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Development of Cloud Network-Based Multi-Port Electric Vehicle Charging Protocol and System

Jae-Hee Lee[1], Chang-Jin Seo[2]

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Abstract- Background/Objectives: The present study aims to develop a multi-port electric vehicle charging protocol and system based on a cloud network in one power grid. Methods/Statistical analysis: The proposed system is designed through the hardware and software, which are part of the electric vehicle charger based on the IoT (internet of things) technology. The proposed system is implemented, manufactured, and tested on an actual charging environment to verify its performance, the real-time power-control technology realization software of the server, and the charger monitoring system software. Findings: We could know our system has more efficiency and economics at the installation cost and user convenience in the experiment than the existing charging system. A plan to efficiently manage multiple chargers connected within the same power grid to reduce the charging station installation building's introductory electricity rate is proposed by more than 55 percent. Improvements: The results are shown through system development and performance verification experiments. The proposed system is expected to contribute to the extension of electric vehicle charging infrastructure.

***Keywords*:** *Electric Car, Charging System, Multi-Port Charger, PLNetworks, Cloud*

1. Introduction

As electric vehicles (EV) are sold in more significant numbers, cases that a large number of EV chargers are installed in a single spot are increasing. Due to the unique characteristic of housing that is concentrated in apartments in South Korea, a large number of EV chargers will be installed in a single place. In this circumstance, conventionally, power for EV chargers is needed in proportion to the number of EV chargers. Therefore, it would be a significantly large amount of power, and few electricity facilities of existing buildings can supply such enormous power. Thus, an additional power supply is needed, including much construction cost and the monthly payment of the basic electricity rate. Therefore, it will be an obstacle to the installation of EV chargers. To solve this, the need for an intelligent EV charging system has increased to have the same effect only with less than half the power compared to the existing method [1,2]. In the case of slow chargers, which account for 90% of the whole charger market, one limitation on the expansion of charging methods is that it is hard to install as several 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 vast installation cost for chargers. This study aims to develop a cloud system-based multi-port EV charger system that can collect charging information from each charger by the server in a cloud system environment and control the charging when multiple chargers are connected and run in a single power network. The EV charger sends its information to the server via the Internet of Things (IoT) technology. The server controls the charging power of individual chargers or interrupts power based on the received information. By doing this, a sum of charging power in the chargers connected in the same power node is monitored in real-time not to exceed the rated capacity. Thus, the power amount is automatically distributed intelligently to avoid the power breaker interruption that may occur when the required power exceeds the suppliable power when multiple chargers are installed and run in a single spot. This study aims to develop this cloud system-based multi-port charging system. Figure 1 shows the cloud system-based multi-port EV charger system. The IoT-based EV charger system in this study did not have an in-built monitor for the user interface inside the charger. However, the user interface is designed based on a user's smartphone for all charging and billing procedures to minimize the EV charger unit price and maintenance

[1]*Dept. of Information & Communication, DongSeoul University, South Korea ORCID ID : 0000-0001-8127-2339*
[2]*Dept. of Information Security Engineering, Sangmyung University, South Korea ORCID ID : 0000-0002-9874-4950*
[2]*Corresponding Author E-mail: cjseo@smu.ac.kr*

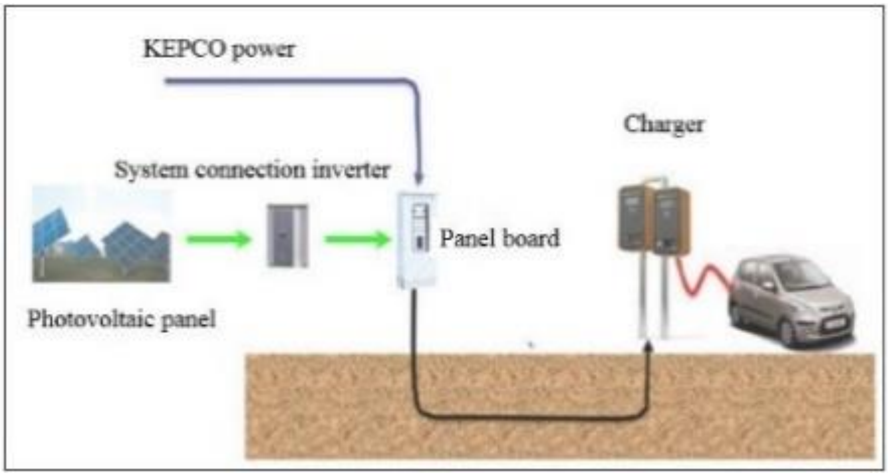
cost [3].

2. Development of IoT technology-based EV charger

2.1 Design of IoT-based EV charger hardware

This study implemented a multi-port charger system using the master-slave mode. It was designed to supply 32A (7kw) power per port, and power is measured for each port to charge the electricity bill [3]. Figure 2 shows the charging and billing in the proposed cloud system-based multi-port charger system.

