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The Development of a Multi-port Slow Charger for Electric Vehicles

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Abstract

Background/Objectives: The EV charging infrastructure consists largely of the power supply facilities, charger, interface, and information system. Charger that supply electricity from an electricity provider to EV batteries can be classified as direct charging, noncontact charging, and battery exchange. **Methods/Statistical Analysis**: Direct charging is divided into slow charging and fast charging based on the charging time. At present, 90% of the charger market is slow chargers. The points to be solved of slow charger is the user discomfort and installation cost due to limitation of space and time. **Findings:** To solve this point, proposed the multi-port slow-charging system in this study. It reduced the installation and maintenance costs in comparison to existing chargers and improved user convenience by providing a multi-port charging feature, which enables multiple EVs to be charged simultaneously with one charger, and by providing a user interface through the driver's smart phone to implement the V2G standard. A prototype of the proposed multi-port slow-charging system was implemented, and performance tests were conducted in situations similar to the actual environment to verify the performance of the proposed system. An analysis of the performance test results reveals that the proposed system was above the KC(Korea Certification) standard values. Furthermore, the proposed multi-port slow-charging system can reduce costs by about 50%, compared to the existing charging system, based on the manufacturing and maintenance costs of the charger. **Application/Improvements:** The user interface of the charger was interfaced with the driver's smart phone, implementing a communication system that is similar to the V2G protocol in order to construct an ICT charging system that can be monitored remotely in real time. It is expected to contribute to the expansion of the EV charging infrastructure.

Keywords: Control Pilot Duty Cycle, EV, Multi-port Slow Charger, RF Card, Smart Phone Interface, V2G

1. Introduction

There are four major parameters that determine the demand for Electric Vehicles (EVs): policy, infrastructure, consumer attitude, and operation environment. An analysis of these major parameters for EV propagation is outlined in Table 1[1].

As shown in Table 1, one of the major parameters for infrastructure construction is the size, composition, and accessibility of charging devices. The installation of many EV charging stations is a prerequisite for accelerating EV propagation.

The global market size for EVs in 2014 was forecasted to reach between 200,000 and 1,060,000. The required number of charging devices is usually double the number of EVs. The EV sales forecasts for major countries in 2020 are shown in Figure 1[2].

In the case of slow chargers, which account for 90% of the total charger market, one limitation on the expansion of charging systems is that it is difficult to install as many charging stations as existing gas stations because the EV charging stations require a large space for simultaneous charging, there is a long charging time, and there is a high installation cost for chargers. To address these issues, a new charging method that lowers the installation cost for the chargers and increases the availability of parking

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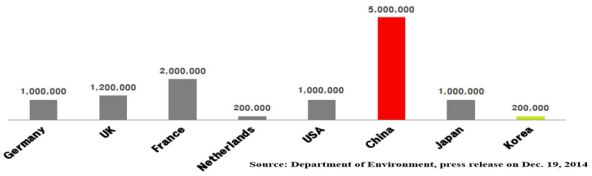
Table 1. Major parameters of EV propagation

Policy Environment	Infrastructure
Regulations on vehicle greenhouse gas emissions and fuel efficiency Incentives for buying EVs Support for EV operation Incentives for infrastructure construction Level of planning	Size, composition, and accessibility of charging devices Degree of smart gridation Reliability of power supply Greenhouse gas emissions from electric power production
Consumer Attitude	**Operation Environment**
Air quality and pollution level Consumer awareness of environmental problems Degree of hybrid electric vehicle (HEV) propagation	Fuel price level and variability Climate conditions Garage possession rate Commuting distance



Source: Department of Environment, press release on Dec. 19, 2014

Figure 1. EV sales forecasts for major countries in 2020.

space for charging is required. In this paper, to overcome the limitations on the expansion of the existing charging infrastructure, a slow-charging system is proposed that can reduce the charger installation and maintenance costs by 50%; this is done by providing a multi-port slow-charging feature, which can charge multiple EVs simultaneously with one charger, and by replacing the user interface with the user's smart phone, which allows for real-time monitoring of the charging status, even from remote places, by interfacing with the driver's smart phone. To verify the performance of this proposed multi-port slow charger, a prototype of the proposed system was developed and fabricated, and its performance was evaluated and verified in an actual charging environment.

1.1 Composition of the Charging Infrastructure

The EV charging infrastructure consists largely of the power supply facilities, charger, interface, and information system. Figure 2 shows a schematic diagram of the EV charging infrastructure[3].

