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A Study on EV Charging Scheme Using Load Control

Hyo-Sang Go*, In-Ho Cho*, Gil-Dong Kim* and Chul-Hwan Kim†

Abstract – It is necessary to charge electric vehicles in order to drive them. Thus, it is essential to have electric vehicle charging facilities in place. In the case of a household battery charger, the power similar to that consumed by a household with a basic contract power of 3kW is consumed. In addition, many consumers who own an electric vehicle will charge their vehicles at the same time. The simultaneous charging of electric vehicles will cause the load to increase, which then will lead to the imbalance of supply and demand in the distribution system. Thus, a smart charging scheme for electric vehicles is an essential element. In this paper, simulated conditions were set up using real data relating to Korea in order to design a smart charging technique suitable for the actual situation. The simulated conditions were used to present a smart charging technique for electric vehicles that disperses electric vehicles being charged simultaneously. The EVs and Smart Charging Technique are modeled using the Electro Magnetic Transients Program (EMTP).

Keywords: Smart charging technique, Electro Magnetic Transients Program (EMTP), Power quality, Load control, Electric vehicle, Power demand and supply

1. Introduction

Recently, the global automobile industry, under the regulations in regards to exhaust gas, mileage, and carbon dioxide, is accelerating the development of various different types of automobiles [1]. Among those newly developed automobiles is the electric vehicle (EV), an environmentally-friendly car with an improved internal combustion engine and a much reduced carbon dioxide and exhaust gas. The Republic of Korea plans to increase the current percentage of the EV among small and middle-sized vehicles to 10% by the year 2020, Korea is on the move for the EV's research, development and commercialization [2].

To ignite an EV, its battery must be charged. To charge the battery, its linkage with the actual power system is an essential element. Currently, since the EV is distributed among very few people, its influence to the current power system is quite insignificant. However, if the number of EVs increase and becomes significantly large in number, as described in Reference [2], the power system will be greatly influenced somewhat directly by the EV's charging.

There are two different types of EV battery chargers. Among the two, the first one is a rapid charger capable of charging the EV battery within 30 minutes. The rapid charger retains more than 50kW of a charging capacity in order to complete the charging within 30 minutes. The other type of charger is a slow charger, which uses its power source from home. Considering the contract demand of a residential house, the charging capacity of the slow charger is mostly 3.3kW [3]. This means that this slow charger takes about the same level of power consumption as a residential house whose contract demand is around 3kW, over a short period of time, when charging the EV. Moreover, it is probable that consumers with EVs are likely to conduct their EV's charging simultaneously. Therefore, this simultaneous charging will lead to a rapid increase in power load, and eventually this will lead to an imbalance between the supply and demand of the power system. This imbalance, in turn, will cause the power quality degradation including voltage fluctuation and frequency variation [3].

At present, various thesis on electric vehicle charging schemes are being published. References [4-6] describe theses on the adjustment of the frequency of the electric power distribution system when charging and discharging electric vehicles. In addition, theses on electric vehicle charging schemes using new recyclable energy appear in References [7-8]. Reference [9] explains the contents of the optimum scheme for charging electric vehicles by minimizing any voltage variation and any power loss. Reference [10] proposes an electric vehicle charging scheme for valley filling. However, Reference [4-10] are the papers proposed based on ideal conditions (the same charging time, the same number of electric vehicles being charged, the same initial SOC, etc.). Any conditions matching the actual situation are not provided by any of reference [4-10]. They just indicate that it is important and necessary to set up a smart charging scheme for electric vehicles. However, above all, it is important to analyze a charging scheme under the actual conditions. Thus, in this paper, we presented a smart charging technique for electric vehicles that disperses electric vehicles being charged