The proposed system consists of four parts, as shown in Figure 3: hardware and software parts of the IoT-based EV charger, software implementation of real-time power control technology in the server, and the charger's monitoring system. It was designed to enable independent pilot communication with EVs for each port and control the charger via communication with the smartphone through Bluetooth communication [4][5]. Figure 4 shows the hardware block diagram of the IoT technology-based EV charger, and Figure 5 shows the part of the circuit diagram. Table 1 presents the significant specifications of the hardware.



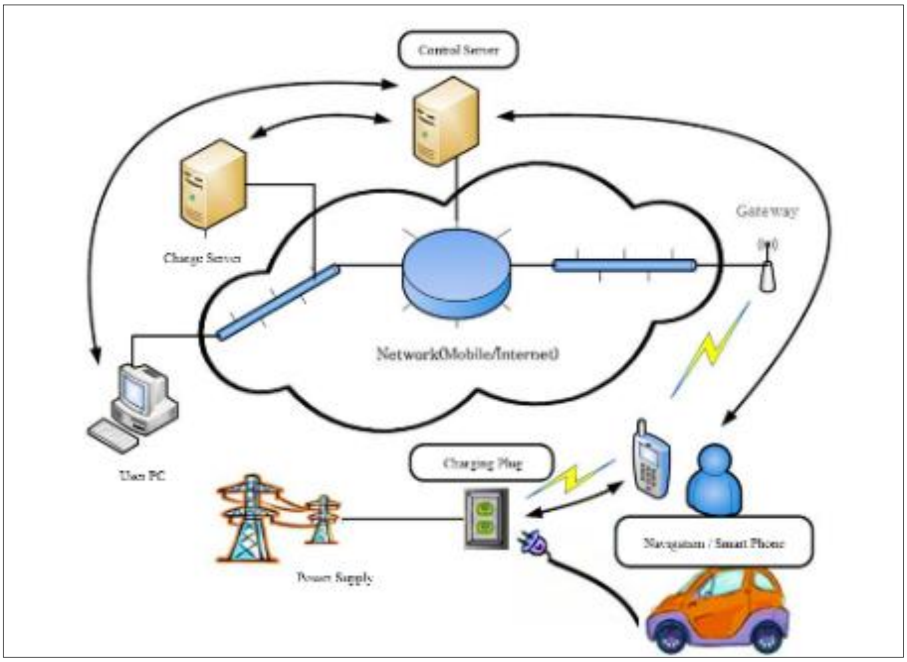


Figure 1- *Conceptual diagram of the multi-port EV charger system based on Cloud Network*

