ISSN 1975-8359(Print) / ISSN 2287-4364(Online)
The Transactions of the Korean Institute of Electrical Engineers Vol. 65, No. 5, pp. 730～737, 2016
http://dx.doi.org/10.5370/KIEE.2016.65.5.730

전기자동차 침투율을 고려한 피크 부하 저감용 스마트 기기의 적응적 제어

An Adaptive Control of Smart Appliances with Peak Shaving Considering EV Penetration

Zunaib Maqsood Haider · Farhan H. Malik · M. Kashif Rafique · 이순정 · 김준혁 · Khawaja Khalid Mehmood** · Saad Ullah Khan** · 김 철 환
Zunaib Maqsood Haider† · Farhan H. Malik* · M. Kashif Rafique** · Soon-Jeong Lee** · Jun-Hyeok Kim** · Khawaja Khalid Mehmood** · Saad Ullah Khan** · Chul-Hwan Kim**

Abstract - Electric utilities may face new threats with increase in electric vehicles (EVs) in the personal automobile market. The peak demand will increase which may stress the distribution network equipment. The focus of this paper is on an adaptive control of smart household appliances by using an intelligent load management system (ILMS). The main objectives are to accomplish consumer needs and prevent overloading of power grid. The stress from the network is released by limiting the peak demand of a house when it exceeds a certain point. In the proposed strategy, for each smart appliance, the customers will set its order/rank according to their own preferences and then system will control the household loads intelligently for consumer reliability. The load order can be changed at any time by the customer. The difference between the set and actual value for each load's specific parameter will help the utility to estimate the acceptance of this intelligent load management system by the customers.

Key Words : Electric Vehicle (EV), Peak Demand, Intelligent Load Management System (ILMS), customer reliability, Load Rank

1. Introduction

Electricity generation and its consumption deal with three important features [1]: 1) power generation and its demand must exactly match; 2) power demand always varies according to the consumer needs during a day; 3) electricity can't be stored economically. The balance between power generation and demand may worsen due to large penetration of non-flexible renewable energy sources in the power system. Furthermore, the large penetration of electric vehicles may significantly de-stabilize the power system. To enhance the stability and reliability of the network, it requires implementation of Demand Response (DR) and other enabling techniques. In demand response, customer controls the load with maximum load limit fixed by the utility or may lower its load than the fixed point, if getting more incentives from the utility. Demand response, as defined by the North American Electric Reliability Corporation (NERC) "is the change in electricity usage by end use customers from their normal consumption patterns in response to changes in the price of electricity (price-based demand response), or to incentive payments designed to induce lower electricity use at the time of high wholesale market prices or when system reliability is jeopardized (incentive-based demand response)" [2],[3].

The integration of electric vehicle to the distribution network may cause various problems. Therefore, to make their appearance transparent, peak load shaving is a major subject of concern from long time. For the purpose of peak load reduction, different strategies can be implied. The distribution network load can be leveled by controlling the charging time of EVs, while batteries can be used as a source of electric energy when EVs are in idle state [4]. To increase consumer reliability, rapid charging stations can be implied in the distribution network to provide fast charging facilities, but the maximum number of electric vehicles that a station can handle depends on its available capacity [5]. The integration of renewable sources increases the generation capacity thus providing more capacity for EVs [6]. However, the impact of EV on distribution network depends on the share of the type of electric vehicle in the

† Corresponding Author : College of Information and Communication Engineering, Sungkyunkwan University, Korea.
E-mail: zmhaider@skku.edu
* Dept of Electrical Engineering, Aalto University, Finland.
** College of Information and Communication Engineering, Sungkyunkwan University, Korea.
Received : March 24, 2016; Accepted : April 19, 2016

network as three types of green vehicles are available in the market: plug-in electric vehicle (PEV), pure battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) [7]. In order to analyze the impact of electric vehicles on distribution network, the charging demand of EV under different scenarios has been analyzed [8]. During peak load period, online charging technique of EV has also been implied [9]. Moreover, Fast charging infrastructure can be implemented on highways for consumer comfort [10]. To reduce the peak demand, various kind of demand response (DR) strategies have been adopted by electric utilities during peak load period [11]. An optimized price-based demand response technique, to control the power transfer in context of V2G system for electric vehicles and storage space heating to control the residential peak power demand has been studied in [12].

