MEASURUNG THE ECONOMIC IMPACT OF ELECTRIC VEHICLES ON POWER SYSTEM AND OPTIMAL STRATEGY FOR CHARGING ELECTRIC VEHICLES

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Abstract

The number of eco-friendly vehicles, such as plug-in hybrid vehicles (PHEVs) and electric vehicles (EVs), is increasing as they are emerging as a solution to environmental problems. These electric vehicles need to be recharged at home or at charging stations. Electric vehicles require large amounts of electricity and this causes an increase in electricity usage and affects the power system. Therefore, the charging strategies for electric vehicles have a significant impact on the peak load of electricity usage on the power system as well as electricity bill for each household. This paper use big data of residential activity and find optimal charging strategies for each user. The results show how the use of electric vehicles changes the peak load and total electricity usage in grid system. Electricity charge and peak load were different depending on the charging strategy, and the optimal charging strategy was different for each individual according to the activity pattern.

1. Introduction

Recently, various environmental problems, including global warming, are increasing. Countries are making efforts such as the Kyoto Protocol to reduce greenhouse gas emissions, such as CO_2. About 60% of anthropogenic greenhouse effect is caused by burning fossil fuels(Achtnicht 2012). The main use of fossil fuels in the transport sector is one of the major source of CO2 emissions. In this situation, electric vehicles have emerged as one of the solutions for environmental problems, and commercial electric vehicle types are increasing. The number of countries making efforts to supply electric vehicles and expects an increase in the share of eco-friendly vehicles. The Korean government is also planning to increase its share of eco-friendly vehicles to 30% by 2025.

Nowadays, energy use is increasing as the industry grows due to economic development and also due to the increasing use of various electronic devices in everyday life. Especially in the summer and winter when energy use increases, the amount of spare energy is sharply reduced. To solve this situations, there exists power management systems including smart grid system. In this situation, the increase of eco-friendly vehicles will cause overload of the power system. Particularly, there will be many differences depending on how and when the electric vehicle is charged.

There are several studies on the use of electricity according to user activity patterns. Bottom-up models, which is introduced on (Capasso et al. 2002), is combine data to determine the electricity demand of households. Framework for stochastic generation of realistic time-resolved data on occupant behavior is modeled on (Widén and Wäckelgård 2010). (Subbiah et al. 2013) propose a modeling framework to generate household energy demand profiles based on energy consuming activities. It focused on energy demand for residential buildings. Improved model for activity-based models or energy demand using socio-technical assumptions is proposed on (McKenna et al. 2017). (Muratori et al. 2013) presented model for find electricity demand of single household consisting of multiple individuals using data collected by the U.S. Bureau of Labor Statistics.

Studies on the impact of the increase of energy-efficient vehicles on the power system are as follows. The impact of charging electric vehicles on distribution system and coordinated charging is studied on (Clement-Nyns, Haesen, and Driesen 2010). (Grahn et al. 2013) proposed a new model for PHEV using patterns and charging patterns and shows changes in the load profiles. (Elyasibakhtiari et al. 2015) presents the real-time simulation analysis of effect on gird system due to electric vehicle charging. Effects of electric vehicles on power systems in Northern Europe is studied on (Hedegaard et al. 2012). They analyzed how electric vehicles would influence the power systems toward 2030. (Božič and Pantoš 2015) researched how electric vehicles will affect the power system reliability. They proposed optimization model for different strategies of charging.

In the micro-gird situation, three kinds of charging strategies of PHEV affect the grid system and the cost of the user is studied on (Kamankesh, Agelidis, and Kavousi-Fard 2016). (Hashemi-Dezaki et al. 2015) introduced risk management method to reduce risk of charging plug-in-hybrid-electric vehicles on grid system. (Mets et al. 2010) proposed smart energy control strategies based on quadratic programming to reduce peak load and compare with benchmark strategies. (Zeng et al. 2017) introduced multi-year expansion planning method for handle the growth of plug-in electric vehicles which can affect distribution systems. The real-time controller that considers bidirectional charging efficiency is proposed on (Wenzel et al. 2018). (Moghaddam et al. 2017) proposed model for finding the optimal charging station that can satisfy multiobjective optimization. (Rahman et al. 2016) introduced charging of electric vehicles and trends in optimization techniques for charging eco-friendly vehicles.

It is obvious that increase in the number of electric vehicles affects the grid system, so charging the electric vehicles must be controlled. Unless there is a difference in electricity rate, it will be difficult to control individual user's electric vehicle charging. However, if there are differences, users will set up charging strategies to minimize their rates.

The purpose of this paper is to research the effect of charging electric vehicles on residential power systems through big data of residential activity and find optimal charging strategies for each member on each situation. We calculate electricity usage of home appliance and electric vehicle usage from activity pattern data. Usage and bills are compared between three kinds of charging strategies and optimal charging strategies for each household is found.

2. Model

2.1 Overview

At first, behavioral data was pre-processed. There are so many different kinds of behavior that those are divided into several activities. After that, the categorized activities are converted to the use of electrical appliance and the electrical usage by time zone is calculated from the use of these electrical appliance. Electric vehicle usage is predicted through driving time of behavior data and electricity consumption is calculated by time according to electric vehicle charging strategy. Based on the power usage of electrical appliances and electric vehicles, the electricity bill is calculated according to the electricity rate policy. This finds an optimal charging strategy that minimizes each individual's electricity bill.