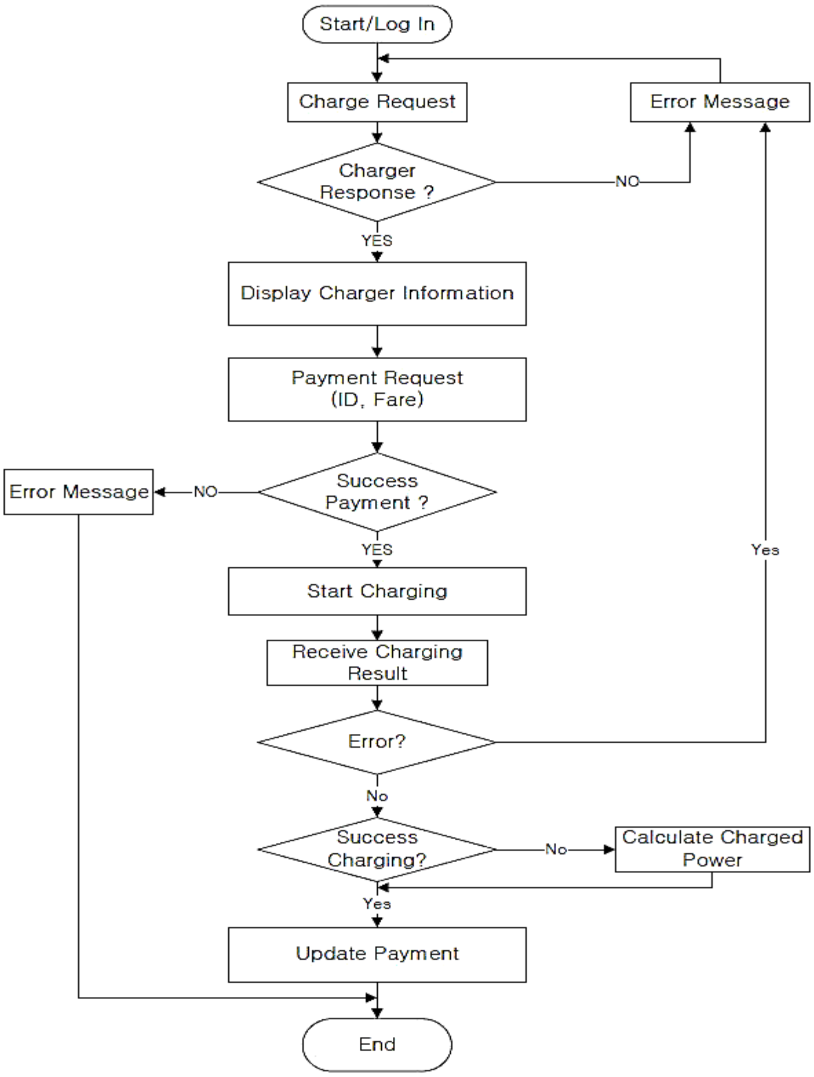


Figure 2- The charging and billing procedure of the proposed system

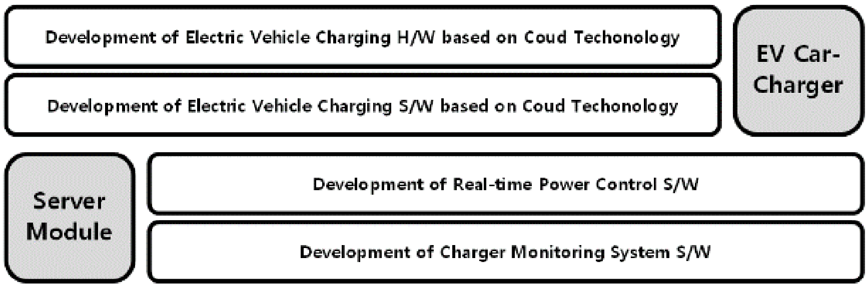


Figure 3- Block diagram of the field in the research and development

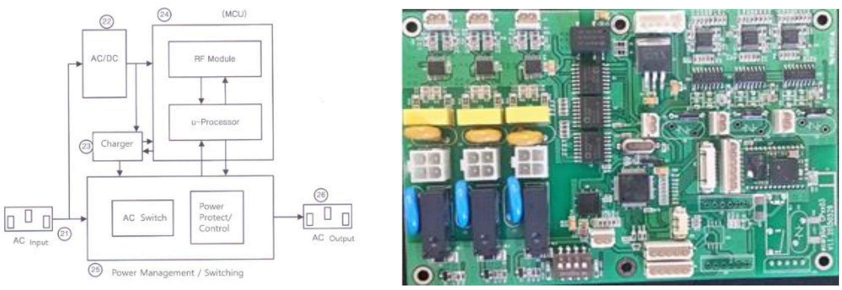


Figure 4- Block diagram and PCB of the proposed system

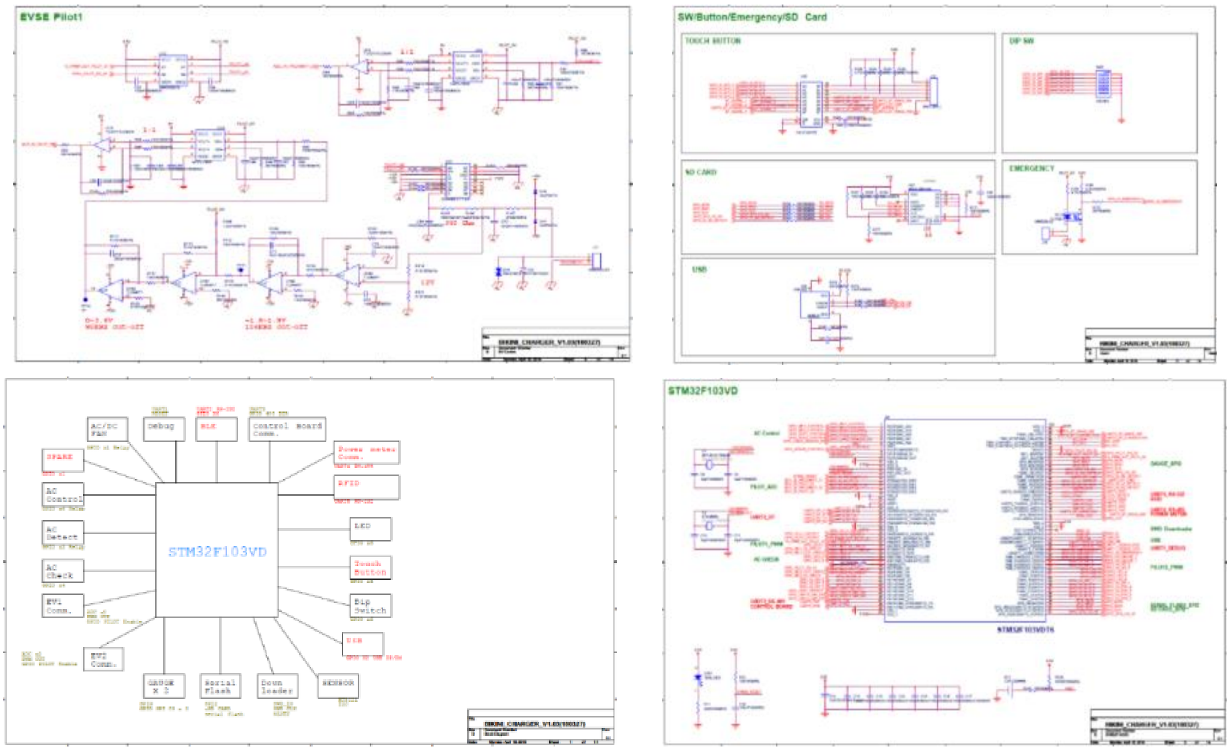


Figure 5- Circuit diagram of electric vehicle charger firmware

Table 1: Major hardware standards used in the IoT-based EV charger system

Main Item	Model Name	Main Features
MCU	STM32F 103VDT	□ Core: ARM 32-bit Cortex™-M3 CPU – 72 MHz maximum frequency □ Memories – 256 to 512 Kbytes of Flash memory □ Up to 112 fast I/O ports – 51/80/112 I/O □ Up to 13 communication interfaces □ CRC calculation unit, 96-bit unique ID □ Pre-programmed bootloader □ Seven DMA controller channels □ Eight communication interface peripherals
Communi cation module	BT1010	□ Bluetooth® Specification Version 2.1 + EDR Compliant □ Upper layer protocol stack (L2CAP, SDP, RFCOMM) □ Output Power: Class 2 (+4 dBm maximum) □ Hardware Interface: UART □ Power Supply: 2.7 ~ 3.6V □ I/O Power supply: 1.7 ~ 3.6V
Current measurem ent module	78M6610 +LMU	□ Building Automation Systems (Commercial, Industrial) □ Inverters and Renewable Energy Systems □ Level 1 and 2 EV Charging Systems □ Grid-Friendly Appliances and Smart Plugs □ Four Configurable Analog Inputs for Monitoring Any Single-Phase Circuit (2/3-Wire) □ Nonvolatile Storage of Calibration and Configuration Parameters □ Internal or External Oscillator Timing References □ Quick Calibration Routines Minimize Manufacturing (System) Cost
Vehicle communi cation module	DG408D Y-T1-E3	□ On-resistance - RDS(on): 100 Ω □ Charge Injection - Q: 20 pC □ Reduced switching errors □ Reduced glitching □ Wide supply ranges : Single supply: +5 V to 36 V Dual supplies: ± 5 V to ± 20 V □ Battery powered systems