This paper focuses on incentive-based demand response. An intelligent system has been developed which controls the load according to the consumer's choice to ensure reliability.

2. Residential and EV Load Modeling

The hourly load data of the household appliances have been taken from the RELOAD database [13], which is used by the Electricity Module of the National Energy Modeling System (NEMS). It contains variety of representations of load shapes for the residential, commercial and industrial demand sectors. In RELOAD database, the following types of residential sector loads have been described: space heating, space cooling, water heater, cooking, microwave, dishwasher, refrigerator, freezer, clothes washer, clothes dryer, television and others.

In this paper, the above mentioned household loads are divided into two categories: smart loads and uncontrollable loads. Smart loads are those loads which respond to intelligent load management system (ILMS) and may affect the consumer life. The uncontrollable loads are those which cannot be controlled or these are very important loads. In this study, space heater, space cooler, clothes dryer and water heater are taken as smart loads whereas other loads are considered as uncontrollable loads.

The mathematical models of these loads and electrical vehicle developed in [14] have been used for study in this paper.

The electric vehicle's load profile depends on its battery capacity and daily travelling distance. There are many valuable considerations about EVs which will simplify this study. It has been considered that the total plugged-in time for an EV in a household is 10-15 hours/day, while the travelled time is only 1-2 hours/day which may be different for weekdays and weekends [15]. This allows the consumer to shift the charging time of EV from plug-in time and helps in reducing the peak power demand as most of the EVs return to home in evening at about 17:00 [16].

Nissan LEAF's electric vehicle [17] has been used in this paper for study and the specifications are given in Table 1:

Table 1 Fault simulation results

Battery Size	Energy Available	Driving Range	Charge Power
24 kWh	19.2kWh	100 miles	3.3kW

The following three parameters of EV has been considered during modeling: the rated charging power, the plug-in time and the Battery State of Charge (SOC). The battery SOC depends on the daily travelling distance of electric vehicle.

3. Strategy Design for Adaptive Control

An intelligent load management system has been developed to control the smart loads. As described earlier, the household loads have been divided into two types: smart loads and uncontrollable loads. If there is the maximum load limit set by the consumer or utility, the system will check the total load demand of household appliances. If the total demand is greater than the set limit, it will turn off some of the smart loads according to the consumer's choice to maintain consumer reliability without increase in load demand limit.

In case, the total household load is greater than the set point, the ILMS system performs its actions. The actions in ILMS system are performed as shown in Fig 1:

In ILMS system, consumer sets the load order from highest to lowest and conditional settings for each household appliance. For example, HVAC may be of highest priority and water heater may be of lowest priority. The conditional setting for EV may be that it must charge before 07:00 and for water heater the temperature must not be lower than 110°F. The consumer can change these settings at any time. The system manages the household load according to the load's order and conditions. If the condition for a load violates then it makes the order of that load higher.

- For water heater and cooling/heating system, the conditional settings are based on the temperature set point. If total demand is more than the peak limit, the temperature set point will change regardless of the load order. The temperature set point will change to its initial value if the load conditions are violated and the order of the load raised enough to turn it on.
- For clothes dryer and EV, the conditional settings are based on the end time of the job. Clothes dryer consist of a heating coil and a motor. The heating coil will turn off if the duration to finish the job is more than the remaining time and the total demand is more than the peak limit. The coil will turn on if the duration is less than or equal to the remaining time and the load order is raised enough. In case of EV, charging depends on the remaining time to finish the recharge process.

The maximum load limit could change according to the time of the day and the consumer can also set different load order and conditional settings according to own preferences for different time duration. Moreover, Consumer can change the settings at any time.

So, the household power demand PH can be defined as follows:

$$P_H = \begin{cases} D_{H,} & D_H < P_L \\ P_{L,} & D_H > P_L \end{cases} \quad (1)$$

where,

P_H : Household power demand (kW)
D_H : Current demand (kW) of the house
P_L : Household load limit (kW) assigned by the utility

The ILMS system optimizes the control of the smart appliances as shown in (2):

$$L_T = \begin{cases} L_H - L_{i,} & L_H > P_L \\ L_{H,} & D_H > P_L \end{cases} \quad (2)$$

where,

L_T : Total load of the house (kW) after ILMS operation
L_H : current load of the house (kW)
L_i : Lowest order load (kW)
P_L : household load limit (kW) assigned by the utility
i : n, ⋯ 2, 1

ILMS system not only controls the smart appliances considering consumer's preferences but also increases the load factor.