2.2 User activity

A user can do activity $a \in A = \{1, ..., N_A\}$, that A is set of various residential activities including "Sleep" and "Away". Each user m's activity on time t is $A_m^t = a$ and it can be determined from behavioral data.

2.3 Electrical appliance

Use of electrical appliance $e \in E = \{1, ..., N_E\}$ can be converted from activity. Each appliance have different scheme depending on the type of device. There are appliances that have constant demand independent from activity and some have different electricity usage over time. There are also appliances that are related to user behavior. The following three are relationship between appliances and behavior. Appliances that use electricity only when activity occurs, in this paper it is called "Scheme A". "Scheme B" is appliances that are used from the end of activity and "Scheme C" is appliances that require standby power and use more electricity during activity.

2.3.1 Constant Demand and Daylight-dependent.

Some appliances are always in operation. This will not always use the same amount of electricity in every time. However, we assumed that this kind of appliance always uses the same amount of electricity to simplify the model. Daylight-dependent means some appliances works differently time, even if they are the same one. These do not consume power if they are not used, but they will consume different electricity over time when they are used.

2.3.2 Scheme A, B, C

Appliance is used only during the activity in "Scheme A", as depicted in Figure 1.(a). This kind of appliance are assumed to be use power P_{on} constantly for the duration of use and 0 for rest of time.

In "Scheme B", appliance works after activity is done, as depicted in Figure 1.(b). The power P_{on} is assumed to be constantly consumed from the end of the activity until time K later.

"Scheme C" is a generalized model of "Scheme A", as depicted in Figure 1.(c). Appliance is used in activity and consumed power P_{on} as same as "Scheme A" but standby power $P_{standby}$ is needed even if it is not used.

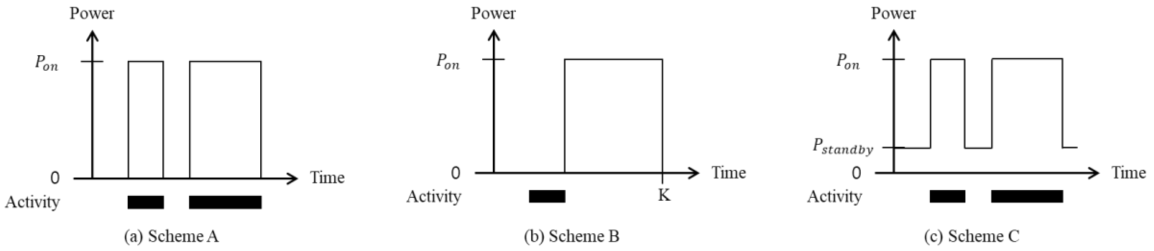

Figure 1

2.4 Driving electric vehicle

The battery of the electric vehicle is consumed when the electric vehicle is used at the state "Moving by car". The electric vehicle is assumed to use power P_{car} when it was operated. P_{car} is calculated by the following (1). $v\ (km/h)$ is the average driving speed over an hour. $c\ (km/kWh)$ means fuel efficiency. Each user m 's electricity consumption for driving U_{car}^{m} is as following (2) when drive D^{m} time a day.

$$P_{car} = \frac{v}{c} \tag{1}$$

$$U_{car}^{m} = \frac{v}{c} \times D^{m} \tag{2}$$

The following assumptions were made for charging electric vehicles. The user uses a slow charger at home and a fast charger outside. Electric vehicle is charged the amount of electricity consumed per day, U_{car}^{m} in the house as much as possible and charges the remaining amount outside. It can be shown as (3), where P_{slow}, P_{fast} are power of slow charger and fast charger, and $T_{home}^{m}, T_{outside}^{m}$ are charging time at home and outside.

$$U_{car}^{m} = P_{slow} \times T_{home}^{m} + P_{fast} \times T_{outside}^{m} \tag{3}$$

2.5 Charging strategy

Charging start time t_{start} depends on charging strategy. This paper assumed three kinds of charging strategies for electric vehicle. These three kinds of charging strategy was proposed on (Kamankesh, Agelidis, and Kavousi-Fard 2016).

The first charging strategy is to start charging as soon as user return home after using electric vehicle. The second charging strategy is to start charging at off-peak times between 21:00 and 24:00. If the car does not arrive home by 21:00, it starts charging between the time of arrival and 24:00. In this case probability density function is (4). The third charging strategy is charging start time t_{start} follow a normal distribution with an average of 1:00 and a standard deviation of 3. Probability density function follows (5).

$$f(t_{start}) = \frac{1}{b-a} \text{ where } a = \max(21, t_{arrive}) \le t_{start} \le b = 24 \tag{4}$$

$$f(t_{start}) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left(-\frac{1}{2}\left(\frac{t_{start}-\mu}{\sigma}\right)^2\right)} \text{ where } \mu = 1, \sigma = 3 \tag{5}$$

3. Case study and input data

3.1 Data

The data used for research was from the 2014 Korean Life Time Survey conducted by KOSTAT. Data is an individual's daily behavior and consists of a total of 53976 datasets. Each data shows where action or movement was made and its details in 10 minutes.

3.2 User activity and Electrical appliance

In this paper each person's behavioral data was classified into nine activities as shown in (Widén and Wäckelgård 2010) and, the use of vehicles is important, so "Moving by car" and "Moving other way" has been added. Therefore, number of activities is $N_A = 11$ and detail is shown in Table 1.