2.2 Design of IoT-based EV charger firmware

Figure 6 shows the firmware block diagram of the Cloud-based EV charger. Table 2 presents the functions of the main modules in the IoT-based EV charger firmware.

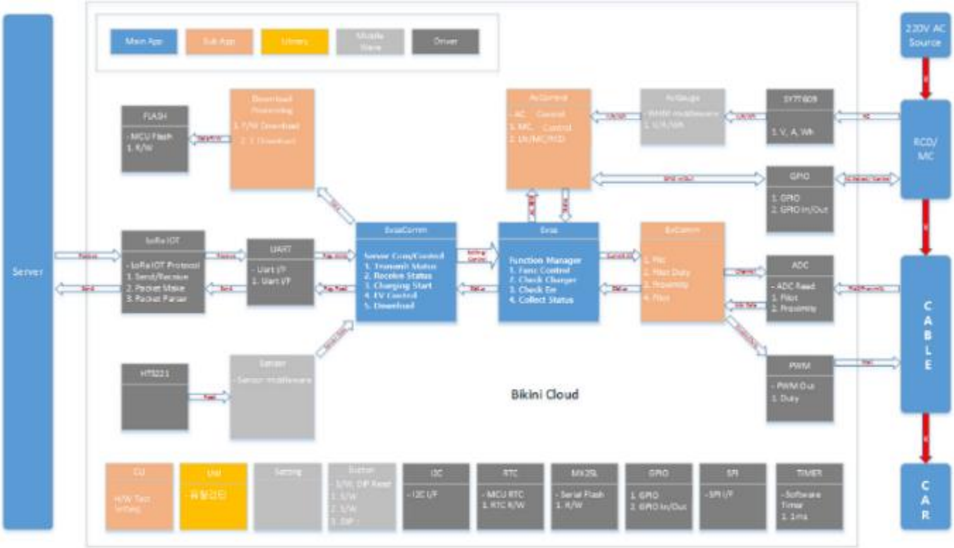


Figure 6- Block diagram of electric vehicle charger firmware

Table 2: IoT technology-based electric vehicle charger firmware's main module functions

Firmware Module	Main Function
Evse	□ Integrated management of charging function □ The charging function is performed using EvComm and AcControl sub-modules
EvComm	□ Module in charge of communication with EVs □ The maximum power is set according to the detection of proximity. □ Pilot duty control according to the detection of pilot status and power amount setup
AcControl	□ Ac-related power control and management □ MC and RCD control □ Control of voltage, current, power, MC, and RCD operation status □ Abnormal status testing such as safety-related over-voltage, low-voltage, over-current, and MC failure
Evse Comm	□ Communication with the server and charger control □ Transmission of charger status information □ Charging start and stop, power amount setup control - Communication with the server and charger control □ Transmission of charger status information □ Charging start and stop, power amount setup control
Drivers for other hardware control	□ Built-in peripheral device drivers of MCU such as FLASH, RTC, GPIO, TIMER, PWM, and ADC □ MCU built-in I/F drivers such as I2C, UART, and SPI □ External chipset drivers such as HTS221, LoRa IoT, and MX25L

2.3 Communication protocol between IoT-based EV charger and server

Figure 7 and Table 3 present the communication protocol's operation diagram between the Cloud-based EV charger and server and communication protocol. For example, the IoT-based EV charger in this study is called "eCarPlug," and the server is called "eCarPlug Server" [6][7].

