/h			
4	40 km/h	41 km/h		Yes
5	50 km/h	51 km/h		
6	60 km/h	61 km/h		
7	70 km/h	71 km/h		
8	80 km/h	77 km/h		

■ Analysis point

- System power measuring point : ⑦
- TP 1 test : ① → ⑦
- TP 2 test : ⑨ → ⑦



✓ Chassis dyno test

①~⑦, ⑨

✓ Hub dyno test

⑦~⑨

★: Reference point (motor output shaft)

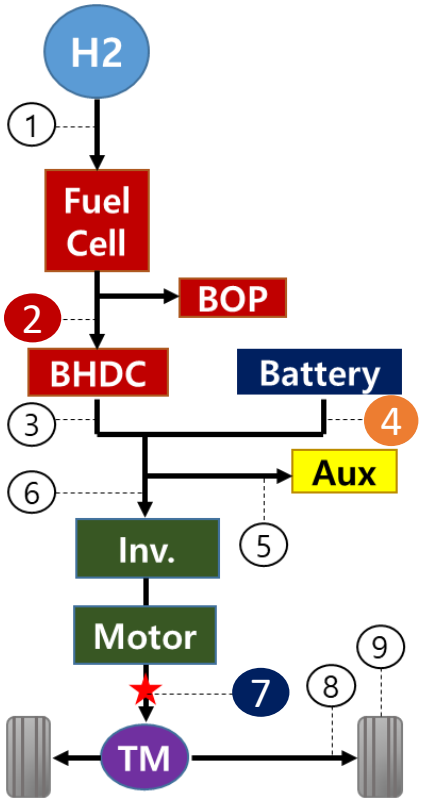
Test video(Hub Dyno for commercial vehicle)

Test Result

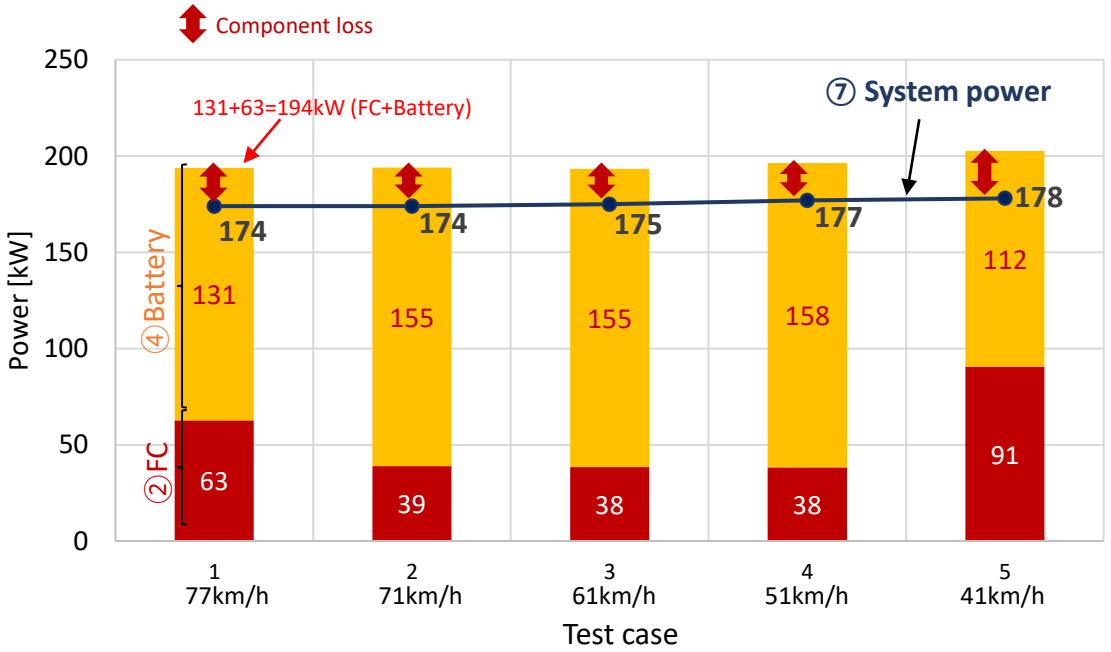
■ System power

- The maximum system power was confirmed in all five tests.
- The system power is less than the sum of the powers of the fuel cell and battery.

: **System power < FC power + Battery power**



<TP1 test system power comparison>



★: Reference point (motor output shaft)

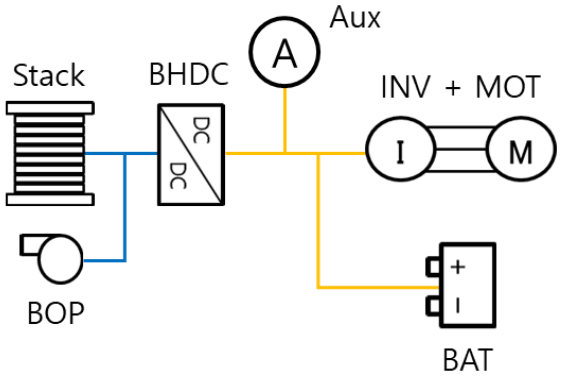
Test Result

(*precisely supply for inverter)