Activity	a
Away	1
Sleeping	2
Cooking	3
Dishwashing	4
Washing	5
TV	6
Computer	7
Audio	8
Additional	9
Moving by car	10
Moving other way	11

Table 1

The use of electrical appliances to obtain electricity usage is obtained as shown in (Widén and Wäckelgård 2010). A brief description of the electrical appliance usage is provided in the table and details follow below Table 2.

Appliance	e	Type	a

Cold appliance	1	Constant demand	
Lighting	2	Daylight-dependent	2-9
Cooking	3	Scheme A	3
Dishwashing	4	Scheme B	4
Washing	5	Scheme B	5
TV	6	Scheme C	6
Computer	7	Scheme C	7
Stereo	8	Scheme C	8
Additional	9	Scheme A	9

Table 2

Cold appliances such as refrigerators have constant demand because they must be on at all times. Lighting appliance is used for all activity, but the brightness varies from time to time, so electricity usage varies by time. Therefore, we assume the following. When user is not at home, do not use the lighting, and if user is sleeping, use the amount of electricity as $P_{lighting,sleep}$. Since other activities require less lighting during daytime, the amount of electricity is used as much as $P_{lighting,day}$, and a lot of lighting is needed during nighttime, so as much as $P_{lighting,night}$ is used. “Cooking” appliance is only used when user is cooking so use the power as “Scheme A”. “Dishwashing” and “Washing” appliances is usually start working after dishwashing and washing like “Scheme B”. Entertainment appliance including “TV”, “Computer” and “Stereo” is “Scheme C”, so it needs standby power. The specific values of these appliance parameters are shown in the following Table 3.

Parameter	Value
P_{cold}	10 (W)
$P_{lighting,sleep}$	12 (W)
$P_{lighting,day}$	40 (W)
$P_{lighting,night}$	104 (W)
$P_{cooking,on}$	1500 (W)
$P_{dishwashing,on}$	1225 (W)
$K_{dishwashing}$	150 (min)
$P_{washing,on}$	404 (W)
$K_{washing}$	130 (min)
$P_{tv,on}$	100 (W)
$P_{tv,stanby}$	20 (W)
$P_{computer,on}$	100 (W)
$P_{computer,standby}$	40 (W)
$P_{stereo,on}$	30 (W)

$P_{stereo,stanby}$	6 (W)
$P_{\mathrm{additional},on}$	11 (W)

Table 3

3.3 Electric vehicle

The electric vehicle was assumed to use U_{car} for an hour when it is driven as follow. v is from (Grahn et al. 2013) and c is from official fuel efficiency of Hyundai Ioniq which is the best-selling electric vehicle in Korea. Power of slow charger is $P_{slow} = 7kW$ and fast charger is $P_{fast} = 50kW$. Because charging strategy 2 and 3 follow the probability distribution, we performed a large number of times to obtain the average charge amount by time.

$$\begin{aligned} U_{car} &= \frac{v}{c} = 7301.587W \\ v &= 46km/h \\ c &= 6.3km/kWh \end{aligned} \tag{6}$$

3.4 Electricity rate for electric vehicle charging

In this paper, we use electricity rate for electric vehicle charging from Korea Electric Power Corporation. The Timeslot is divided as shown in Table 4, and accordingly the electric vehicle charging rate is as shown in Table 5. In the case of fast charging, the price is 173.8 KRW / kWh.

Time period	Summer (Jun. ~ Aug.)	Spring / Fall (Mar. ~ May. / Sep. ~Oct.)	Winter (Nov. ~ Feb.)
off-peak load	23:00 ~ 09:00	23:00~09:00	23:00~09:00
mid-load	09:00~10:00 12:00~13:00 17:00~23:00	09:00~10:00 12:00~13:00 17:00~23:00	09:00~10:00 12:00~17:00 20:00~22:0
peak-load	10:00~12:00 13:00~17:00	10:00~12:00 13:00~17:00	10:00~12:00 17:00~20:00 22:00~23:00

Table 4

Price (Korea Won / kWh)			
Time period	Summer	Spring / Fall	Winter

off-peak load	57.6	58.7	80.7
mid-load	145.3	70.5	128.2
peak-load	232.5	75.4	190.8

Table 5

4. Result

오류! 참조 원본을 찾을 수 없습니다. shows how many users do each activity at each time. A brief summary of the data is shown in **오류! 참조 원본을 찾을 수 없습니다.**. Obviously, many people are out of the house during the day, the rest of the time at home, and most are sleeping at night.