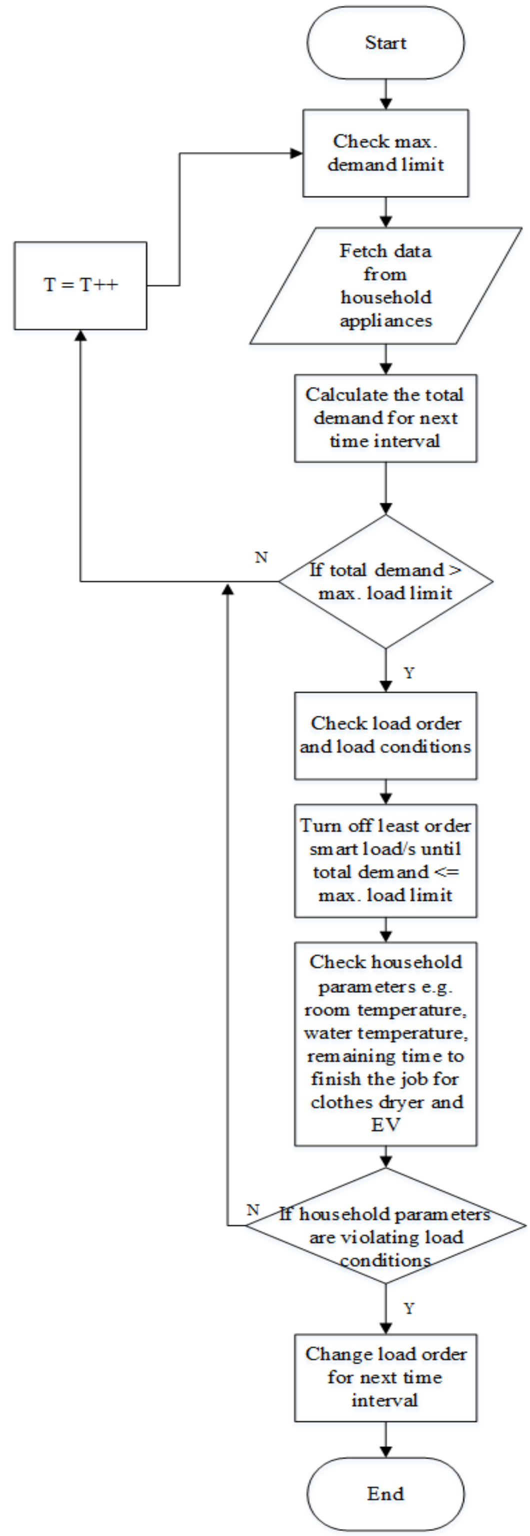


Fig. 1 Control Algorithm for ILMS system

4. Case Study

In this case study, a household with all of the above loads has been considered and the values for the rated power of appliances are taken from RELOAD database and [18].

The simulation is performed from 17:00 to 8:00 as most of the EVs reach home after 17:00. For peak power limit, time duration is divided into three regions as illustrated in Table 2. In a distribution system, the peak power limit can be applied by the utility for different time durations and may also vary during these durations depending on the generation capacity or only set during the peak load period. This limit can also be set by the consumer if utility is offering more incentives for lowering the load than the fixed load limit.

Different parameters such as total area of house, solar heat gain constant, temperature ranges for hot water and rooms, SOC of EV are fetched using uniform random distribution within a predefined range. The outdoor temperature data available in [19] has been considered in this study. The charging power for EV is assumed 3kW and it remains fixed during the whole charging time for simplicity. The time step considered for this simulation study is 15 minutes. The simulation has been performed by considering the average temperature range of Seoul for the month of January (coldest) because the maximum peak demand occurs in this month. However, the study can also be performed for a typical weekday, typical weekend and peak day of each month to analyze the impact of ILMS on consumer's life more precisely. In this study, the load conditional settings are as follows:

1) If the room temperature goes below 65°F then make the heating system order high.
2) If the temperature of water heater goes below 115°F then make its order high.
3) If the remaining time to finish the job for cloth dryer is exceeding midnight, then its order gets high.
4) If charging of electric vehicle is not completing till 7:00 then change its order to high.