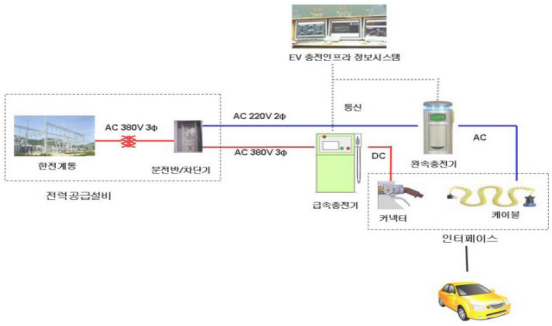
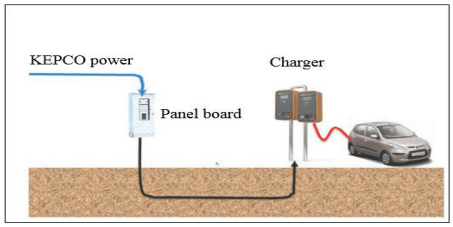


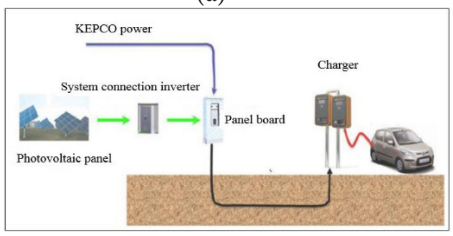
Figure 2. Schematic diagram of the EV charging infrastructure.

1.1.1 Power Supply Facilities

The main power supply method is to receive power from the Korea Electric Power Corporation (KEPCO) is shown in Figure 3(a), but another option is to use new and renewable energy, such as receiving power from photovoltaic power-generation facilities and power-generation facilities that use the waste heat of incineration facilities is shown in Figure 3(b).



(a)



(b)

Figure 3. EV power supply methods. a) KEPCO power supply (b) KEPCO + photovoltaic power supply

To apply electric power-load management and the power rates for EVs, separate power for EV charging must be received from KEPCO which requires the installation of a separate meter. The incoming line can be installed as an underground or aerial service, and the installation method and cost will vary based on the conditions at the

installation site. A distribution board with an earth leakage breaker or a molded-case circuit breaker—to ensure the safe use of electricity—will be installed near the charging station to allow easy access to the electric circuits.

1.1.2 Types of Charger

Chargers that supply electricity from an electricity provider, such as KEPCO, to EV batteries can be classified as direct charging, noncontact charging, and battery exchange.

1.1.2.1 Direct Charging

Power is supplied by directly connecting a charger to the charging port of an EV to recharge the battery mounted inside the EV. Direct charging is divided into slow charging and fast charging based on the charging time. Slow charging can be performed through an ordinary home outlet, as it is rated as a single-phase AC 220V. For fast charging, 380-450V is usually supplied for high-voltage and high-capacity charging, which requires safety mechanisms for the internal batteries and external charging system. At present, 90% of the charger market is slow chargers. Figure 4 shows a schematic diagram of direct charging

1.1.2.2 Noncontact Charging

A feeder line, which generates an alternating current under the floor of the parking lot, is buried with a magnetic material (core), and a current collector—which receives energy by generating an induced current after receiving a magnetic field from the AC generated under the ground—is mounted on the bottom of the vehicle. The current generated from this current collector charges the battery after rectification. Figure 5 shows a schematic diagram of Noncontact charging

1.1.2.3 Battery Exchange

The owner of the charging station will charge reserve batteries using power during the day with a low load rate, and the drivers will exchange their EV batteries by the cooperation of man and machine at the charging station.

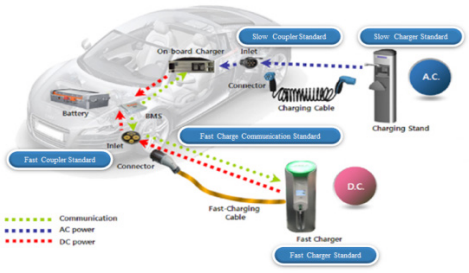


Figure 4. Direct charging.

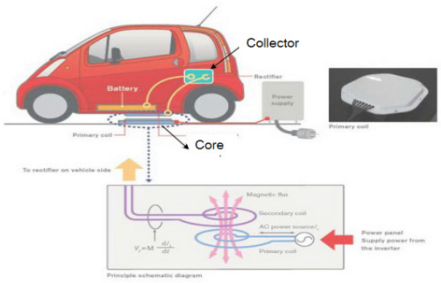


Figure 5. Noncontact charging type.