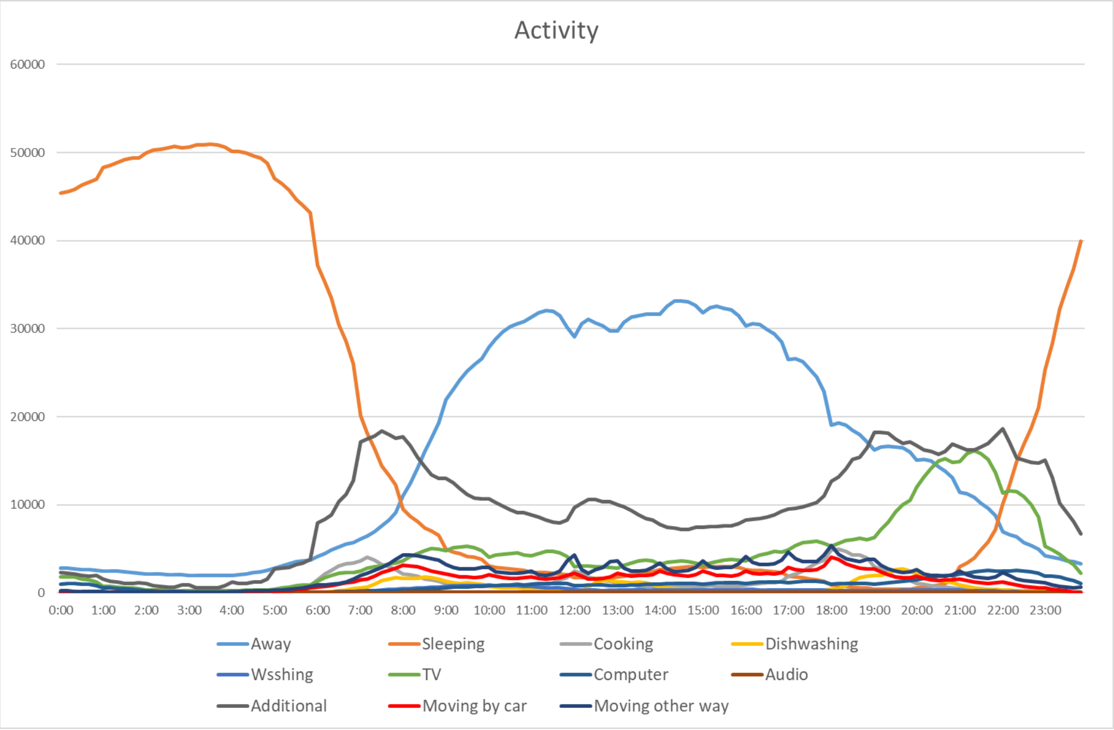

Figure 2

	Time											
Activity (%)	0:00	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Away	5.20	3.95	3.75	7.68	20.38	51.69	53.82	58.70	56.15	35.37	27.96	12.91
Sleeping	84.18	92.61	92.91	68.91	17.60	5.68	3.25	4.87	4.83	1.61	1.10	18.70
Cooking	0.07	0.03	0.10	2.83	4.05	1.40	4.54	1.33	1.69	9.06	2.00	0.57
Dishwashing	0.03	0.02	0.02	0.16	3.08	1.43	0.43	1.26	0.36	0.76	3.93	0.59
Wsshing	0.03	0.00	0.01	0.12	0.90	1.65	0.73	0.66	0.68	0.50	0.54	0.33
TV	3.38	0.55	0.41	2.41	6.74	7.54	5.58	5.97	6.68	9.77	22.20	21.09
Computer	1.87	0.41	0.09	0.11	0.60	1.45	1.52	1.80	2.00	1.86	2.75	4.52
Audio	0.10	0.01	0.01	0.07	0.08	0.14	0.12	0.15	0.15	0.11	0.13	0.18
Additional	4.35	1.94	2.30	14.75	32.77	19.85	17.98	14.40	15.29	23.41	30.97	34.54
Moving by car	0.32	0.21	0.16	1.28	5.78	3.80	4.07	4.64	4.56	7.57	3.48	2.36

Moving other	0.47	0.26	0.23	1.68	8.01	5.37	7.98	6.22	7.61	9.98	4.95	4.22

Table 6

Figure 3 shows the sum of amount of home charging by time for each strategy when all users selected the same charging strategy. In this result, those who did not park their cars at home were excluded from the calculation of electricity usage. Because the charging strategy is meaningless for those who cannot do home charging. Table 7 shows the amount of slow charging at home and the amount of fast charging outside when every user selects each charging strategy. Charging strategies 2 and 3 have a greater amount of fast charging than charging strategy 1 because they are more likely to charge late at night, which increases the likelihood that they will not be able to charge all amounts.