TABLE 3: Communication protocol between IoT-based electric vehicle charger and server

<table>
<tr><th>Category</th><th colspan="2">Value</th><th>Note</th></tr>
<tr><td>Message transmission time</td><td colspan="2">up to 10 sec</td><td>PLNetworks</td></tr>
<tr><td>Reception elapsed time of response message after request message transmission</td><td colspan="2">up to 30 sec</td><td></td></tr>
<tr><td rowspan="2">Re-attempt if the response message is not received after the request message transmission</td><td>Interval</td><td>30 sec</td><td rowspan="2">Up to 1 min 30 sec</td></tr>
<tr><td>Count</td><td>3 times</td></tr>
<tr><td>New request message transmission interval</td><td colspan="2">2–10 min.</td><td></td></tr>
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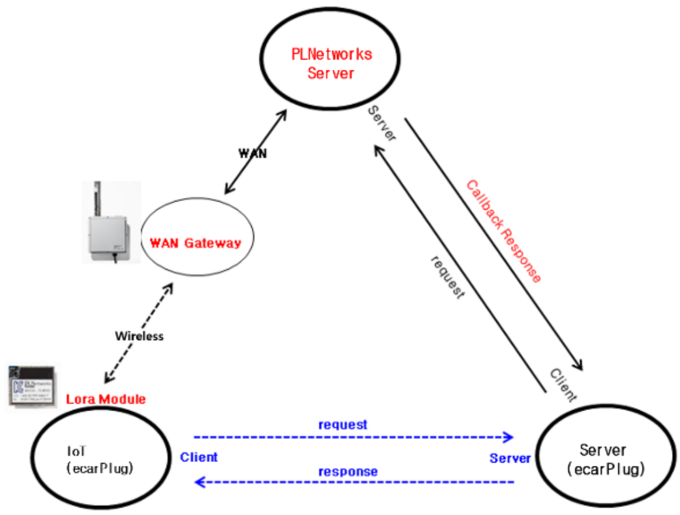

Figure 7- Diagram of communication protocol operation

2.4 Real-time power control technology

The operation principle of the real-time power control technology is as follows: Once another charger attempts new charging while the charger group that shares the same power is already charging, the server controls the current of existing charging chargers to supply 1/n current for each charger (n is the number of chargers) to ensure no interruption of the total power supply and no safety issue, and the server conducts the 1/n current control for the new charging charger and distributes power through the charging start command. Figure 8 shows the block diagram of the real-time power control. It is implemented according to the Electric vehicle conductive charging system standard (KC 61851-1) in Korea for EV charging control method. The operation block diagram of the KC 61851-1 standard is shown in Figure 9 [8][9]. In addition, the real-time power control technology is implemented that if the charging amount requested from a charger connected to a node exceeds the threshold, the charging amount of each charger is reset, and the reset amount is transmitted to each charger.

