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The smart EV charging system based on the big data analysis of the power consumption patterns

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Abstract

The high costs of electric vehicle supply equipment (EVSE) and installation are currently a stumbling block to the proliferation of electric vehicles (EVs). The cost-effective solutions are needed to support the expansion of charging infrastructure. In this paper, we develope EV charging system based on the big data analysis of the power consumption patterns. The developed EV charging system is consisted of the smart EV outlet, gateways, powergates, the big data management system, and mobile applications. The smart EV outlet is designed to low costs of equipment and installation by replacing the existing 220V outlet. We can connect the smart EV outlet to household appliances. Z-wave technology is used in the smart EV outlet to provide the EV power usage to users using Apps. The smart EV outlet provides 220V EV charging and therefore, we can restore vehicle driving range during overnight and work hours.

Keywords: *Electric Vehicle (EV), Charging, IoT, Big data, Non-intrusive Load Monitoring (NILM).*

1. Introduction

The electric vehicle supply equipment (EVSE) charges the EV battery from the power network. The EV charging methods can be divided into the AC charging method for slow charging and the DC charging method for fast charging according to the electrical power source to EVs. The AC charging method is used in on-board charger (OBC). The DC charging method is often used in off-board charging stations.

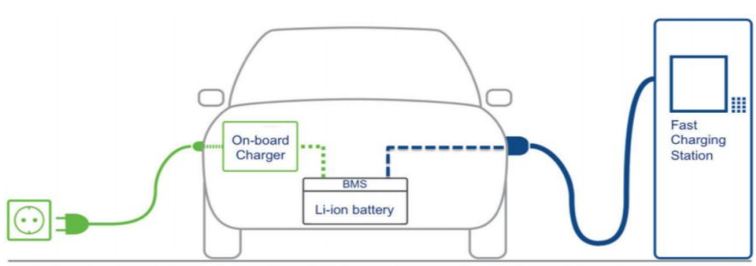

Figure 1. The EV charging methods [1]

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ISO (International Organization for Standardization), IEC (The International Electrotechnical Commission), and SAE (Society of Automotive Engineers) provide standards specific to electric vehicles with a focus on the plugs and sockets, the inlets and connectors, the chargers voltages, the communication between EV and EVSE [2]-[8]. The charging level describes the power level of a charging outlet: AC level 1 charging uses existing 120V AC outlets and can be a good fit for many home and workplace. AC level 1 provide maximum power of about 2kW using 120V and 16A and therefore the charging time is from 6 hours to 24 hours. Level 1 charging has sufficient power to restore vehicle driving range during overnight and work hours. AC level 2 charging uses a single or three phase 240V AC outlet and provides fast AC charging with a peak current of 80A and the maximum power up to 20kW. DC Level 3 charging is fast DC charging with 200~600V DC, up to 400A, and the maximum power of 240kW.

The charging mode describes the safety communication protocol between EV and charging station. The IEC 61851-1 standard [6] defines four different charging modes as follows : In Mode 1, EV is connected to a direct AC supply network using a non dedicated household socket. Mode 1 charging provides the charging current up to 16A, up to single-phase 250V or three-phase 480V. Mode 1 charging has the problem of overheating risk and therefore is not permitted in some countries. In Mode 2, EV is also is connected to an AC supply network with a special in-cable EVSE usually supplied with an EV from the manufacturer. Mode 2 charging provides the charging current up to 32A, up to single-phase 250V or three-phase 480V. Mode 2 provides the communication device and monitoring of charging. Mode 2 charging provides a moderate level of safety using over-current protection, over-temperature protection, protective earth detection (from wall socket). Mode 3 charging provides AC supply with the dedicated EV socket-outlet or connector. The control pilot signal is provided by the EVSE. Mode 3 charging provides the maximum current of 250A, up to one-phase 250V or up to three-phase 480V. Mode 4 charging is DC fast charging with up to 600V DC and the maximum current of 400A. This mode uses a high-power off board charger.