† Corresponding Author: College of Information and Communication Engineering, Sungkyunkwan University, Korea. (hmwkim@ hanmail.net)
* KRRI(Korea Railroad Research Institute), Korea. ({ghs015, inhocho, gdkim}@krri.re.kr)
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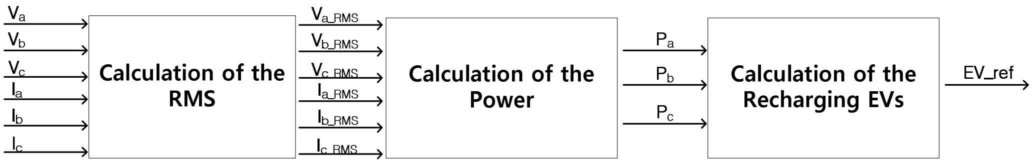


Fig. 1. Block diagram of smart charging technique

simultaneously by means of charging conditions suitable for the actual circumstances of Korea. The experimental conditions applied in this paper prove that a charging technique more suitable for the actual situation has been proposed by utilizing traffic volume and electric vehicle charging prediction techniques. Moreover, we also applied a prediction method using the traffic volume, which is a universal prediction method. Experimental conditions matching the actual situation better were also designed by setting up a total of two simulated conditions. The prediction technique applied in this paper makes it possible to perform organic predictions according to changes in the real data (the real-time traffic volume, the battery efficiency, the charger capacity, the daily driving distance of electric vehicles, etc.). In other words, the prediction technique is a prediction method designed based on only real data. In chapter 2, a simulation condition based on domestic data is briefly discussed, while chapter 3 is allotted to discuss the Smart charging technique of the EV. Discussed in chapter 4 is a method for calculating the number of charging EVs. Additionally, in chapter 6, the result from the simulation on the Smart charging technique of the EV will be discussed, while deriving the conclusion, based on the result of Chapter 5.

2. Simulation Condition based on Domestic Data

The simulation conditions applied in this paper are based on domestic data, including the battery capacity and power consumption of the EV as shown in Reference [3, 11-13], seasonal power load, the total number of EV, and number of EV recharging per hour. The EV's power consumption is at 6.2 kWh, this amount can be charged in less than 2 hours when the charging capacity of the EV battery charger is assumed to be 3.3 kW. The assumption on the actual seasonal distribution system load value of the KEPCO (Korean Electric Power Corp.) is described in more detail in Reference [3]. The simulation scenario using the assumption is also described in more detail.

3. Smart Charging Technique of Electric Vehicle

3.1 Block diagram and algorithm of smart charging technique

The Smart charging technique applied in this paper is capable of determining the actual number of chargeable electric vehicles, by using the maximum available power per hour. This method, as shown in Fig. 1, can be divided into three parts, which are: calculation of the RMS calculation of the power; and the calculation of the recharging EVs. Fig. 1 reveals a block diagram of the smart charging technique [12].

- Calculation of the RMS: Since the instantaneous voltage is a sine wave component with both positive and negative values, the sine wave voltage and current are converted into a root mean square value, in order to facilitate a comparison and calculation.
- Calculation of the Power: The voltage and current from the root mean square calculation are input, in order to calculate the real-time power consumption. Additionally, after determining the maximum daily generation as well as comparing the same with the power consumption, available power can then be calculated.
- Calculation of the Recharging EVs: The available power is input to calculate the number of recharging EVs. Moreover, after comparing the number of recharging EVs with the number of consumers who are demanding for a recharge, a real-time recharging number is determined and linked with the distribution system.

In this paper, in order to suggest suitable charging condition in Korea, and to provide the smart charging technique of electric vehicle for minimizing the impact on the power system, while dispersing the simultaneous charging of EVs, a Smart Charging Technique Algorithm is determined as shown in Fig. 2.

Based on the domestic data, the algorithm uses: the calculation of power consumption rate per hour; calculation of the available power rate; calculation of rechargeable EV numbers per hour; and the comparison between rechargeable EV numbers and the number of EVs demanding for recharge, in order to determine the chargeability and to calculate the number of chargeable EVs. Detailed explanations regarding each step shown in the Smart Charging algorithm are provided in Sections 3.2 through to 3.5.