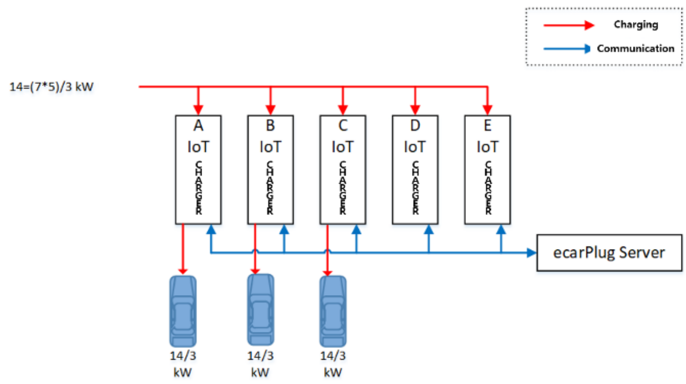

Figure 8- Block diagram of the real-time power control technology

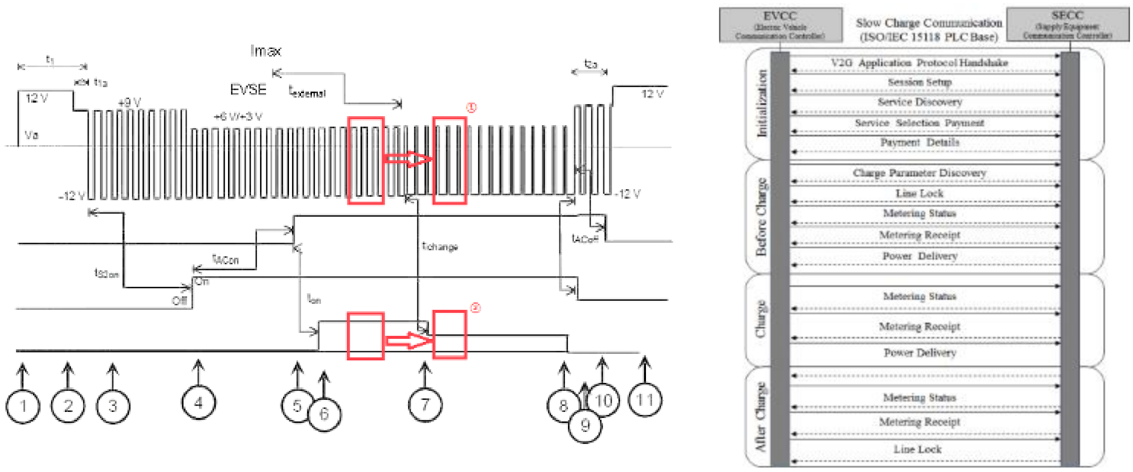

Figure 9- Operation block diagram of the KC 61851-1 standard

If the requested charge on a charger connected to one node exceeds the baseline, the charge on each charger is reset, and real-time power volume control technology is implemented by transmission method to each charger. Figure 10. shows a real-time power redistribution procedure.

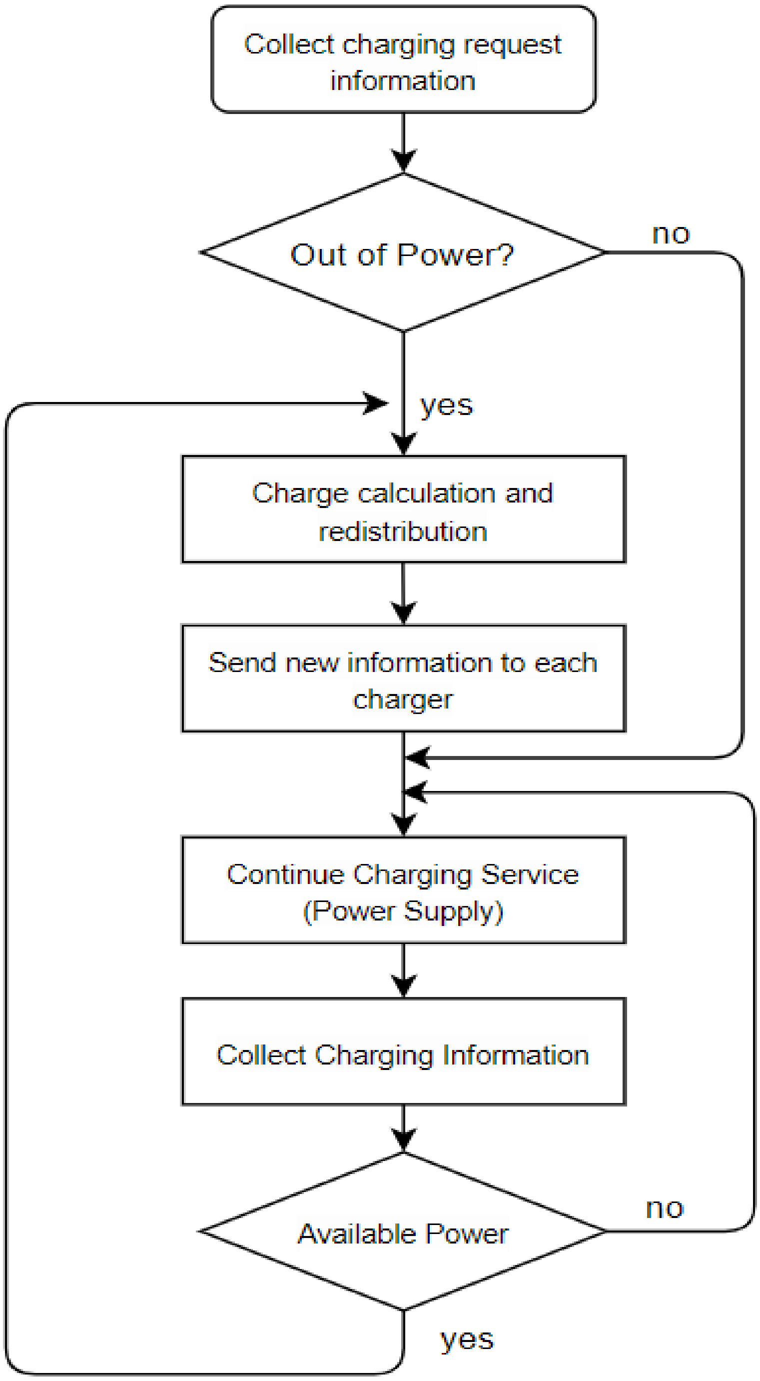

Figure 10- Real-time power redistribution procedure

2.4 Development of server module to manage the IoT-based EV

The following server module functions are implemented: Registration of Cloud-based chargers, storing charger information received from each charger in the database and monitoring. The server user interface (UI) web application is implemented using Java language to meet future compatibility and technical trend. For the server platform, Linux is used for performance, and the database management system (DBMS), MySQL, was employed to consider the economy and stability viewpoints. The database table design and attributes are made using the entity-relationship diagram (ERD), and the relationships between tables are set up to verify the efficiency of the database design [10]. Figure 11. shows a charger monitoring server module.