The IEC 62196-2 standard [7] defines different types of sockets on charging station and plugs on cable towards charging station, inlets on EV and connectors on cable towards EV. The type 1defines the plug and socket type that is also known as SAE J1772 [8] and is the standard inlet and connector in the USA and Japan. The type 1 plug have five pins with AC Line 1, AC Line 2, ground pin, proximity detection, control pilot. The type 1 couplers are rated for 250V at 32A (80A in the USA). The type 2 allows for Mode 1, 2 and 3 charging and used in Europe. The Type 2 connector supports both single-phase and three-phase charging at higher power rates for a charging output of up to 43.5kW and a charging current of up to 63A. The type 2 plug has 7 pins with AC line 1, AC line 2, AC line 3, neutral, proximity detection, control pilot, and ground. The type 3 allows for Mode 3 charging and used in Europe. Several connector types for DC charging currently exist: the first DC charging standard was the Japanese CHAdeMO(Mode 4 off-board charging) [9]. CCS(Combined Charging System) combines AC and DC charging in a single connector and inlet. There are two types of the CCS: Combo 1 is based on SAEJ1772 socket interface (equivalent to IEC Type 1 socket) and Combo 2 based on IEC Type 2 socket interface. CCS is used in EVs from USA and European countries. Inductive charging will be another EV charging method.

Non-intrusive load monitoring (NILM) is a technique to recognize, disaggregate, and determine the power consumption of a specific device from the whole-house consumption profile. NILM bases on analysis of aggregate electrical load data together using knowledge of electrical signatures of appliances as shown in Figure 2. The total power consumption (kWh), voltage, current of appliances are used to determine individual power consumption without actual measurement of individual loads. NILM was first proposed by George W. Hart in the 1980s [10][11]. NILM can use of machine learning and pattern recognition such as decision tree learner (DTL), artificial neural networks (ANN), support vector machine (SVM), k-nearest neighbor (KNN), support vector machines[12]-[14]. NILM can disaggregate Electric Vehicle Battery (EVB) charging signal [15] as a load type from aggregated real power signals. NILM plays key roles in HEMS (Home Energy Management System), BEMS (Building Energy Management System), and FEMS (Factory Energy Management System).

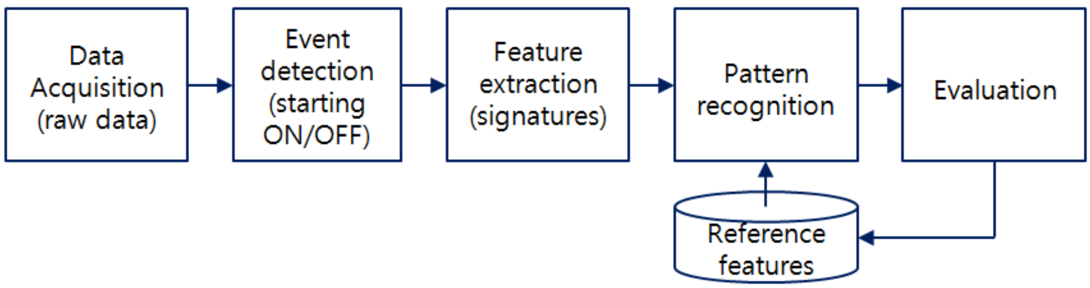


Figure 2. Non-intrusive load monitoring procedures

In this paper, we propose low costs of the smart EV charging equipment and installation. The proposed charging system has been developed to replace the existing sockets using bid data and IoT technologies. In section 2, we describe the proposed EV charging infrastructure. Finally, we draw our conclusion and future works in Section 3.