3.2 Calculation of the Power Consumption Rate per Time

In order to predict the available power per hour, the calculation of power consumption per hour is essential.

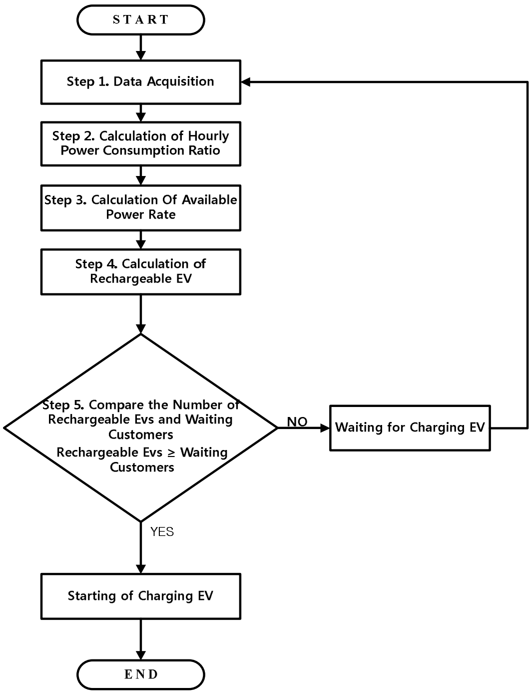


Fig. 2. Algorithm of smart charging technique

Table 1. Rate of load according to summer

Time	Summer (consumption rate)	Time	Summer (consumption rate)	Time	Summer (consumption rate)
1	0.678	9	0.829	17	0.957
2	0.647	10	0.915	18	0.942
3	0.623	11	0.956	19	0.932
4	0.609	12	0.962	20	0.931
5	0.607	13	0.925	21	0.924
6	0.615	14	0.953	22	0.888
7	0.654	15	0.964	23	0.843
8	0.722	16	0.956	24	0.808

Therefore, by using the quarterly average (four-seasonal) per real-time power consumption, provided by the KPX (Korean Power Exchange), and formula (1), the power consumption rate per hour was obtained.

$$\frac{P_{use}}{P_{supply}} \times 100 = R_u \tag{1}$$

Hereon, P_{use} : Available power rate
P_{supply} : Supplied power per hour
$EV_{charging}$: Number of chargeable EVs

The following is Table 1, which shows the power consumption rate in the summer, determined by the process of calculating the power consumption rate.

3.3 Calculation of the available power rate

The process of the available power rate calculation is

Table 2. Rate of available Power according to summer

Time	Summer (available power rate)	Time	Summer (available power rate)	Time	Summer (available power rate)
1	0.27	9	0.119	17	-0.008
2	0.301	10	0.033	18	0.006
3	0.325	11	-0.008	19	0.016
4	0.339	12	-0.014	20	0.017
5	0.341	13	0.023	21	0.024
6	0.333	14	-0.005	22	0.06
7	0.294	15	-0.016	23	0.105
8	0.226	16	-0.008	24	0.14

an important procedure when calculating the number of rechargeable EVs per time. Formula (2) is used to calculate the available power consumption rate. Formula (2) was determined by using both the power consumption rate and the power reserve rate. Hereon, the power reserve rate refers to the rate of power that remained after satisfying the demand during the peak times of power consumption. Republic of Korea is recently undergoing an abrupt and unexpected demand on the increase in power consumption, thereby setting a predetermined amount of power reserve rate, in order to prevent a massive blackout and also to maintain a stable power frequency and voltage.

$$1-\left(R_u + R_{rv}\right) = R_f \tag{2}$$

Hereon, R_u : Power consumption rate per time
R_{rv} : Power reserve rate (4 million kW)
R_f : Available power rate

Therefore, in this paper, in order to maintain a constant power reserve rate, the power consumption rate, along with power reserve rate, is included in Formula (2). Table 2 reveals the available power calculated by using formula (2).