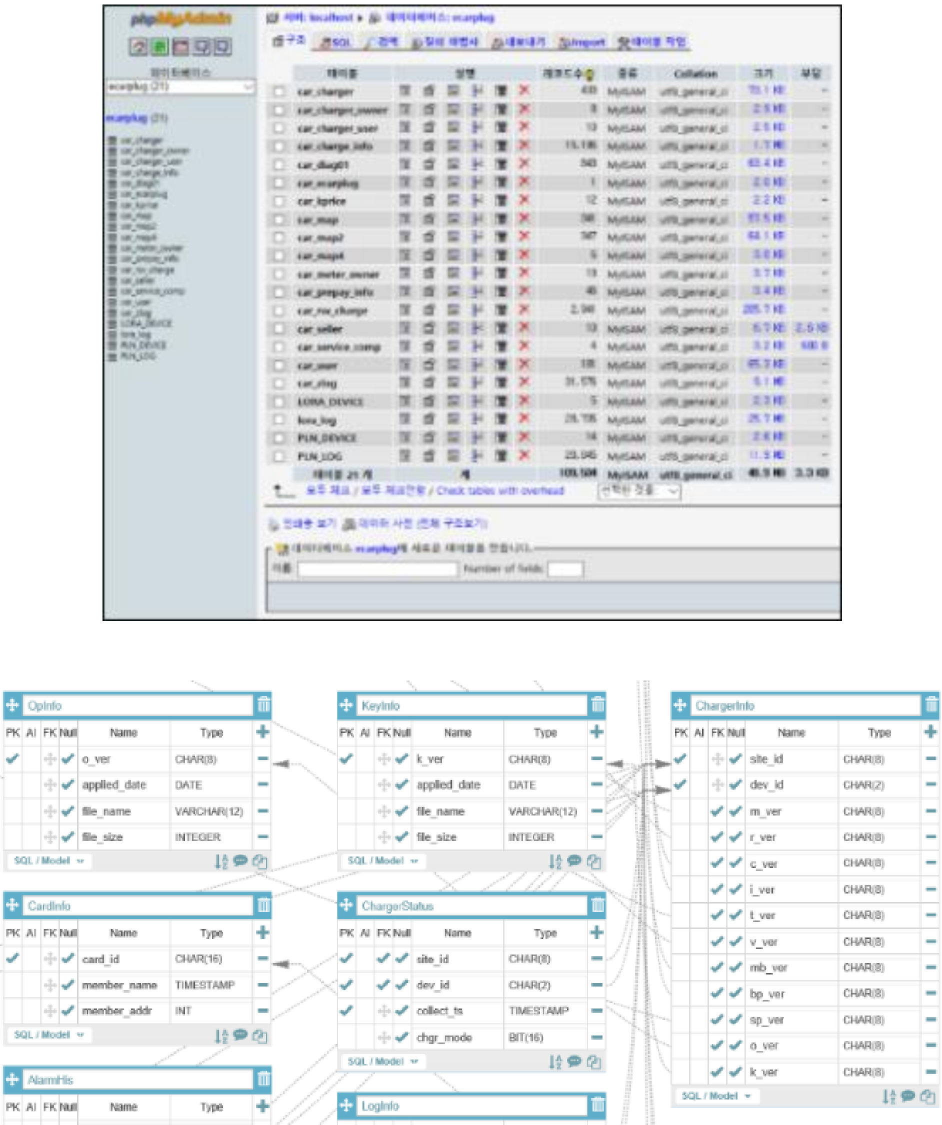

Figure 11- Charger Monitoring Server Module and ER diagram

3. Study Results

3.1 Implementation of the IoT-based EV charger

Figure 12 shows the external and internal models of the IoT-based EV charger.