2. Smart EV charging system

The high costs of EV charging equipment and installation are currently a stumbling block to the proliferation of electric vehicles. Therefore, cost-effective solutions are need to support the expansion of EV charging infrastructure and EV supply. We need solutions to reduce time taken for EV charger installation. When charging at home, many EV owners are content to charge overnight plugging into their regular home 240V outlet using level 1 or 2 equipment. In this paper, we develop the EV charging infrastructure using the smart EV charging outlet that can be installed simply by replacing the existing socket-outlet. The proposed EV charging equipment may be installed at home and workplace. The proposed smart EV charging system is consisted of the big data management system, the smart EV outlets, gateways, and mobile applications as shown in Figure 3 .

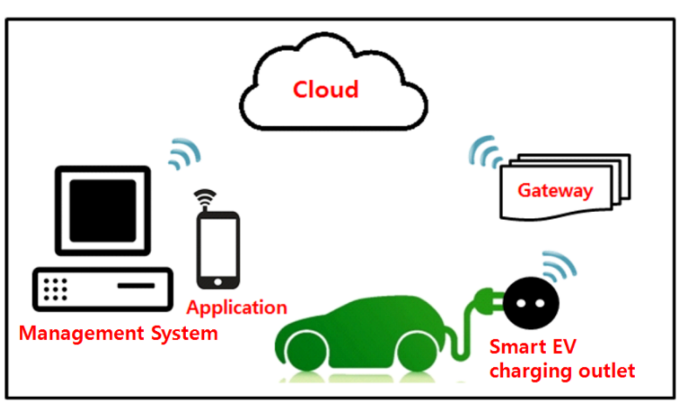


Figure 3. The proposed EV charging system

2.1 Smart EV charging outlet

The developed smart EV charging outlet is a new product that can distinguish the power consumption of a device connected to an outlet in real time by power consumption pattern analysis. The developed smart EV charging outlet is designed to minimize the investment cost by replacing the existing outlet and providing electric vehicle charging service as shown Figure 4. The smart EV charging outlet was made using a 3D printer. The smart EV charging outlet was developed as a 16A 220V EV charging specification and can be installed in less than 15 minutes when replacing the existing outlet. The developed smart EV outlet provides EV charging as well as the functionality of an existing outlet for appliances. The smart EV charging outlets can be installed not only in a house but also in the parking lots of an assembly building such as an apartment or a villa. The smart EV outlet provides the separate EV charging bill from that of the meter. The major functions of the developed EV charging outlet are shown in Figure 5.