3.4 Calculation of the rechargeable EV number per time

By using the available power rate calculated above, the charging capacity of the charger is 3.3 kW. Therefore, the power consumption of an electric vehicle per hour can be assumed to be 3.3 kW. By using formula (3), the number of chargeable EVs per hour can be calculated. Table 3 shows the number of chargeable EVs per hour, calculated by formula (3).

$$\frac{R_f \times P_{supply}}{3.3\left(kW\right)} = EV_{charging} \tag{3}$$

Hereon, R_f : Available power rate
P_{supply} : Supplied power per hour
$EV_{charging}$: Number of chargeable EVs

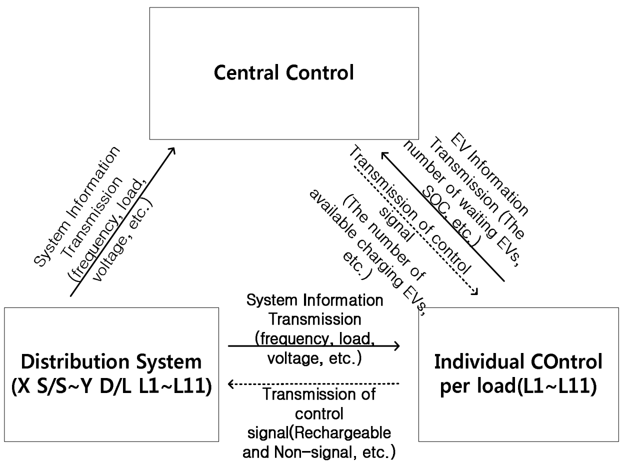


Fig. 3. Central control of smart charging technique

3.5 Controlling the number of charging EVs per load, by a central control

The smart charging technique suggested above is based on a central control system, by using real-time information received from each type of load. Below Fig. 3 shows a block diagram of a central cooperative control system regarding the smart charging technique. As shown in Fig. 3, there is a central control and individual control by load type.

Central Control System: The amount of load, voltage, frequency and the number of EVs demanding for charging by the time are being received as input data. Moreover, through the calculation process of the smart charging technique, the number of chargeable EVs per hour is calculated, its result is signaled to the individual control system.

Individual Control System per Load Type: The number of EVs that are demanding for charging per load type is transmitted to the central control system, the number of chargeable EVs per hour is received from the central control system as input, thereby directly controlling the charge number of EVs.

In this paper, the central system is assumed to be as one. However, since the simulated system comprises of 11 types of load, there are 11 individual control systems. Hereon, the central control can be expected to be controlled by each substation, and the individual control can be configured differently by the preferences set by the substation's working staff.

4. Calculation of Number of Charging EVs Per Hour

The Korean Institute of Construction Technology provides statistics regarding the annual automobile traffic by season, weekdays, and real-time [3, 13]. By using the traffic statistics shown in Reference [14], the total number of EVs was assumed separately by season and weekdays. Additionally, in order to predict the charging number, the methods that are described in Sections 4.1 and 4.2 were used to assume the number of EVs per hour.

4.1 Prediction of the charging number by using domestic traffic

In this paper, based on the charging scenario described in Reference [3], the number of charging EVs was assumed differently. The number of EVs being charged per hour was assumed by season, weekdays, and hourly traffic. Furthermore, a simultaneous charging rate [13] was applied, in order to reflect the number of EVs being charged at the same time, thereby calculating the number of EVs that were demanding charging. The detailed calculation process and the number of EVs being charged are described in Reference [3, 11-13].