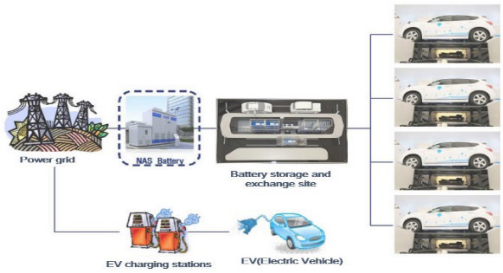


Figure 6. Battery exchange method.

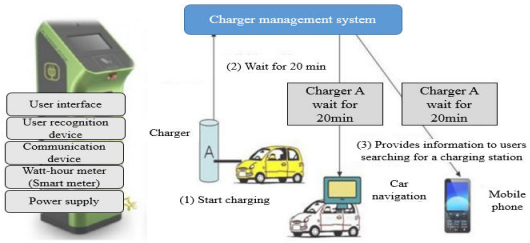


Figure 7. Outline of the charging information system.

Table 2. Comparison of direct charging types

Division	Voltage		Supply capacity	Charging time	Market share
	Input	Output			
Slow charging	AC single-phase 2-wire 220V	AC single-phase 220V	3 ~ 7 kW	5 ~ 6 hours	90%
Fast charging	AC 3-phase 4-wire 380V	DC 380 ~ 450V Or AC 380V	50 kW	15 ~ 30 minuites	10%

Figure 6 shows a schematic diagram of Battery exchange.

1.1.3 Charging Information System

This system collects and provides the locations and use-state information of the chargers for EV users and monitors the operation state of the charging facilities. Figure 7 shows a schematic diagram of Outline of the charging information system. Slow-charging communication can be implemented using two methods. The first method is a signal system that uses Pulse Width Modulation (PWM) and control pilot wires, which enables the charging system to send the available power information to vehicles. This allows simple load control by an external energy controller[4]. The second method is high-level communication that enables more complex and intelligent services that use IP, which requires a more complex protocol for communication between an EV and a charging system. Implementing slow charging based on high-level communication means that the EV and charging system can be connected to a network. In this way, the charging network can be configured in various ways, depending on the character and place of the charging infrastructure, with the EV as one node of the network. This method is being standardized now in ISO/IEC V2G JWG. The structure of the V2G communication protocol and the charge communication messages are shown in Figures 8 and 9 [5–7].

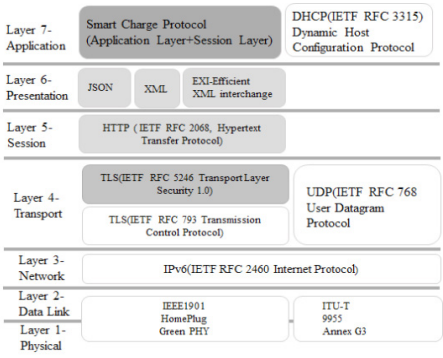


Figure 8. Structure of the V2G communication protocol.

- Layer 7: Application layer; defines the messages for smart charging and has functions in contrast to the application protocol related to the EVs of ZigBee SEP 2.0
- Layer 6: Expresses messages by applying XML or JSON, and it uses EXI for their compression.

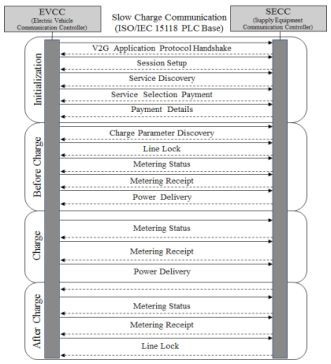


Figure 9. Message composition for slow-charge communication.

- Layer 5: Session layer; the DoIP (ISO 13400) defined for vehicle diagnosis based on IP has changed a little.
- Layer s 3 and 4: Adopts TLS to ensure the security of the connection between the terminals of the EV and charging system along with the usual TCP/IP stack.
- Layers 1 and 2: Physical and data link layers; the power line communication (PLC) technology is applied .