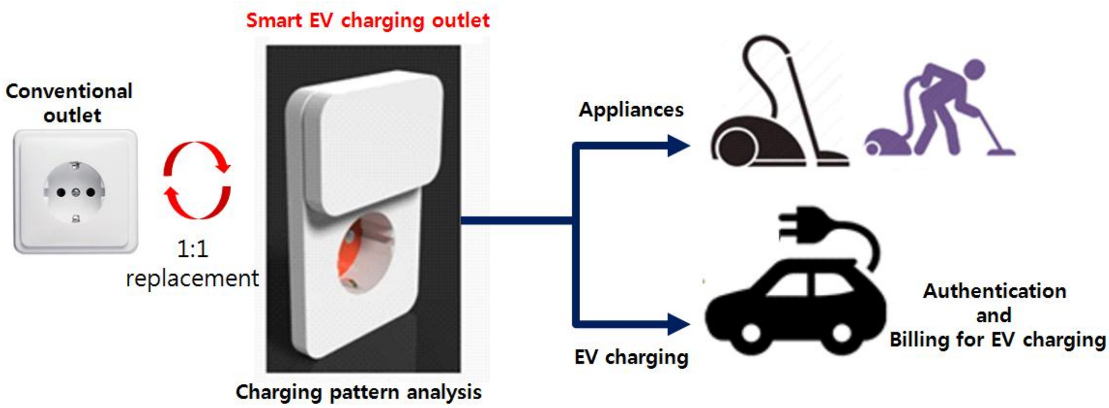


Figure 4. The proposed EV charging outlet

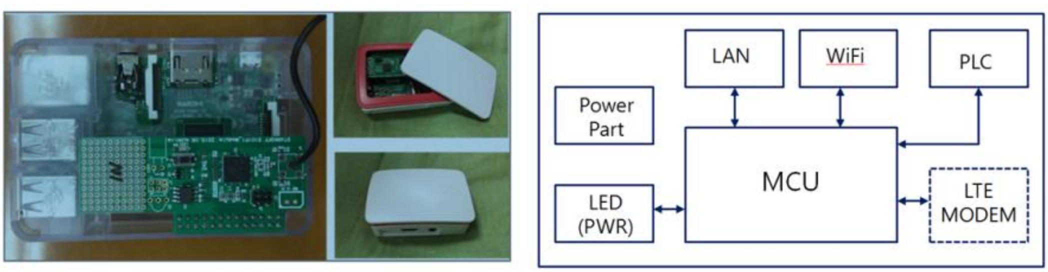
Smart EV outlet functions and Specifications
o Built-in charging power pattern analysis module o Built-in load analysis and over-current stabilizer o Billing Control Board and Firmware o Manual remote switching ON/OFF function
o Maximum load : 220V, 16A, 3200W o Z-wave (920.9, 921.7, 923.1MHz) range up to 100 feet at LOS o operating temperature : -10~40°C o Dimensions : 92x156x62 (mm)

Figure 5. The functions and specifications of the smart EV charging outlet

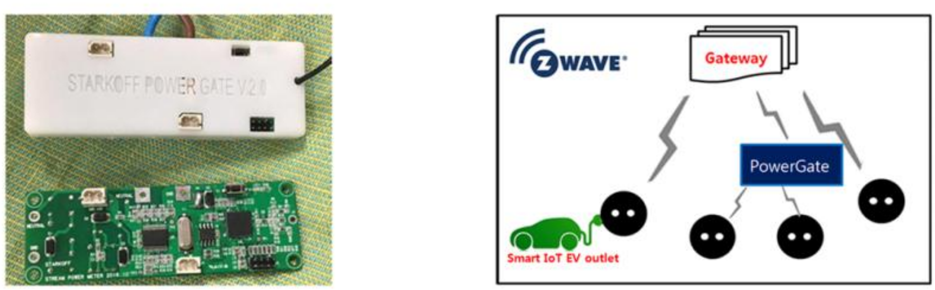
The smart EV charging outlet has the EV charging control board and distinguishes EV from appliances by analyzing the power consumption patterns of the products connected to the outlet. The smart EV charging outlet provides the EV charging service through authentication when EV is connected to the outlet. If EV connected to the outlet fails to authenticate the electricity supply is cut off. The smart EV charging outlet has an RFID card reader for user authentication. The built-in over-current stabilizer is designed to analyze the current so that the current can be cut off when the wire is overload or over-current. The built-in over-current stabilizer is designed by the wiring method of KS C IEC 60364-5-52 (2004) and applied to non-external cables and insulated conductors with nominal voltage of AC 1kw and DC 1.5kv. The smart EV charging outlet uses a 900 MHz Z-wave communication technology with a maximum power of 20mW to communicate with the gateway.

2.2 Gateway and PowerGate

The gateway connects the smart EV charging outlet and the management server using wireless communications. The gateway can manage outlets installed in apartments and houses using the PLC modem, Z-Wave, and WiFi. The smart EV charging outlet network consists of a Z-wave mesh topology. We use BananaPi and RaspberryPi for gateway. We use PowerGate when communication between the smart EV outlet and gateway does not work well.



(a) Gateway



(b) PowerGate

Figure 6. The gateway and Powergate block diagram

2.3 Data analysis of the power consumption patterns

We developed an energy big data analysis system that identifies load through the real-time power consumption pattern analysis. We have built the EV and appliance classification system testbed to verify the proposed power consumption pattern analysis algorithm as shown in Figure 7. EVs have distinct patterns of power consumption and power factor from other electronic products. Figure 8 shows the measured power consumption patterns of household appliances such as TV, refrigerator, fluorescent lamp, microwave, and coffee pot. Figure 9 shows the power consumption pattern of the Kia Ray EV. The developed energy big data system can be used to distinguish EV connected to the outlet from other devices. We use the power fingerprinting algorithm for the equipment plugged into outlet. The power consumption pattern analysis algorithm is performed in the following steps.