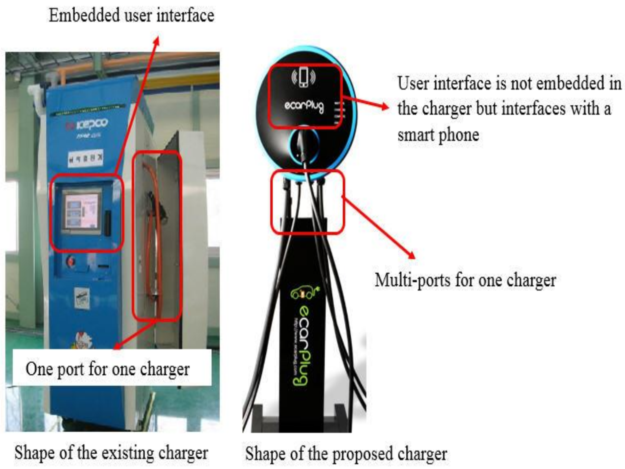

Figure 12- External and internal model of the Cloud based EV charger

3.2 Implementation results of the real-time power control technology

Assuming that three vehicles are charged simultaneously, three loads in a single charger were applied to a single charger simultaneously. The experimental environment is developed to verify whether the power is evenly distributed and charged in three vehicles, as shown in Figure 13. The experimental results verified that the power is distributed and charged evenly. Figures 14, 15, and 16 show the performance verification of real-time power control technology implementation.

Figures 14, 15, and 16 show the output waveforms of the IoT-based EV charger, indicating that the power is distributed in real-time when one, two, and three loads are applied to the IoT-based EV charger. In addition, these figures verify that multiple chargers connected to the same power network can be efficiently managed, and the basic rate for EV charging can be reduced by more than 55%.

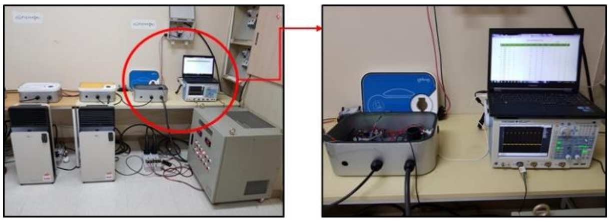

Figure 13- Experimental environment for performance verification of the real-time power control technology

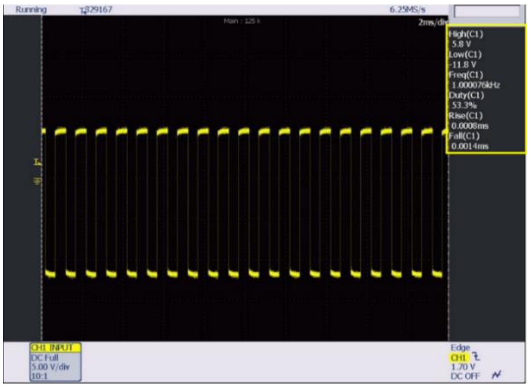

Figure 14- Charger waveform when one load is applied (32[A], 53.3%)

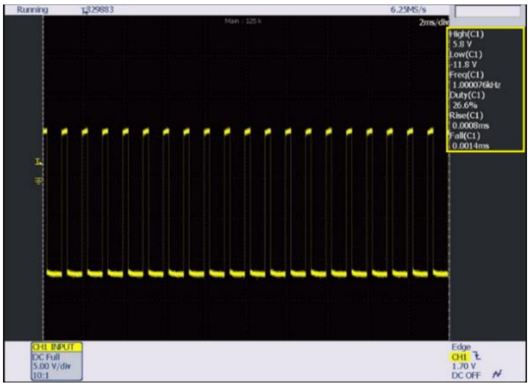

Figure 15- Charger waveform when two loads are applied (16[A], 26.6%)

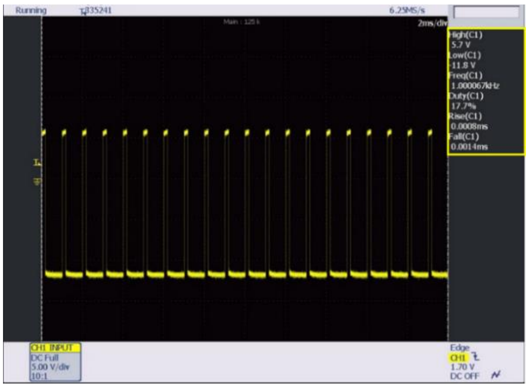

Figure 16- Charger waveform when three loads are applied (11[A], 17.7%)

4. Conclusions

Currently, nations support and install the cost of unmanned EV charger systems, which is highly costly. In this study, the cloud system-based multi-port EV charger system that can provide a new function of charging service was proposed, in which the IoT-based EV charger was developed to contribute to the development of rapid and stable operating environments for the EV market by promoting EV market and relieving the financial burden of the nation. This study also developed the server module, which collected information in real-time from the IoT-based EV charger and stored the information in the database. Furthermore, this study presented a measure to save the basic electricity rate by more than 55% in the building where the charger was installed by efficiently managing multiple chargers connected to the same power network and verified the performance through the development of the system and performance verification experiments. Furthermore, this study proposed the cloud system-based EV charger system environment and implemented the environment, thereby providing the environment that can give economic benefits and additional services to users and charging service business providers. If continuous studies are conducted based on the results of this study, it will contribute to the more affordable and rapid development of the EV charger system infrastructure in Korea than using existing methods to be better prepared for the future EV era.

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