4.2 Prediction of the chargeable number by using the EV charging number prediction algorithm[28]

When predicting the number of chargeable EVs, conditions regarding the efficiency between the maximum driving time and charging time should be taken into consideration. However, currently, the method for predicting the number of chargeable EVs is based on a much simpler method, in which traffics and battery power are used, as described in 4.1 [15-19]. Additionally, the Gauss method, the moving average method, exponential smoothing method, and the regression analysis method [20-23] are used for the prediction. These methods are based only data from the past when predicting the future. Therefore, accuracy of the values obtained by the above methods cannot be secured, since not many EVs are actually distributed yet. Thus, in this paper, a new prediction method was used in reference [28].

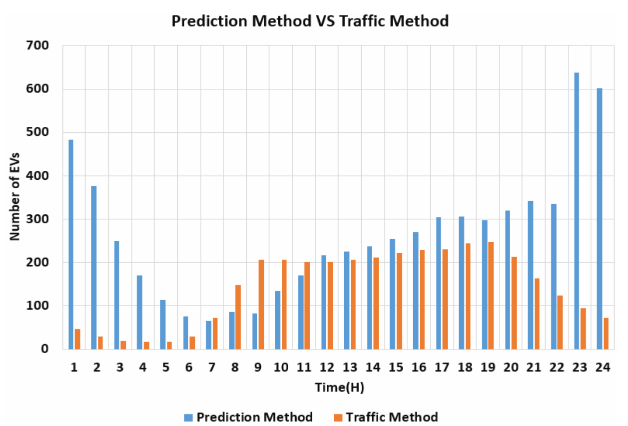


Fig. 4 Hourly charging EVs according to the prediction method

4.3 Comparison of Number of Charging EVs

In this paper, two prediction methods are used to predict the number of EVs being recharged. One of which was a method using traffic, and the other was a method using the charging prediction algorithm. Fig. 4 shows the numbers of EVs being recharged, predicted by each method.

The biggest difference between the two methods lies within the application of the price plans. Since the method using traffic is not affected by the price, more charging is conducted during the daytime rather than at night. However, when price is applied, this situation is then reversed. As can be seen in Fig. 4, since the price at night is cheaper, most EVs are expected to be recharged at night.

5. Simulation

5.1 Calculation of the simulation system and system load

Fig. 5 refers to the simulation system that was used in this paper, modified from an actual distribution system used by KEPCO. The system comprises of two 1.5 km-long columns, with intervals of X-Y and X-Z. Hereon, the interval of X-Z was modeled. 22.9 kV of power is supplied from a substation, and distributed to 11 places [27].

Table 3. Comparison of 2013 and 2020 load [MW]

Time	2013	2020	Time	2013	2020	Time	2013	2020
1	5.1	6.1	9	5.5	6.6	17	7.0	8.4
2	4.5	5.4	10	6.3	7.6	18	8.4	10.1
3	4.2	5.1	11	6.5	7.8	19	8.8	10.6
4	4.1	4.9	12	6.7	8.1	20	7.3	8.8
5	4.1	4.9	13	6.9	8.3	21	7.7	9.3
6	4.1	4.9	14	6.9	8.3	22	7.2	8.7
7	4.4	5.3	15	7.0	8.4	23	6.7	8.1
8	4.9	5.9	16	7.0	8.4	24	6.3	7.6

The reason for the application only to the area of Part 2 is because Part 1 and Part 2 are actually different areas. Only the simulation condition of Part 2 area was applied. Moreover, all of the contents regarding the EV is based on the prediction of 2020. Therefore, in this paper, the power demand predicted for the year 2020, as predicted in the Sixth Basic Plan on the Electricity Demand and Supply, is used, to set the load of the Part 2 area. Table 4 shows the predicted result of the 2020 load, using the summer load of the Part 2 area, in the year of 2013.

5.2 Method for Linkage with Electric Vehicle

The method for the linkage with the electric vehicle is applied in the same manner as Reference [3]. The target of the method was general automobiles in the Part 2 area. By applying 10% of the small and medium-sized automobiles predicted in Reference [2], the total number of EVs linked to the distribution system was predicted.