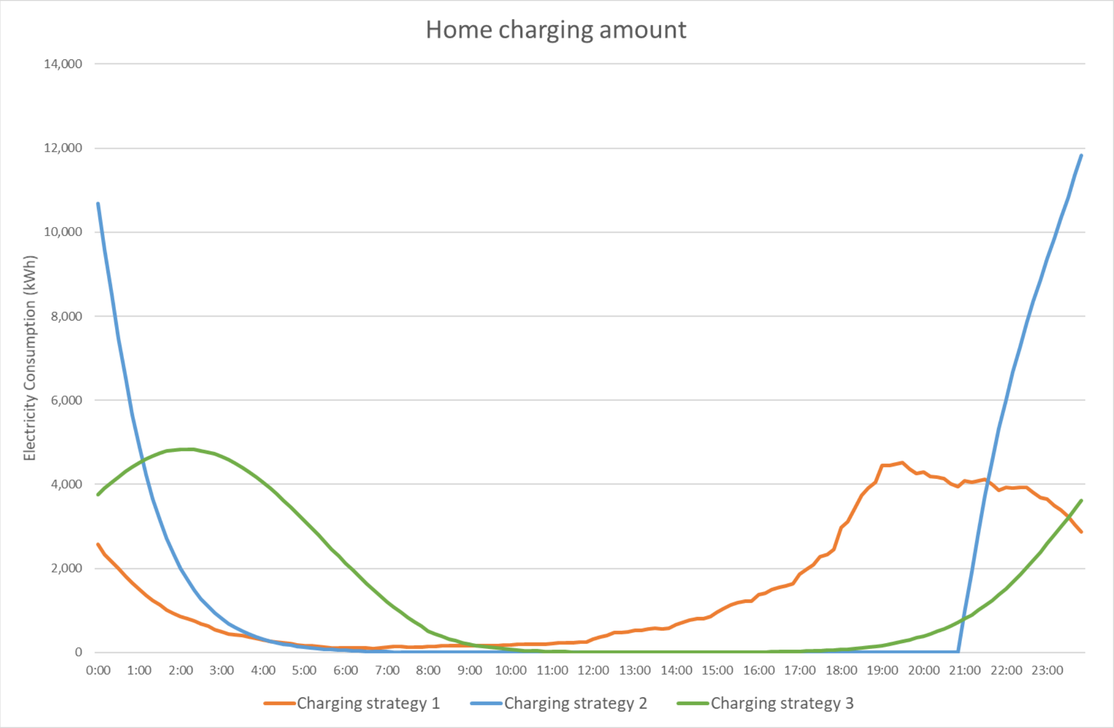

Figure 3

Electricity Consumption (kWh)		
	Slow Charging	Fast Charging
Charging strategy 1	213,188	3,184
Charging strategy 2	211,228	1,012
Charging strategy 3	208,167	3,656

Table 7

Figure 4 and Table 8 show the total electricity bill if all users have chosen charging strategy 1, 2, and 3 together and the total electricity bill if each individual chooses a strategy that minimizes their charges. Charge the electric vehicle as soon as user arrive at home, which is an uncontrolled strategy, is more expensive than other strategies. Also, in spring / summer, where electricity prices are not much different by time of day, the difference in charge rates by charging strategy is not big compared to summer / winter situation. The ratio of the optimal strategy chosen by the user for each season can be seen at Table 9. Strategy 3 tends to be the most chosen in every case.

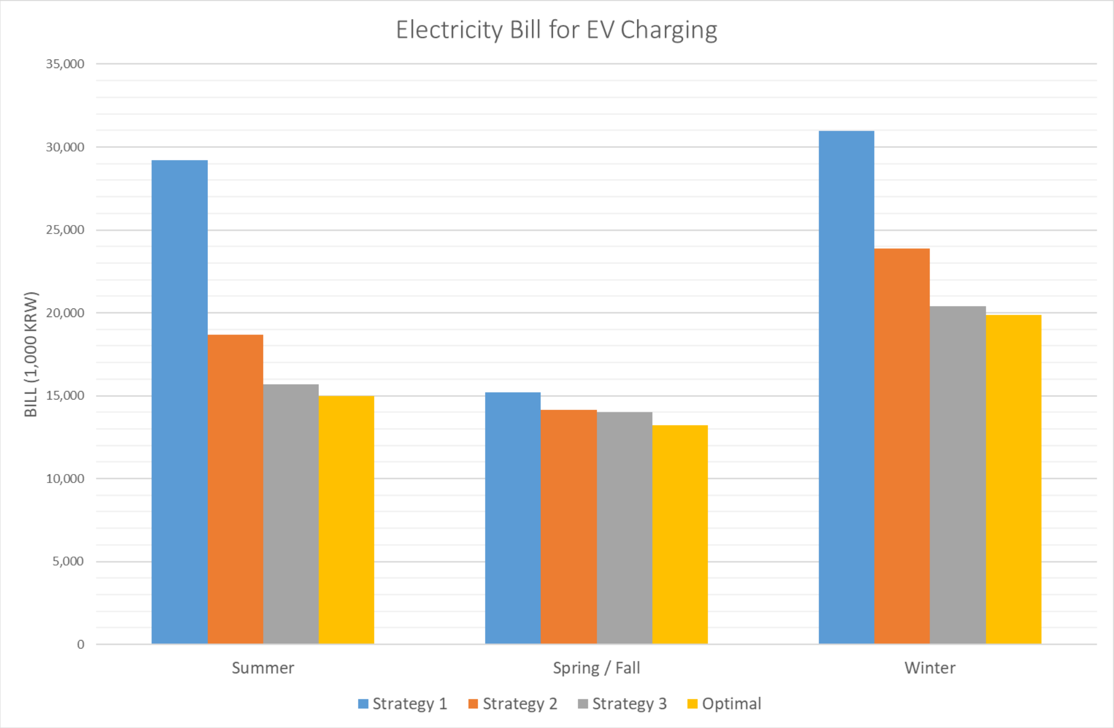

Figure 4

Electricity Rate (1,000 KRW)				
	Strategy 1	Strategy 2	Strategy 3	Optimal
Summer	29,220	18,669	15,695	14,989
Spring / Fall	15,196	14,133	14,024	13,228
Winter	30,974	23,894	20,396	19,874

Table 8

Ratio of the optimal strategy			
	Strategy 1	Strategy 2	Strategy 3
Summer	5.80%	12.89%	81.31%
Spring / Fall	6.27%	26.98%	66.75%

Winter	6.07%	10.57%	83.36%

Table 9

Figure 5 shows the charging power consumption of total electric vehicle according to seasonal optimal charging strategy. Figure 6 shows the sum of charging power and appliance consumption. It can be seen that the use of the electric vehicle has a great influence on the total electric consumption.