■ Component loss equation (=Motor supply power equation) for TP1 test method

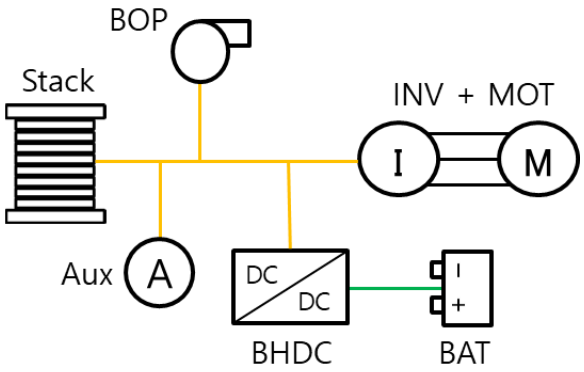
- Since the configuration of components are different for each vehicle, the component loss equation formula for TP1 is different depending on the vehicle.

<Hyundai Elecity FCEV>



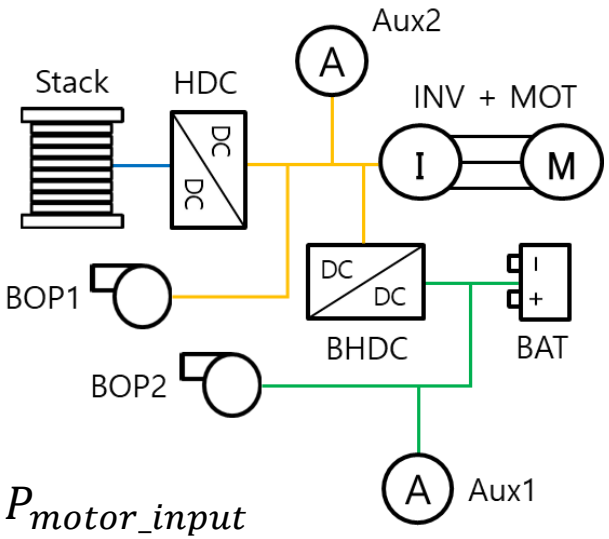
$$P_{motor\_input} = (P_{FC} - P_{BOP,FC})\eta_{DCDC,FC} + P_{Bat}\eta_{DCDC,Bat} - P_{Aux,HV}$$

<Hyundai NEXO>



$$P_{motor\_input} = P_{FC} + P_{Bat}\eta_{DCDC,Bat} - P_{BOP,HV} - P_{Aux,HV}$$

<TOYOTA MIRAI>



$$P_{motor\_input} = P_{FC}\eta_{DCDC,FC} + (P_{Bat} - P_{BOP,Bat} - P_{Aux,Bat})\eta_{DCDC,Bat} - P_{BOP,HV} - P_{Aux,HV}$$

*BOP: Balance of plant(Peripheral devices for fuel cell operation)

Test Result

■ Component loss equation (=Motor supply power equation) for TP1 test method

- The component loss equation can be generalized because it is determined by the BOP's power supply source and the location of the DC/DC converter.

<General equation of motor supply power>

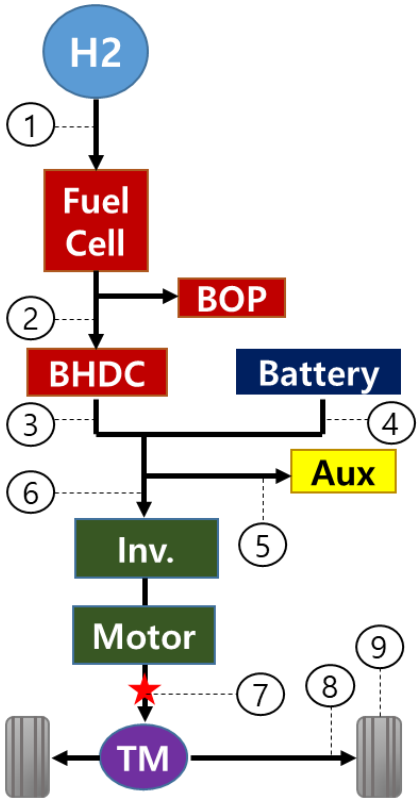
$$P_{motor\_Input} = \left(P_{FC} - P_{BOP,FC} - P_{Aux,FC}\right)\eta_{DCDC,FC} + \left(P_{Bat} - P_{BOP,Bat} - P_{Aux,Bat}\right)\eta_{DCDC,Bat} - P_{BOP,HV} - P_{Aux,HV}$$

(*precisely supply for inverter)