Table 2 Peak Power Limit and Time Regions

Category	Region 1	Region 2	Region 3
Time Region	17:00 – 19:00	19:00 – 23:00	23:00 – 08:00
Peak Power (kW)	10	8	10

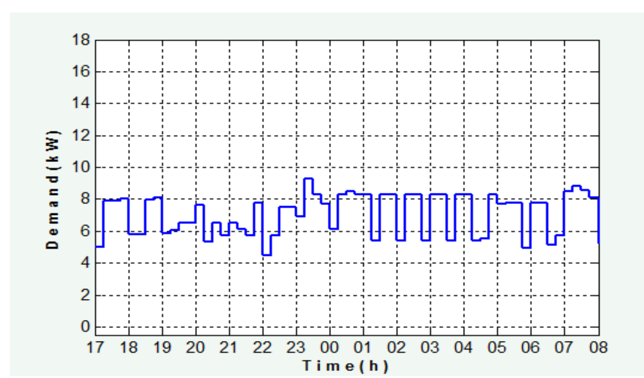
Load order considered in this simulation for different time intervals are given in Table 3.

Table 3 Load order for simulation

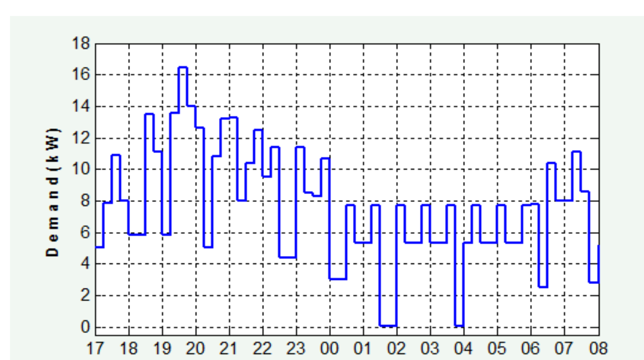
Time of the day	Load Order / Rank			
Highest	High	Low	Lowest	
17:00 – 23:00	HVAC	Water Heater	Cloth Dryer	Electric Vehicle
23:00 – 05:00	Electric Vehicle	HVAC	Cloth Dryer	Water Heater
05:00 – 08:00	Water Heater	HVAC	Electric Vehicle	Cloth Dryer

4.1 Simulation Results

Figs. 2-6 show the simulation results to restrict the peak demand by using ILMS system. As shown in Fig. 2(b), there is a continuous increase in peak demand during 17:00 to 20:00 because of EVs arriving at home and increment in household load. By restricting the peak demand, not only the stress from the distribution circuit is removed, but also the valley situation in load demand during night is also improved, with little influence on consumer's life.



(a)



(b)

Fig. 2 Total Household Load profiles (a) with Intelligent LMS (b) without Intelligent LMS