→ X S/S～Z D/L(Part 2) Electric Vehicle: 896 (Assuming that 10% of the small to medium-sized automobiles are electric)

5.3 Simulation result

Provided in this paper is a Smart Charging Technique of the Electric Vehicle, devised to disperse the EVs conducting simultaneous charging, under the assumed charging circumstances. Moreover, based on the determination of the charging number described from paragraph 3.5.1 to 3.5.4 chapter, two cases in total were assumed. By measuring the load of the Part 2 area, the load control of the suggested Smart Charging Technique was confirmed.

5.3.1 The result of the smart charging technique simulation following the method for determining the charging number applied with domestic traffic

The load data shown in Fig. 6, as a result of the Smart

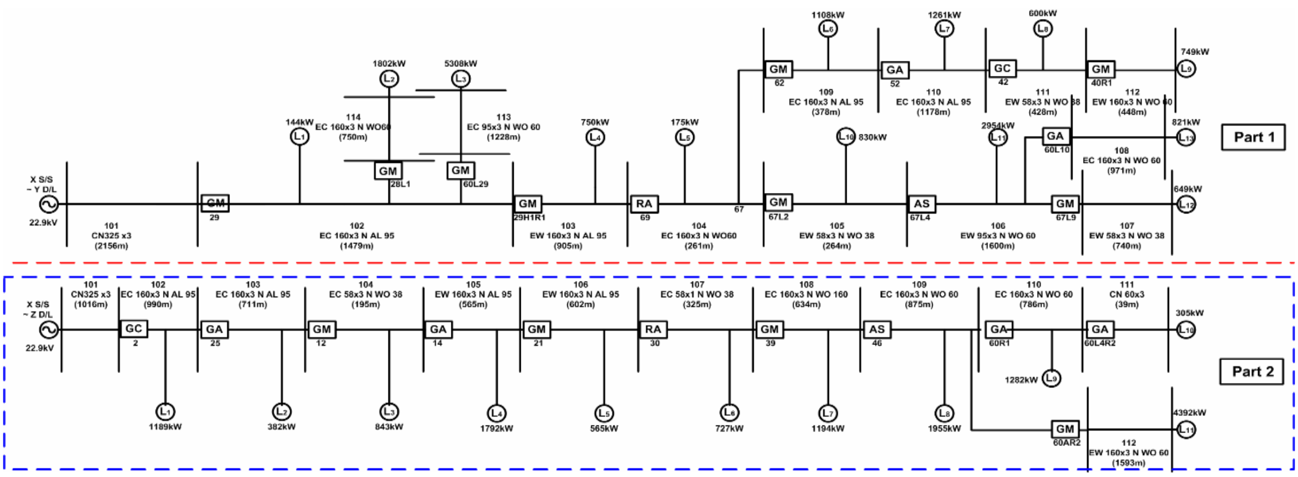
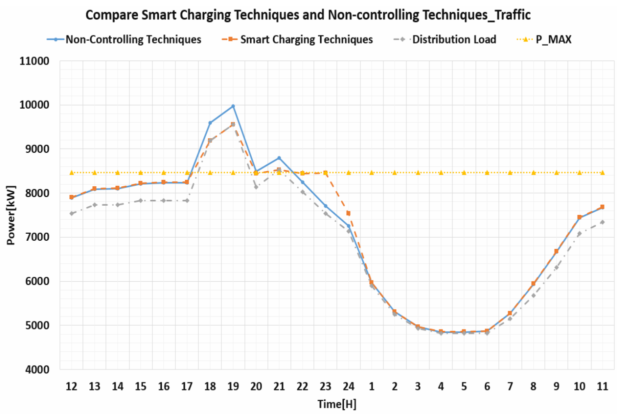
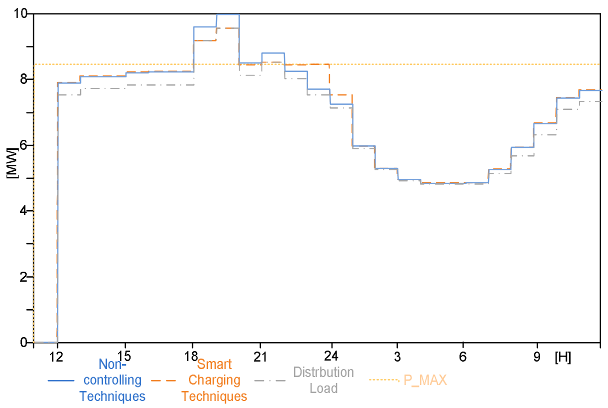