2. Main Characteristics of the Proposed Charging System

In this study, a multi-port slow-charging system was proposed and implemented; it reduced the installation and maintenance costs in comparison to existing chargers and improved user convenience by providing a multi-port charging feature, which enables multiple EVs to be charged simultaneously with one charger, and by providing a user interface through the driver's smart phone to implement the V2G standard.

2.1 Main Features of the Proposed Multi-port Slow Charger

Table 3 compares the performance of the proposed multi-port slow charger to the existing slow charger.

The proposed multi-port slow-charging system consists of three main parts: the charger, the service server, and the driver's smart phone. When the driver requests charging through his or her smart phone, the service server analyzes the request, checks the condition of each charger in the charging station, and sends the charging state to the charger. Then the charger distributes power to

Table 3. Main features of the proposed multi-port slow-charging system

	Existing slow-charging system	Proposed multi-port slow-charging system
Contents	A larger parking space is required, as it is impossible to charge multiple vehicles with one charger. The production, operation, and maintenance costs are high because the charging system UI is a kiosk type. Users cannot remotely monitor the charging state in real time.	The chargers can supply 7 kW per port and 21 kW in total. The 7 kW power can be divided into three ports for charging. Power can be distributed arbitrarily to each port. Each port can perform pilot communication independently from the vehicle. The charger can interface with the user's smart phone to provide a charge-communication service and user interface functions.

the port and starts charging. Furthermore, after a certain period of time, the system sends the charging state of the chargers to the service server, and the service server sends the received charging state to the driver's smart phone app. The driver can then monitor the current charging situation even from remote locations. The multi-port charger is composed of a Micro Control Unit (MCU) that controls all situations, a communication module for communicating with the service server, a vehicle communication module that interfaces with the smart phone, a relay control module that controls relay operations, and a current measure module. Figure 10 shows a schematic diagram of the proposed multi-port slow-charging system.

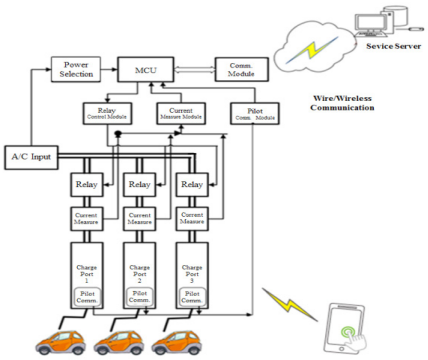


Figure 10. Schematic diagram of the proposed multi-port slow charging system.

2.2 Charging Flow of the Proposed Charging System

The charging flow of the proposed charging system is shown in Figure 11.

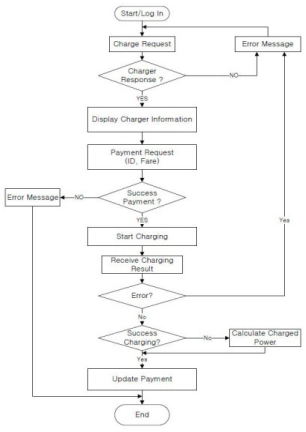


Figure 11. Charging flow chart for the proposed system.

3. Implementation of the Proposed Charging System

3.1 Circuit Diagram of the Proposed Charging System

The main circuit diagram of the charger and the fabricated PCB are shown in Figure 12.

The specifications and characteristics of the main parts of the proposed charger are shown in Table 4.

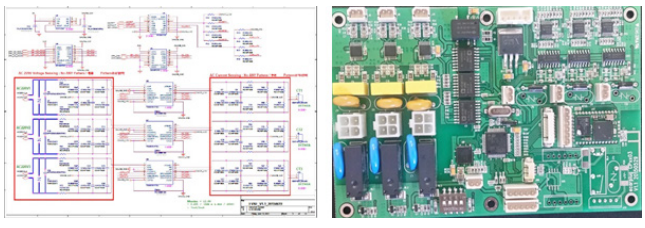


Figure 12. Circuit diagram and PCB of the proposed system.