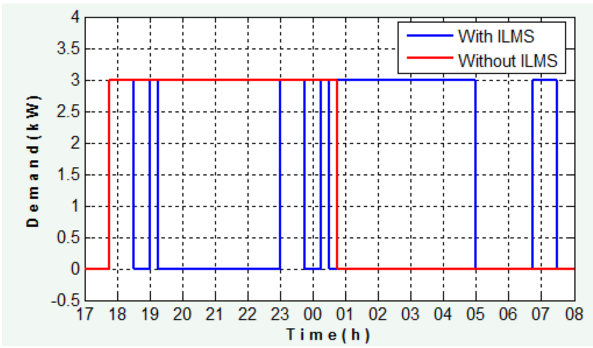


Fig. 3 EV Load profiles with and without ILMS

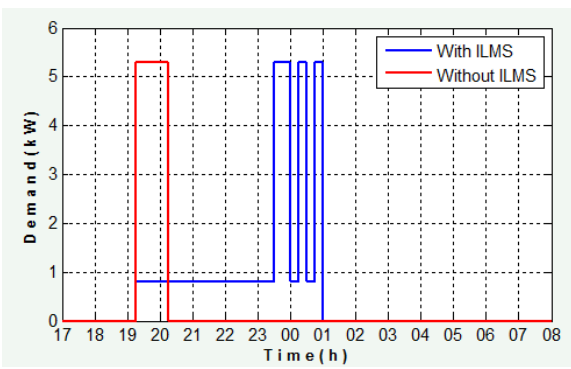
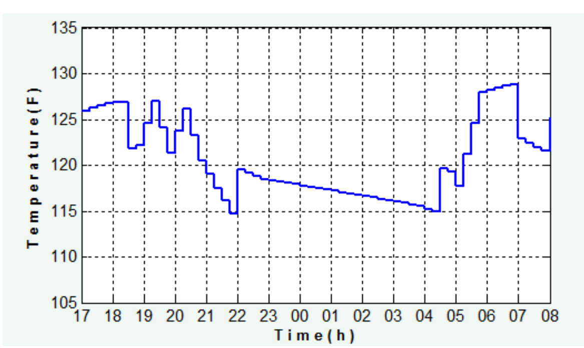
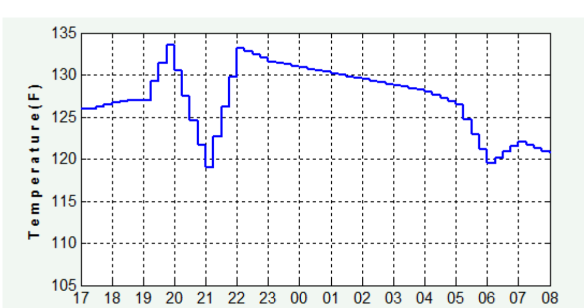


Fig. 4 Cloth Dryer Load profile with and without ILMS

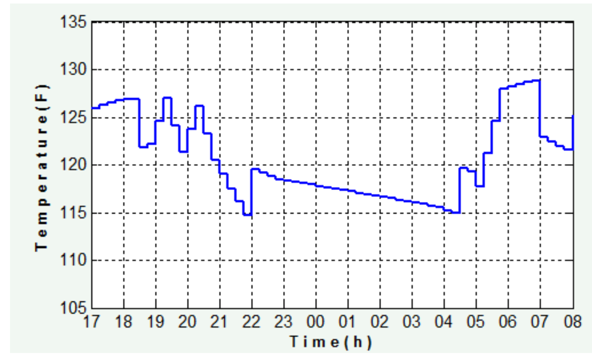


(a)

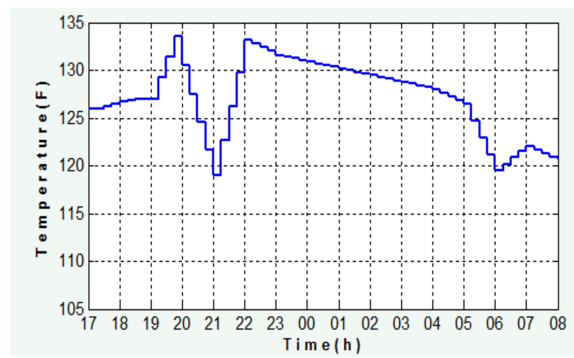


(b)

Fig. 5 Water Heater Temperature profile (a) with Intelligent LMS (b) without Intelligent LMS



(a)



(b)

Fig. 6 Room Temperature profile (a) with Intelligent LMS (b) without Intelligent LMS

Table 4 Simulation Results

Category	Heating System	Water Heater	Clothes Dryer	Electric Vehicle
Load Conditional Setting	65°F	115°F	Job must finish till 00:30	Charging must complete till 07:00
Actual Results	64.01°F	114.68°F	Job finished at 01:00	Charging Completed at 07:30

As shown in Fig. 2 (a), peak demand of the house has been limited according to Table 2 whereas in Fig. 2 (b), it is 16.48 kW without using intelligent LMS system.

In Table 4, actual results have been compared with the conditional setting, which show the degree of effectiveness of consumer for each type of load. The load order that has been considered for this study is mentioned in Table 2. Moreover, the consumer can change it any time or fix it for other time durations. The load factor is also improved by using ILMS system. The results of load factor are given in Table 5.