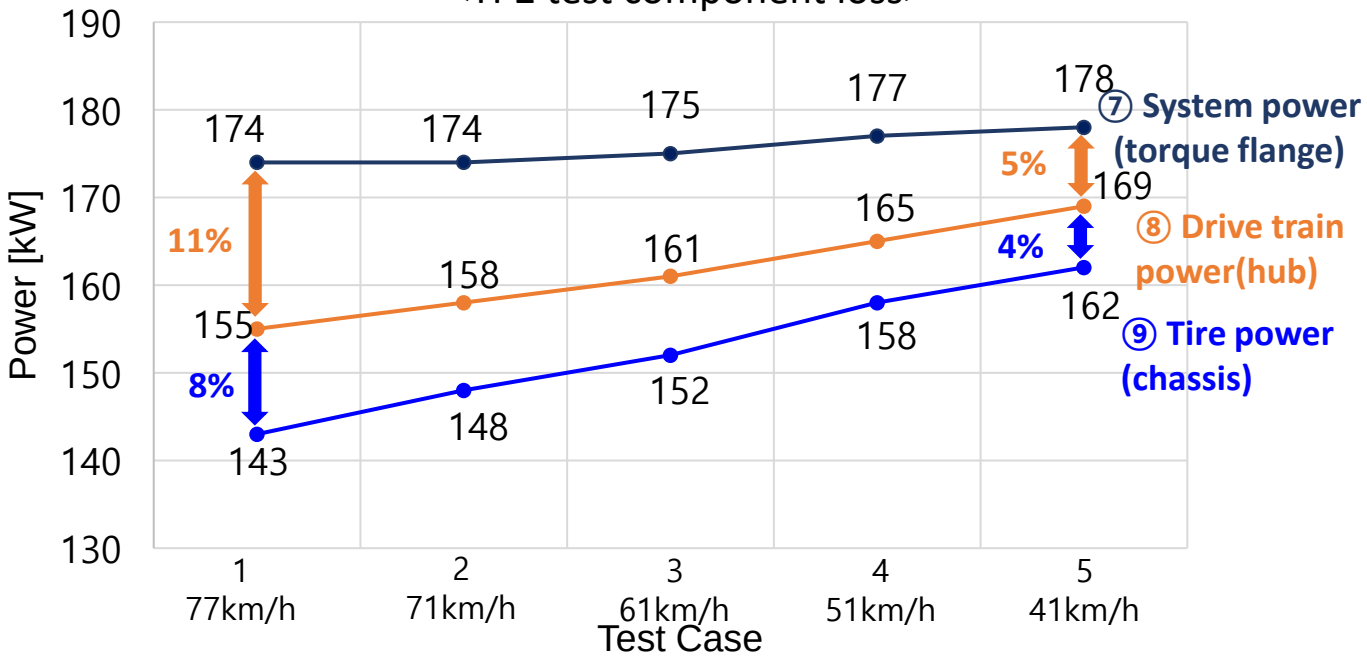
Test Result

■ Component loss for TP2 test method

- For chassis dyno testing, both tire loss and drive train loss must be considered.
- For hub dyno testing, only drive train loss needs to be considered.
- **Drive train loss increases from 5% to 11% as vehicle speed increases.**
  → **Must be considered when calculating maximum power test conditions.**
- **Tire loss (Rolling resistance) increases from 4% to 8% as vehicle speed increases.**
  → **Hub dyno testing without tire loss is recommended, and test conditions for equalization of rolling resistance must be added.**



<TP2 test component loss>



★: Reference point (motor output shaft)

Test Result

■ Through chassis dyno testing and hub dyno testing, we confirmed whether FCEV system power can be measured using the concept of the GTR21's system power test method.

■ If the following three items are considered, FCEV system power can be measured using the GTR21 test method concept.

① For TP1 test method, the component loss equation can be generalized

$$P_{motor\_Input} = \left(P_{FC} - P_{BOP,FC} - P_{Aux,FC}\right)\eta_{DCDC,FC} + \left(P_{Bat} - P_{BOP,Bat} - P_{Aux,Bat}\right)\eta_{DCDC,Bat} - P_{BOP,HV} - P_{Aux,HV}$$

② For TP2 test method, drive train loss must be considered when calculating system power test conditions.

③ For TP2 test method, hub dyno testing without tire loss is recommended, and test conditions for equalization of rolling resistance must be considered.

(Ex. Tire pressure., warm up time, etc.)

Conclusion & Suggestion

It is possible to consider FCEVs in GTR21.

① Scope and application revision

It is necessary to expand the scope of GTR21 and apply it to FCEVs.

However, considering the following, it is necessary to review from a long-term perspective when a change in GTR21 scope is necessary.

- Research and development on FCEVs continues, there are automobile manufacturers that do not sell FCEVs, and there are countries where the supply of FCEVs is still low.

~~2.2.This UN GTR does not apply to fuel cell vehicles.~~ => need to delete

② Revised to add FCEV-related definitions, abbreviations, and powertrain architecture..

In fact, a lot of complementary work is needed to consider FCEVs (Scope and application, Definitions, Abbreviations, Test conditions, Test procedure.)

Also, like hybrid vehicles, FCEVs can be equipped with various powertrain architectures and technologies, so it is necessary to review various vehicles developed in the future from a long-term perspective over time.

T H A N K Y O U

Research No. RS-2020-KA158067

Development of technology and equipments for evaluating hydrogen bus safety