3.2 Comparison of the Shape of the Proposed Charger and the Existing Charger

Figure 13 shows the differences in shape between the existing slow charger and the prototype of the proposed

Table 4. Main hardware specifications for the proposed system

Main components	Model names	Main characteristics
MCU	STM32L100RB	- Ultra-low-power platform - Core: 32-bit ARM® Cortex®-M3 CPU - Up to 51 fast I/Os - Pre-programmed bootloader - Seven DMA controller channels - Eight communication interface peripherals - CRC calculation unit
Communication Module	BT1010	- Bluetooth® Class 2 v2.1+EDR system - Enhanced Data Rate (EDR) compliant for both 2Mbps and 3Mbps modulation modes - Full-speed Bluetooth operation with full Piconet - 1.8V core, 1.8 to 3.6V I/O - Interfaces: PIO, AIO, UART, USB - Support for 802.11 coexistence
Current Measure Module	78M6610+LMU	- Four configurable analog inputs for monitoring any single-phase circuit (2/3-wire) - Supports current transformers (CT) and resistive shunts - Flexible SPI, I2C, UART interface options with configurable I/O pins for alarm signaling, address pins, or user control
Vehicle Communication Module	DG408DY-T1-E3	- Low on-resistance - rDS(on): 100 Ω - Low charge injection - Q: 20 pC - Fast transition time - tTRANS: 160 ns - Low power - ISUPPLY: 10 µA - Single supply capability - 44 V supply max rating - TTL compatible logic

multi-port slow charger. The user interface of the existing charger is a kiosk type. The proposed charging system replaces the user interface with the user's smart phone, which improved user convenience by providing real-time remote monitoring of the charging situation and payment. Furthermore, the charger's manufacturing and maintenance costs were reduced by at least 50% in comparison to the existing charger.

3.3 Interface between the Proposed Charger and a Smart Phone

Figure 14 shows the smart phone interface screens for the proposed charging system, which interacts with the EV driver's smart phone. Figure 14 (a) is a screen that shows the locations of available charging stations based on the current location of the driver; (b) is an operation screen for starting the charging; (c) is a user screen for when the user wants to stop charging; (d) is a screen that indicates the current charging state; (e) is a screen that downloads data about the charging by interfacing with the service server; and (f) is a user screen that shows the charging history data of the service server.

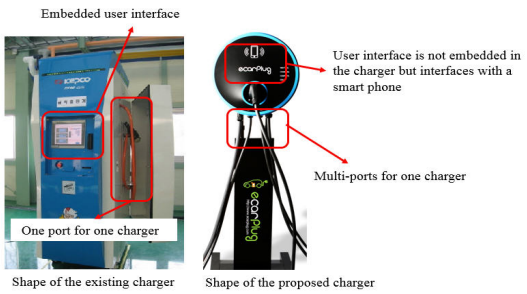


Figure 13. Comparison of the shape of the existing and the proposed slow-charging systems.

(a)

(b) (c) (d)

(e) (e)

Figure 14. Smart phone interface screens for the proposed charging system (a) Locations of available charging stations (b) Charging start screen (c) Charging stop screen (d) Current charging state (e) Communication with service server (f) Data received from service server.

4. Performance test and the Results of the Proposed System

4.1 Test Scenario

A prototype of the proposed multi-port slow-charging system was installed at the test, site as shown in Figure 15, and a performance test was conducted.

Figure 15. Performance test of the prototype of the proposed system

The performance test was divided into two parts. In the first part, the operation of the multi-port pilot charging function, which automatically distributes power depending on the charging situation, was checked. In the second part, a test was done to ensure that the output satisfies the KC standards for EVs provided by the Department of Environment.

4.1.1 Multi-port Automatic Distribution Test Scenario

To test the automatic power distribution to three ports, depending on the charging situation, the charging situation was changed every 30 minutes with a supply of 7 kWh power. Then, the performance of the charging system was tested according to five test scenarios, as shown in Table 5.

Table 5. Multi-port automatic distribution test scenario

Test sequence number	Charging scenario
1	Charging through port C0 only
2	Simultaneous charging through two ports: C0 and C1
3	Simultaneous charging through three ports: C0, C1, and C2
4	Simultaneous charging through two ports: C2 and C3
5	Charging through port C3 only

4.1.2 Results of the Multi-port Automatic Distribution Test

Figure 16 shows the control-pilot duty-cycle output screen when the charging system used only one port, C0, for charging. Figure 17 shows the control-pilot duty-cycle output screen when the charging system used two ports, C0 and C1, for charging. Figure 18 shows the control-pilot duty-cycle output screen when the charging system used three ports, C0, C1, and C2, for charging. For the control-pilot duty cycle, the international rules of the Society of Automotive Engineers (SAE) technical report SAE J1772TM[8] were used. Figures 16 to 18 show the output screens of the control-pilot duty cycle according to the use of ports. Figure 19 shows the monitor screen that displays, in real time, the log data of the charging system

through the RS232 communication. Table 6 shows the voltage, current, and power results for the test scenarios.