(1) Data acquisition

Data acquisition is performed at 20 samples (data) per second.

(2) Event detection

In order to prevent too many patterns from occurring, an event is processed when the maximum value difference is more than 70 or less than -60 in three consecutive data.

(3) Input pattern generation

We use a sliding window of 8 or 20 samples length to generate the pattern after event detection. The input pattern is created as "base/local minimum/local maximum" pattern. The "base/local maximum /local minimum" pattern is generated in the sliding window of 8 samples. In the sliding window of 20 samples, we create the pattern of the average value except the upper and lower 5 samples.

(4) Pattern recognition

In this stage, the input patterns are compared with existing reference patterns. In the 8 samples window, we define PEAK as the transition from the local maximum to base and MIN as the transition from the local minimum to base. We consider the same pattern if the difference between PEAK and MIN and the existing reference pattern are less than 0.2 and 0.1, respectively. In the 20 samples window, we compare the average value of the input pattern with that of the reference pattern and consider the same pattern if the difference is less than 0.1.

(5) Merging the same pattern

The input pattern merges with the existing reference patterns in real time if the input pattern is determined as the same as the existing reference pattern. The number of reference patterns is reduced by using a k-means clustering algorithm.

(6) Save to Database

The generated patterns are stored in the DB that is consisted of ID, Delta, PEAK, MIN, Avg, the number of occurrences of the event, the occurrence period, and the gap of the occurrence period.

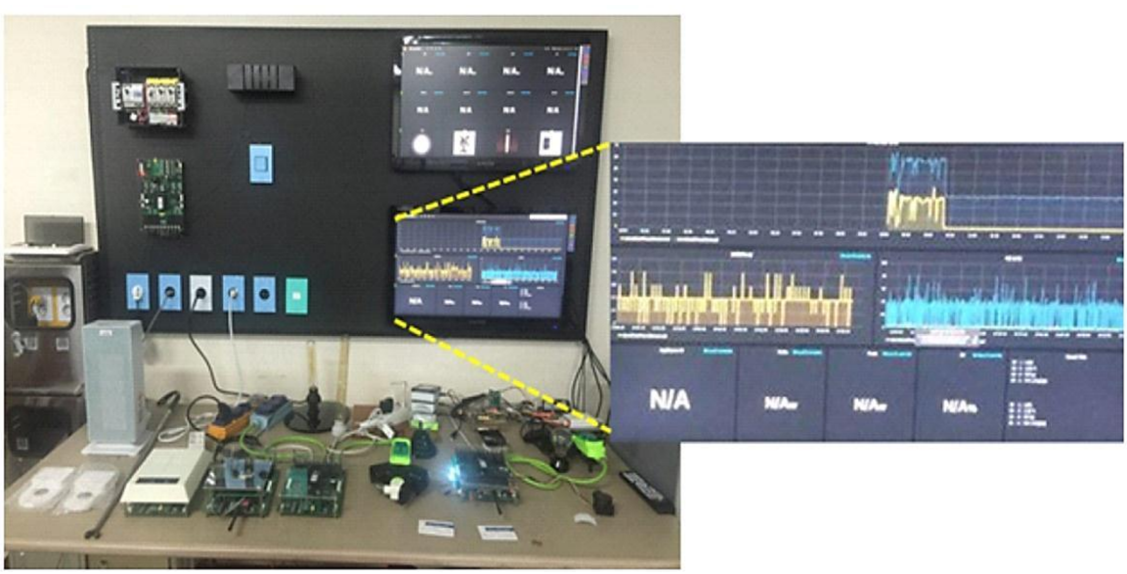


Figure 7. Experiment set-up in laboratory for EV and appliance classification using big data and IoT technologies