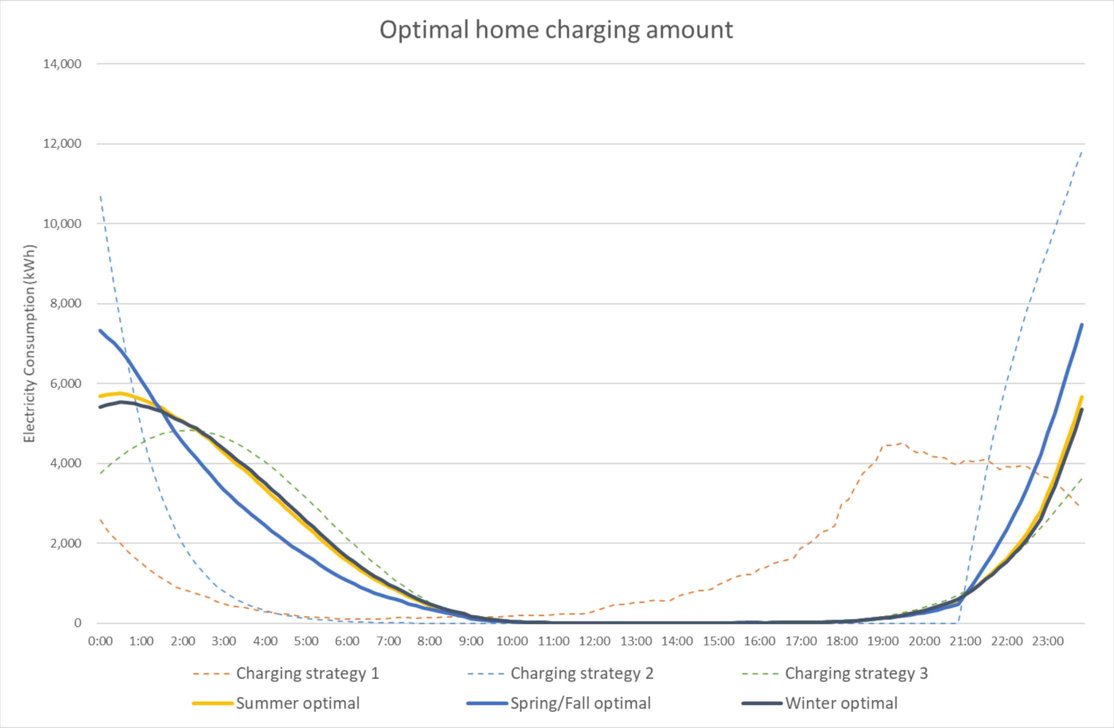

Figure 5

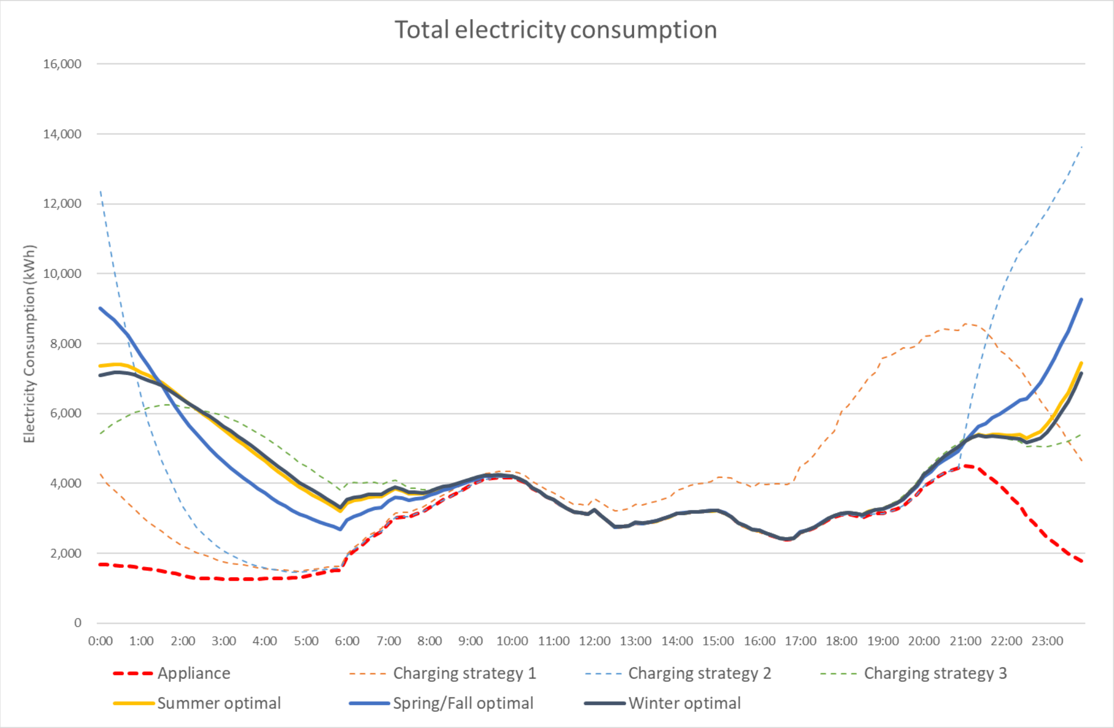

Figure 6

Table 10 shows the calculation of peak-to-average-ratio (PAR) when there is no electric vehicle and when there is an electric vehicle for each strategy. PAR is increased in strategy 1, an uncontrolled charging strategy, when there is an electric vehicle rather than when there is no electric vehicle. In strategy 2, you can see that PAR is the highest because it started charging in 3 hours. In strategy 3, the PAR is the lowest, because it started charging start time spread widely low middle of the night when price is low. It can be seen that PARs are lower when individuals choose the optimal charging strategy than in the uncontrolled case, except in spring and autumn, where there is no significant difference in power rates by time of day.