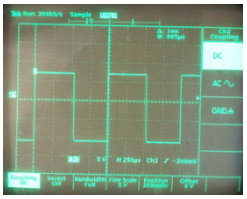


Figure 16. Control-pilot duty-cycle output screen when the charging system used only one port: C0.

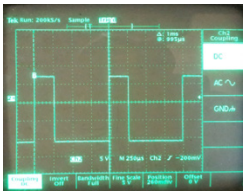


Figure 17. Control-pilot duty-cycle output screen when the charging system used two ports: C0 and C1.

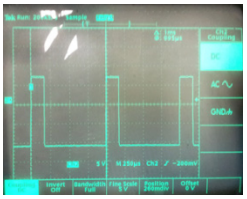


Figure 18. Control-pilot duty-cycle output screen when the charging system used three ports: C0, C1, and C2.

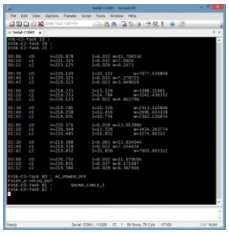


Figure 19. Log-data output screen of the charging system for the test scenarios.

4.1.3 Charger Output Values for the Proposed Charging System

Table 7 shows a comparison of the test results for the proposed charging system to the KC standards for EVs provided by the Ministry of Environment.

5. Conclusion

At present, the South Korean government is installing unmanned pilot charging systems for EVs at a high cost.

Table 6. Output values by port for the test scenarios

Hr: Min	Port	Voltage [V]	Current [A]	Power [kw]
00: 00	c0	220.878	0.053	11.70653
00: 10	c1	221.325	0.032	7.0824
00: 12	c2	223.125	0.028	6.2475
00: 30	c0	220.124	32.152	7077.427
00: 40	c1	220.325	0.033	7.270725
00: 42	c2	219.523	0.023	5.049029
01: 00	c0	218.235	15.526	3388.317
01: 10	c1	219.253	14.784	3241.436
01: 12	c2	220.123	0.022	4.842706
01: 30	c0	219.781	10.526	2313.415
01: 40	c1	218.258	11.416	2491.633
01: 42	c2	219.651	10.754	2362.127
02: 00	c0	220.576	0.059	13.01398
02: 10	c1	220.549	15.526	3424.244
02: 12	c2	220.485	14.852	3274.643
02: 30	c0	219.588	0.063	13.83404
02: 40	c1	219.528	0.033	7.244424
02: 42	c2	219.852	31.856	7003.605
03: 00	c0	220.752	0.052	11.4791
03: 10	c1	220.851	0.037	8.171487
03: 12	c2	219.584	0.029	6.367936

Table 7. Output values of the proposed charger

Test items	Unit	KC standard values		Test results
Use environment	-	IP44		IP44
Input power	V(AC)	220V 2-wire		220V 2-wire
Charge amount	kW	7 kWh/21 kWh		7 kWh/21 kWh
Conductive interference (grade B) Power port	dB(uV)	66~56	1.5 ~ 0.5 MHz	51.6
		56 or lower	0.5 ~ 5 MHz	44.3
		60 or lower	5 ~ 30 MHz	42.4
Radioactive interference (grade B)	dB(uV/m)	30 or lower	30 ~ 230 MHz	25.6
		37 or lower	230~1000 MHz	20.1

In this study, improvement measures were derived by analyzing the existing EV charging system, and a multi-port slow-charging system that provides improvements was proposed. A prototype of the proposed multi-port slow-charging system was implemented, and performance tests were conducted in situations similar to the actual environment to verify the performance of the proposed system. An analysis of the performance test results reveals that the proposed system was above the KC standard values. Furthermore, the proposed multi-port slow-charging system can reduce costs by about 50%, compared to the existing charging system, based on the manufacturing and maintenance costs of the charger. In other words, the proposed system can not only save charging infrastructure construction costs by charging three vehicles simultaneously with one charger, but it can also make more efficient use of the parking space. Furthermore, the user interface of the charger was interfaced with the driver's smart phone, implementing a communication system that is similar to the V2G protocol in order to construct an ICT charging system[9–12] that can be monitored remotely in real time. Thus, the foundation has been laid for expanding user service functions in the future. The proposed multi-port slow-charging system will contribute to the propagation of EVs in the future by facilitating the construction of the charging infrastructure.

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