Fig. 5 Distribution system

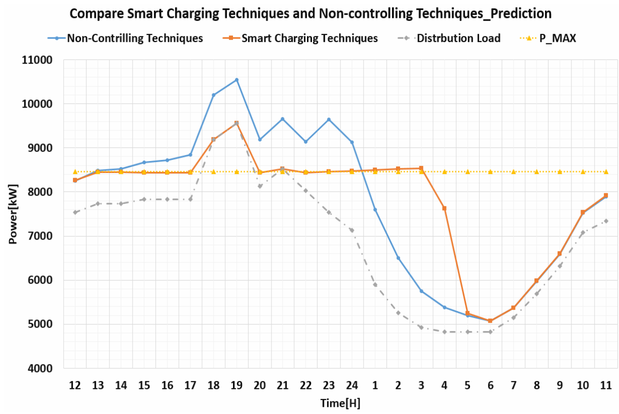


(a) EMTP simulation data using Excel

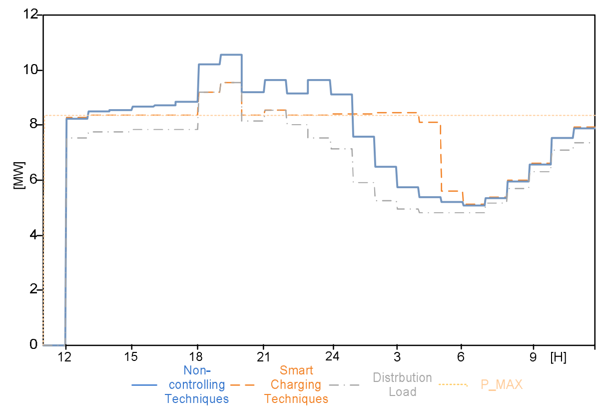


(b) EMTP simulation data

Fig. 6. Smart charging technique applied to the traffic volume system



(a) EMTP simulation data using Excel



(b) EMTP simulation data

Fig. 7. Smart charging technique applied to the charge fee system

Charging Technique simulation following the method for determining the charging number applied with domestic traffic, has resulted from the non-control charging and smart charging simulation in accordance with the method for determining the number of EVs being recharged, applied with domestic traffic. As shown in Fig. 6, when applying the non-control charging, the load increases, in proportion to the number of EVs being charged. The method applied in this paragraph is simply based on the traffic. Therefore, the load increases at a time with more traffic. The time at which most loads had increased was at the hour of 19:00, with its increased amount of 0.5MW, which is 0.06% increment. However, when applying the smart charging technique, the exceeding loads can be controlled under the maximum objective value, while inducing more charging to happen at a time with a low load, as shown in Fig. 6.

Fig. 6 shows both the load that was applied with the smart charging technique for controlling the number of EVs being recharged and the load which is not applied with the technique.