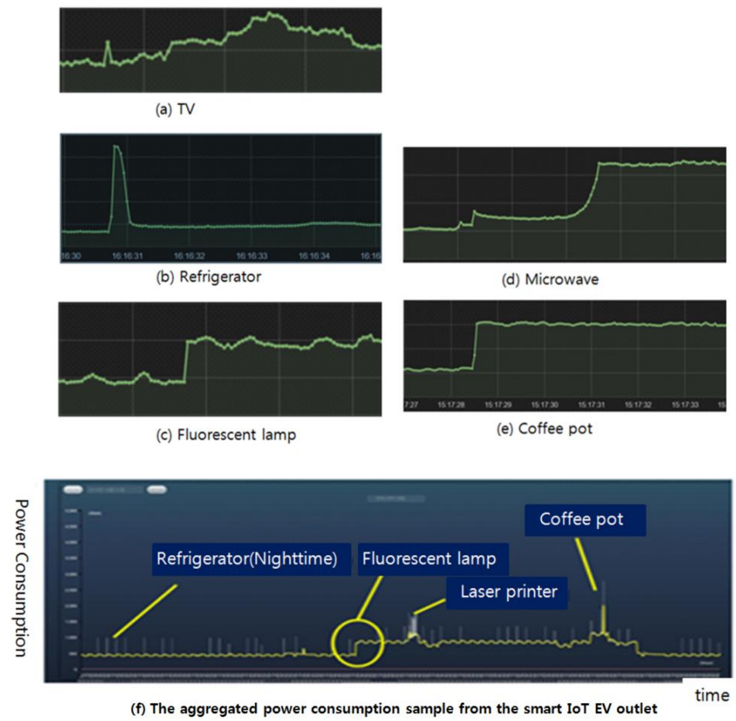


Figure 8. Typical power consumption patterns of household appliances

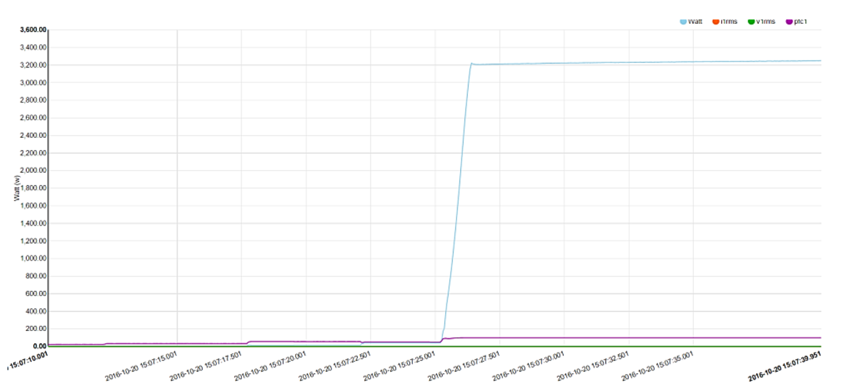


Figure 9. The power consumption of Kia Ray EV

Figure 10 shows the functional block diagram of the smart EV charging system. The functional blocks of the EV charging management system is consisted of rule engine, security, data analysis, management, push server, app and web servers. The Rule Engine uses Akka and distinguish the incoming data from the gateway. The 1st power consumption pattern analysis is performed at the smart EV charging outlet and the 2nd analysis is performed at the data analysis module of the management server. Figure 11 shows the EV charging pattern analysis procedures in the smart EV charging outlet. The data analysis module distinguishes the use of EV charging and household appliances using power consumption data gathering from the smart EV charging outlet. The management module performs functions such as authentication by a user's RFID card, control and management of an outlet for charging electric vehicles, and separate charging of EV charging.