	PAR
Appliance only	1.63
Charging strategy 1	2.02
Charging strategy 2	3.22
Charging strategy 3	1.49
Summer optimal	1.76
Spring/Fall optimal	2.18
Winter optimal	1.70

Table 10

The fast charge rate of 173.8 KRW / kWh, which is used in the paper, is a discounted price for electric vehicle diffusion. We do a sensitivity analysis for the case of discounting the fast charge rate. The fast charging price before discounted is 313.1 KRW / kWh. Figure 7, Table 11 and Table 12 show the result when the price of fast charge changed. Comparing Table 11 with Table 7, we can see that the rate of fast charging is reduced a lot. This is a obvious result. Because of the high cost of fast charging, you will probably want to charge it at home. If we compare Table 12 and Table 9, we can see that the ratio of strategy3, which is more likely to fail to fill all of the desired amount of electricity, is reduced.

Electricity Consumption (kWh)	Slow Charging	Fast Charging
Charging strategy 1	213,653	2,054
Charging strategy 2	215,824	615
Charging strategy 3	213,181	2,339

Table 11

Ratio of the optimal strategy	Strategy 1	Strategy 2	Strategy 3
Summer	5.96%	16.76%	77.28%
Spring / Fall	6.51%	36.50%	56.99%
Winter	6.17%	14.39%	79.45%

Table 12

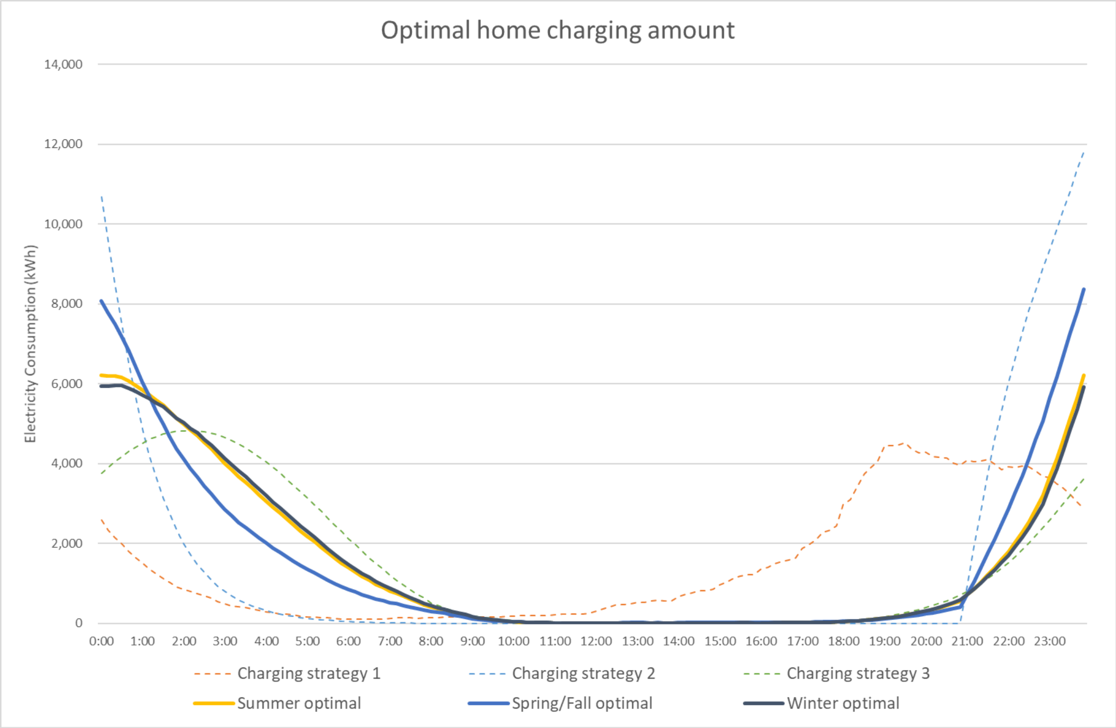

Figure 7

5. Conclusion

In this paper, we use the behavior data from questionnaires in Korea to predict the electric power consumption of household electric appliances. Also, by analyzing the behavior data, the travel time using the car is calculated and the electric charge demand for electric vehicle of each user is predicted. Through this, how the electric vehicle affects the power system is researched. The analysis of various electric vehicle charging strategies is as follows. It can be seen that the electricity bill of the household is reduced when everyone use same charging strategies or the optimal charging strategy is selected among the various charging strategies than the case where the user's charging strategy is uncontrolled. It was also found that PAR was lowered in most cases. In order to diffuse electric vehicles, it will be necessary to manage the charging strategy through the smart grid as well as increase the maximum capacity of the power system.

In the future research, model to select more individualized strategies such as different parameters for each person rather than setting the parameters of the three charging strategies as fixed values can be done. Also, research will be conducted to select optimal charging strategy through interaction between electric vehicle users.

References

Achtnicht, Martin. 2012. “German Car Buyers’ Willingness to Pay to Reduce CO2 Emissions.” *Climatic Change* 113 (3–4): 679–97. https://doi.org/10.1007/s10584-011-0362-8.

Božič, Dušan, and Miloš Pantoš. 2015. “Impact of Electric-Drive Vehicles on Power System Reliability.” *Energy* 83: 511–20. https://doi.org/10.1016/j.energy.2015.02.055.