Table 5 Load Factor

Category	without ILMS	with ILMS
Load Factor	45.97%	73.98%

5. Conclusion

The number of electric vehicles is increasing in vehicle industry worldwide. This increased penetration will jeopardize the stability of electrical distribution network. One way to handle new peak demands is to increase the generation capacity and upgrade the existing distribution networks to accommodate increasing demand. Other way is the use of demand response techniques. This study discussed a way to control household appliances while peak demand remains the same thus making the electric vehicle contribution, transparent in the distribution network without affecting the consumer. In this technique, the control of appliances is in consumer's hand. This method will help the utilities to analyze the effects of ILMS system on customer's routine life. Furthermore, this method can be extended for whole distribution network to consider its acceptance by the consumers. If electric vehicles are available with different charging rates, more charging power can be selected during night time. This will not only lower the effects of this technique on consumer but will also improve the valley situation in load demand during night.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (MSIP) (No.2015 R1A2A1A10052459).

References

[1] POWER GENERATION in CANADA," C. E. Association, Ed. Ed. Ottawa, Ontario, 2006.

[2] North American Electric Reliability Corporation, "Demand response discussion for the 2007 long-term reliability assessment," May 18, 2013

[3] U.S. Department of Energy, "Benefits of demand response in electricity markets and recommendations for achieving them," A report to the U.S. Congress, Feb 2006 [Online]. Available: http://eetd.lbl.gov/ea/EMS/reports/congress-1252d.pdf

[4] Fumiko Koyanagi, Yoshihisa Uriu, "A strategy of Load Leveling by charging and discharging time control of Electric Vehicle," IEEE Transactions on Power Systems, Vol. 13, No. 3, August 1998.

[5] Mehdi Etezadi-Amoli, Kent Choma, Jason Stefani, "Rapid-Charge Electric-Vehicle Stations," IEEE Transactions on Power Delivery, Vol. 25, No. 3, July 2010.

[6] Zhanle Wang and Raman Paranjape, "An evaluation of electric vehicle penetration under demand response in a multiagent based simulation," Electrical Power and Energy Conference, 2014, IEEE Computer Society

[7] Luis Pieltain Fernandez, Tomas Gomez San Roman, Rafael Cossent, Carlos Mateo Domingo, Pablo Frias, "Assessment of the impact of Plug-in Electric Vehicles on Distribution Networks," IEEE Transactions on Power Systems, Vol. 26, No. 1, February 2011.

[8] K. Qian, C. Zhou, M. Allan and Y. Yuan, "Modeling of load demand due to EV battery charging in distribution system," Power Systems, IEEE Transaction on, vol. 26, pp. 802-810, 2011.

[9] Seungmin Jung, Hansang Lee, Chong Suk Song, Jong-Hoon Han, Woon-Ki Han, Gilsoo Jang, "Optimal operation plan of the Online Electric Vehicle System through Establishment of a DC Distribution System," IEEE Transactions on Power Electronics, Vol. 28. No. 12, December 2013

[10] Farhan H. Malik, Matti Lehtonen, Eero Saarijarvi, Amir Safdarian, "A feasibility study of fast charging infrastructure for EVs on Highways," International Review of Electrical Engineering, Vol. 9, No. 2, 2014.

[11] "Benefits of demand response in electricity markets and recommendations for achieving them: A report to the United States Congress pursuant to section 1252 of the Energy Policy Act of 2005," U.S. Dept. Energy, Feb. 2006

[12] Farhan H. Malik, Mubbashir Ali, Matti Lehtonen, "Collaborative Demand Response Optimization of Electric Vehicles and Storage Space Heating for Residential Peak Shaving," International Review of Electrical Engineering, Vol. 9, No. 6, 2014.

[13] RELOAD Database Documentation and Evaluation and Use in NEMS [Online]. Available: http://www.onlocationinc.com/LoadShapesReload2-001.pdf

[14] Shengnan Shao, Manisa Pipattanasomporn, Saifur Rahman, "Development of Physical-Based Demand Response-Enabled Residential Load Models," IEEE Transactions on Power Systems, Vol. 28, No. 2, May 2013.