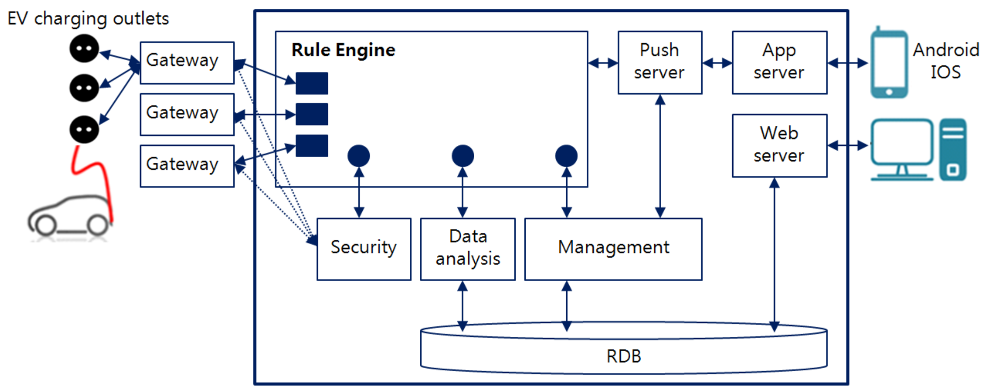


Figure 10. The functional block diagram of the smart EV charging system

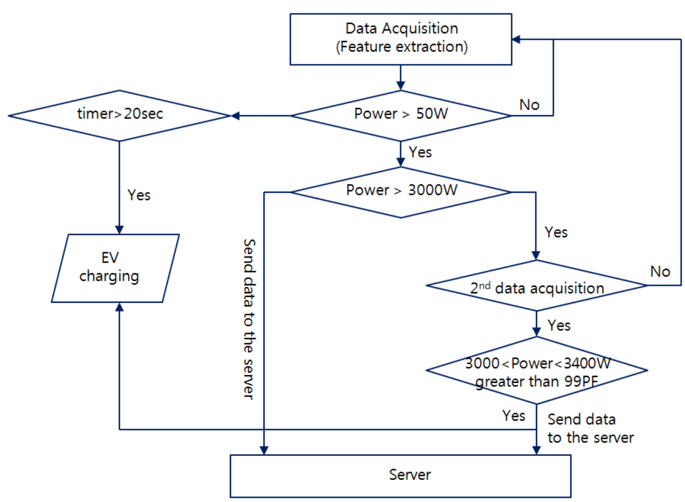


Figure 11. The EV charging pattern analysis procedures in the smart EV charging outlet

The EV charging management server can push the authentication result and the charging result to the mobile app. The main screen consists of four main menus as shown Figure 12: charging status, EV chargers on the map, charging history, and settings. EV charger users can check their charge status through the mobile app.

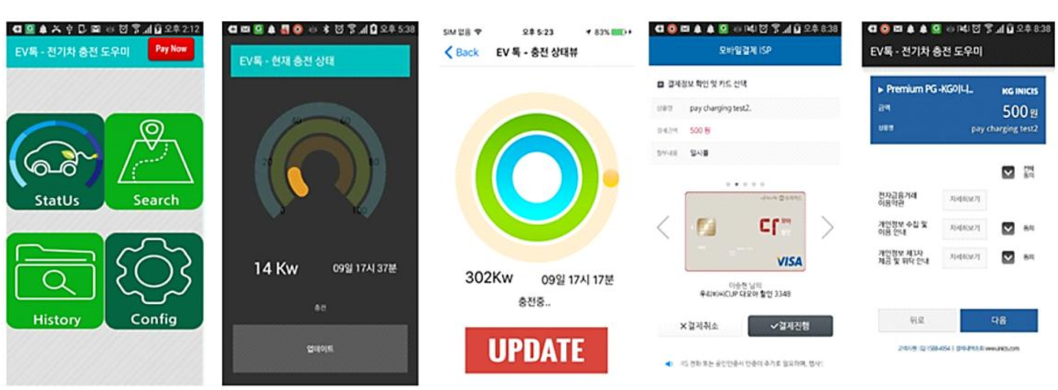


Figure 12. Smart EV charging outlet App.