Capasso, A., W. Grattieri, R. Lamedica, and A. Prudenzi. 2002. “A Bottom-up Approach to Residential Load Modeling.” *IEEE Transactions on Power Systems* 9 (2): 957–64. https://doi.org/10.1109/59.317650.

Clement-Nyns, Kristien, Edwin Haesen, and Johan Driesen. 2010. “The Impact of Charging Plug-in Hybrid Electric Vehicles on a Residential Distribution Grid.” *IEEE Transactions on Power Systems* 25 (1): 371–80. https://doi.org/10.1109/TPWRS.2009.2036481.

Elyasibakhtiari, Kiyan, Maher A. Azzouz, Elham Akhavan Rezai, and E. F. El-Saadany. 2015. “Real-Time Analysis of Voltage and Current in Low-Voltage Grid Due to Electric Vehicles’ Charging.” *International Conference on Smart Energy Grid Engineering, SEGE 2015,* 3–7. https://doi.org/10.1109/SEGE.2015.7324607.

Grahn, Pia, Joakim Munkhammar, Joakim Widen, Karin Alvehag, and Lennart Soder. 2013. “PHEV Home-Charging Model Based on Residential Activity Patterns.” *IEEE Transactions on Power Systems* 28 (3): 2507–15. https://doi.org/10.1109/TPWRS.2012.2230193.

Hashemi-Dezaki, Hamed, Mohsen Hamzeh, Hossein Askarian-Abyaneh, and Homayoun Haeri-Khiavi. 2015. “Risk Management of Smart Grids Based on Managed Charging of PHEVs and Vehicle-to-Grid Strategy Using Monte Carlo Simulation.” *Energy Conversion and Management* 100: 262–76.

https://doi.org/10.1016/j.enconman.2015.05.015.

Hedegaard, Karsten, Hans Ravn, Nina Juul, and Peter Meibom. 2012. “Effects of Electric Vehicles on Power Systems in Northern Europe.” *Energy* 48 (1): 356–68. https://doi.org/10.1016/j.energy.2012.06.012.

Kamankesh, Hamidreza, Vassilios G. Agelidis, and Abdollah Kavousi-Fard. 2016. “Optimal Scheduling of Renewable Micro-Grids Considering Plug-in Hybrid Electric Vehicle Charging Demand.” *Energy* 100: 285–97. https://doi.org/10.1016/j.energy.2016.01.063.

McKenna, Eoghan, Sarah Higginson, Philipp Grunewald, and Sarah J. Darby. 2017. “Simulating Residential Demand Response: Improving Socio-Technical Assumptions in Activity-Based Models of Energy Demand.” *Energy Efficiency*, 1–15. https://doi.org/10.1007/s12053-017-9525-4.

Mets, Kevin, Tom Verschueren, Wouter Haerick, Chris Develder, F. De Turck, and Filip De Turck. 2010. “Optimizing Smart Energy Control Strategies for Plug-in Hybrid Electric Vehicle Charging.” *2010 IEEE/IFIP Network Operations and Management Symposium Workshops*, 293–99. https://doi.org/10.1109/NOMSW.2010.5486561.

Moghaddam, Zeinab, Iftekhar Ahmad, Daryoush Habibi, and Quoc Viet Phung. 2017. “Smart Charging Strategy for Electric Vehicle Charging Stations.” *IEEE Transactions on Transportation Electrification* 4 (1): 76–88. https://doi.org/10.1109/TTE.2017.2753403.

Muratori, Matteo, Matthew C. Roberts, Ramteen Sioshansi, Vincenzo Marano, and Giorgio Rizzoni. 2013. “A Highly Resolved Modeling Technique to Simulate Residential Power Demand.” *Applied Energy* 107: 465–73. https://doi.org/10.1016/j.apenergy.2013.02.057.

Rahman, Imran, Pandian M. Vasant, Balbir Singh Mahinder Singh, M. Abdullah-Al-Wadud, and Nadia Adnan. 2016. “Review of Recent Trends in Optimization Techniques for Plug-in Hybrid, and Electric Vehicle Charging Infrastructures.” *Renewable and Sustainable Energy Reviews* 58: 1039–47. https://doi.org/10.1016/j.rser.2015.12.353.

Subbiah, R., K. Lum, A. Marathe, and M. Marathe. 2013. “Activity Based Energy Demand Modeling for Residential Buildings.” In *2013 IEEE PES Innovative Smart Grid Technologies Conference (ISGT)*, 1–6. IEEE. https://doi.org/10.1109/ISGT.2013.6497822.

Wenzel, George, Matias Negrete-Pincetic, Daniel E. Olivares, Jason MacDonald, and Duncan S. Callaway. 2018. “Real-Time Charging Strategies for an Electric Vehicle Aggregator to Provide Ancillary Services.” *IEEE Transactions on Smart Grid* 9 (5): 5141–51. https://doi.org/10.1109/TSG.2017.2681961.

Widén, Joakim, and Ewa Wäckelgård. 2010. “A High-Resolution Stochastic Model of Domestic Activity Patterns and Electricity Demand.” *Applied Energy* 87 (6): 1880–92. https://doi.org/10.1016/j.apenergy.2009.11.006.

Zeng, Bo, Jiahuan Feng, Jianhua Zhang, and Zongqi Liu. 2017. “An Optimal Integrated Planning Method for Supporting Growing Penetration of Electric Vehicles in Distribution Systems.” *Energy* 126: 273–84. https://doi.org/10.1016/j.energy.2017.03.014.