[15] A. Brooks, E. Lu, D. Reicher, C.Spirakis, B. Weihl, "Demand Dispatch," Power and Energy Magazine, IEEE, Vol. 8, pp. 20-29, 2010.

[16] J. Taylor, A. Maitra, M. Alexander, D. Brooks, M. Duvall, "Evaluation of the impact of plug-in electric vehicle loading on distribution system operation," Power and Energy Society General Meeting, IEEE, 2009.

[17] Nissan Leaf ZEV Features & Specifications [Online].

Available: http://www.nissanusa.com/ev/media/pdf/s-pecs/FeaturesAndSpecs.pdf
[18] Average Power Consumption of household appliances [Online]. Available: http://www.absak.com/library/-power-consumption-table.
[19] Seoul Climate and Temperature [Online]. Available: http://www.seoul.climatemps.com

저 자 소 개

Zunaib Maqsood Haider

He received his B.Sc. degree in Electrical Engineering from Bahauddin Zakariya University, Multan, Pakistan in 2010. At present, he is working on his Ph.D. course at Sungkyunkwan University, Suwon, Republic of Korea. His research interests are demand response, smart grids and electric vehicle.

Farhan H. Malik

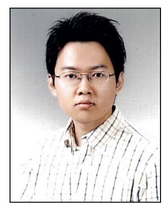
He received his B.Sc. degree in Electrical Engineering from Bahauddin Zakariya University, Multan, Pakistan in 2010 and M.Sc. Electrical Engineering degree from Aalto University (Formerly, Helsinki University of Technology), Helsinki, Finland in 2012, where currently he is continuing his D.Sc. Electrical Engineering degree. His research interests include, agent based control of smart grids, electric vehicles and demand response in smart grids.

Muhammad Kashif Rafique

He received his B.Sc. and M.Sc. degree in Electrical Engineering from University of Engineering and Technology, Taxila, Pakistan in 2007 and 2011, respectively. At present, he is working on his Ph.D. course at Sungkyunkwan University, Suwon, Republic of Korea. His research interests are power system analysis and power system dynamics.

Soon-Jeong Lee

He received his B.S. degree in Department of Electrical and Electronics Engineering from Kangwon National University, Chuncheon, Republic of Korea in 2010 and M.S. degree in College of Information and Communication Engineering from Sungkyunkwan University, Suwon, Republic of Korea in 2012. At present, he is working on his Ph.D. thesis in Sungkyunkwan University. His research interests are power quality, electric vehicle, Vehicle-to-Grid system and electrical energy storage system.



Jun-Hyeok Kim

He received B.S and M.S degree in College of Information and Communication Engineering from Sungkyunkwan University, Suwon, Republic of Korea in 2012 and 2014, respectively. At present, he is working on his Ph.D. course in Sungkyunkwan University. His research interests include power system transients, protection and stability with electric vehicle and Vehicle-to-Grid system (V2G).

Khawaja Khalid Mehmood

He received B.S. degree in Electrical Engineering from Mirpur University of Science and Technology, Mirpur, Pakistan in 2012. He is currently working on his Ph.D. course in Sungkyunkwan University, Suwon, Republic of Korea. His research interests are distribution system planning, electric vehicle and electrical energy storage system.

Saad Ullah Khan

He received B.S. degree in Electrical Engineering from University of Engineering and Technology, Taxila, Pakistan in 2012. At present, he is working on his Ph.D. course in Sungkyunkwan University, Suwon, Republic of Korea. His research interests are power system transients, protection and electric vehicle.

Chul-Hwan Kim

He received the B.S., M.S., and Ph.D. degree in electrical engineering from Sungkyunkwan University, Suwon, Republic of Korea in 1982, 1984, and 1990, respectively. In 1990, he joined Cheju National University, Cheju, Republic of Korea, as a Full-Time Lecturer. He was a Visiting Academic at the University of Bath, Bath, U.K., in 1996, 1998, and 1999, respectively. He has been a Professor in the College of Information and Communication Engineering, Sungkyunkwan University, since 1992. Currently, he is a Director with the Center for Power IT (CPIT) at Sungkyunkwan University. His research interests include power system protection, artificial-intelligence applications for protection and control, modeling/protection of underground cable, and Electromagnetic Transients Program software.