5.3.2 Simulation result of the smart charging technique applied with the charging number determination method in accordance with the algorithm for predicting the number of charging EVs

The load data shown in Fig. 7 are the simulation results of the non-control charging and the smart charging, in accordance with the charging number determination method applied with the method for predicting the actual number of EVs being charged. The prediction method applied in this paragraph is capable of predicting the number of EVs being recharged, by using traffic and price plans for charging EVs. As shown in Fig. 7, when applying the non-control charging, the load increases in proportion to the number of EVs actually being charged. The method applied in this paragraph is not simply based on the increasing number of EVs being charged, but is applied with the traffic condition and prices plan for electricity charging. The hour with the lowest price actually recorded the highest increment of load. The time was at the hour of 23:00, with its increment of 2.35 MW, which is a 0.3% increase. However, when applying the Smart Charging

Technique, the exceeding loads can be controlled under the objective value, while inducing part of the loads to move to the hour with lower load and the lower price, as shown in Fig. 7. Fig. 7, which is similar to Fig. 6, graphs and an ATPDraw were used to show the loads applied with the Smart Charging Technique as well as the loads which is not applied with the technique.

6. Conclusion

Simultaneous charging of electric vehicles can cause an abrupt increase of power load and an imbalance between the supply and demand of power, which eventually leads to damaged quality of power, such as fluctuations of voltage and frequency. Therefore, as suggested in this paper is a “Smart Charging Technique” capable of dispersing the number of EVs being recharged, in accordance with the charging condition (seasonal load, seasonal and weekday traffic, EV distribution plan, etc.). As revealed in the simulation results, an increased number of EVs will result in an increased power load. However, a method based on price further increases the load rather than a method based on the traffic amount. This is because the traffic-based method induces the driver to charge the vehicle immediately after the ignition, whereas the price plan-based method induces the consumers to be concentrated on the hours with the lowest charging prices. Likewise, the imbalance between the supply and demand of power is inevitable, when non-control methods are introduced. When applying the Smart Charging Technique, however, 1.2 MW of electric power can be saved during the peak time, while inducing the load to Off-peak hours. In the case of a price plan, approximately 7.5 MW of power was confirmed to have been decreased at peak times. Therefore, by applying the Smart Charging Technique to the oncoming era of electric vehicles, the dispersion of electric vehicles, from peak time to off-peak time, will be available, in an efficient and very effective manner.

Acknowledgements

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Hyo-Sang Go was born in Korea, 1985. He received his B.S in School of Department of Physics from Chungbuk National University, Korea, 2010. At present, he is working on his Master and Ph. D thesis at Sungkyunkwan University. His research interests include power system transients, protection and power quality with electric vehicles.

In-Ho Cho received the B.S. degree from Han-Yang University, Seoul, in 2007 and the M.S. degree and Ph.D. degrees in the Electrical Engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, in 2009 and 2013, respectively. From 2013 to 2014, he was a senior research engineer in LG Electronics, Seoul. He is currently a senior research engineer in Korea Railroad Research Institute (KRRI). His main research interests are DC/DC converter, power-factor-correction (PFC) AC/DC converters, and railroad power system.

Gil-Dong Kim He received his B.S degree in Electronics engineering in 1986, M.S degree in 1991 and Ph.D from Myongji University in 2003. At present, he is working for Korea Railroad Research Institute and also Propulsion System Team as a Head/ Chief research engineer. His research interests include propulsion control system, power conversion systems, power electronics, and rolling stocks.

Chul-Hwan Kim was born in Korea, 1961. In 1990 he joined Cheju National University, Cheju, Korea, as a full-time Lecturer. He has been a visiting academic at the University of BATH, UK, in 1996, 1998, and 1999. Since March 1992, he has been a professor in the School of Electrical and Computer Engineering, Sungkyunkwan University, Korea. His research interests include power system protection, artificial intelligence application for protection and control, the modelling/protection of underground cable and EMTP software. He received his B.S and M.S degrees in Electrical Engineering from Sungkyunkwan University, Korea, 1982 and 1984, respectively. He received a Ph.D in Electrical Engineering from Sungkyunkwan University in 1990. Currently, he is a director of Center for Power IT (CPIT) in Sungkyunkwan University.