3. Conclusion and Future Works

In this paper we develop low costs of EV charging equipment and installation. The developed charging infrastructure is consisted of the smart EV outlets, gateways, the big data management system, and mobile applications. The developed smart EV outlet provides 220V, 16A, and the maximum power up to 3.2kW for EV charging. The smart EV charging outlet can be installed in less than 15 minutes by replacing the existing outlet and therefore, the developed smart EV outlet provides EV charging as well as the functionality of an existing outlet for appliances. The developed smart EV outlet has the built-in over-current stabilizer to provides a moderate level of safety. The smart EV charging outlet uses a 900 MHz Z-wave technology with a maximum power of 20mW to communicate with the gateway. The power consumption analysis to distinguish EV from household appliances is first performed at the smart EV charging outlet and secondly at the data analysis module of the management server. We can restore vehicle driving range during overnight and work hours using the smart EV outlet. In future studies, we develop the commercial products of advanced metering infrastructure (AMI) with NILM technolgy. The AMI to be developed is expected to play key roles in HEMS, BEMS, and FEMS.

Note

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References

[1] Revolutionizing Fast Charging for Electric Vehicles, *www.intel.com*, 2012.

[2] M. Falvo, D. Sbordone, I. S. Bayram, M. Devetsikiotis “EV Charging Stations and Modes: International Standards,” 2014 International Symposium on Power Electronics, Electrical Drives, Automation and Motion, pp.1134-1139 2014.

[3] V. Schwarzer, R. Ghorbani, Current State of-the-Art of EV Chargers, Technical Report, Hawaii Natural Energy Institute, Report Number: HNEI-01-05, 2015.

[4] J. Y. Yong, V. K. Ramchandaramurthy, K. M. Tan, N. Mithulananthan “A review of the state-of-the-art technologies of electric vehicle, its impacts and prospects,” Renewable and Sustainable Energy Reviews, vol. 49, pp.365-385, 2015.

[5] D. Kettles, Electric Vehicle Charging Technology Analysis And Standards, FSEC Report Number: FSEC-CR-1996-15, Feb. 2015.

[6] IEC, Electric vehicle conductive charging system - Part 1: General requirements, IEC 61851-1:2017, Feb. 2017.

[7] IEC 62196-2, Plugs, socket-outlets, vehicle connectors and vehicle inlets–Conductive charging of electric vehicles – Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories, 2016.

[8] SAE International, SAE J1772 Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler, 2012.

[9] CHAdeMO Association, *www.chademo.com*.

[10] G. Hart, Prototype Nonintrusive Appliance Load Monitor, MIT Energy Laboratory and Electric Power Research Institute Technical Report, Tech. Rep., Sept. 1985.

[11] G. W. Hart "Nonintrusive appliance load monitoring," Proceedings of the IEEE, vol. 80, no.12, pp.1870–1891, 1992.

[12] A. Zoha, A. Gluhak, M. A. Imran, and S. Rajasegarar, "Non-intrusive load monitoring approaches for disaggregated energy sensing: A survey," Sensors, vol. 12, no. 12, pp. 16838-16866, Dec. 2012.

[13] Z. Zhang, J.H. Son, Y. Li, M. Trayer, Z. Pi, D.Y. Hwang, J.K. Moon "Training-free non intrusive load monitoring of electric vehicle charging with low sampling rate," IECON, pp.5419 - 5425, 2014.

[14] C. Laughman, K. Lee, R. Cox, S. Shaw, S. Leeb, L. Norford, and P. Armstrong, "Power signature analysis," IEEE Power and Energy Magazine, vol. 1, no. 2, pp. 56–63, 2003.

[15] Z. Zhang, J.H. Son, Y. Li, M. Trayer, Z. Pi, D.Y. Hwang, J. K. Moon "Training-Free Non-Intrusive Load Monitoring of Electric Vehicle Charging with Low Sampling Rate," IECON 2014, pp. 5419 - 5425, 2014.