ISSN 1975-8359(Print) / ISSN 2287-4364(Online)
The Transactions of the Korean Institute of Electrical Engineers Vol. 66, No. 2, pp. 347～353, 2017
http://doi.org/10.5370/KIEE.2017.66.2.347

한국의 스마트 그리드를 위한 신재생에너지원 생산과 활용률 간의 상관관계 분석

Correlation Analysis between the Renewable Energy Source Generation and the Utilization for Smart Grid in Korea

현 정 석* · 박 찬 정† · 이 정 훈** · 박 경 린**
(Jung Suk Hyun · Chan Jung Park · Junghoon Lee · Kyung Leen Park)

Abstract – In order to prohibit global warming, various kinds of regulatory policies have been established in the whole world. One example is the establishment of the Renewable Portfolio Standard. It requires the increased portion in energy production from renewable energy sources. The Republic of Korea adopted the act on the promotion of the development, use, and diffusion of new and renewable energy since 2012. However, in spite of the effort on the consideration of the renewable energy sources, it was reported the carbon intensity of electricity in Korea was not that low in 2015. Thus, it is required to examine the recent state of the utilization degree of the renewable energy sources in Korea. This paper analyzed the statistical data provided by Korea Power Exchange (KPX) to examine any problems and solutions for generating electricity from the renewable energy sources. We focused on the generation capacity provided by the power plants participated in the market, the electric power trading amount, and the utilization coefficient for 10 years. By analyzing the data, we provide an alternative to solve some imbalance among the factors contributing to renewable energy use.

Key Words : Electricity trade, Electric vehicle, Renewable energy source, Smart grid, Utilization coefficient

1. Introduction

Global warming, one of the main cause for climate change, gives us many research questions [1]. For protecting the global warming, it is necessary to change the use of electric power from the traditional energy power. As a result, electric power systems have become very important and had various industrial applications recently [2][3].

However, when we consider the electric power, another problem occurs. The problem is how we can get the electric power for replacing the traditional energy sources such as gas. One possible answer is the use of renewable energy source [4][5]. Recently, in many countries, for the diffusion of renewable energy sources, the Renewable Portfolio Standard was established [6]. It requires the increased portion in energy production from renewable energy sources. Thus, many research works related to develop methods for renewable energy sources [7] have been published.

The Republic of Korea also adopted the act on the promotion of the development, use, and diffusion of new and renewable energy since 2012 [8]. However, Korea has limitations on solar power and wind power generation due to environmental reasons. In addition, Korea manages the independent power system of renewable energy sources [8]. Thus, we provide against the changeable characteristics of the renewable energy sources.

On the other hand, an article reported that Korea emits approximately 500 tons of carbon to generate 1GWh [9]. It is not a low carbon intensity of electricity. Another article pointed out the problem of establishing a large-scale bituminous coal-fired plant in a Province in Korea, which is the leading province in renewable energy business [10]. In a research work proposed by Kennedy [11], a new measure was proposed, which plays an important role to make a decision when to move from fossil fuel to electric power. According to the research, a region needs to produce its electricity at a rate below 600 tons of carbon dioxide emission to generate 1 gigawatt hour (GWh). Thus, for a region meets the 600-ton threshold, running electric vehicles emits less carbon dioxide

† Corresponding Author : Dept. of Computer Education, Jeju National University, Korea.
E-mail: cjpark@jejunu.ac.kr
* Dept. of Management Information Systems. Jeju National University, Korea. (jshyun@jejunu.ac.kr)
** Dept. of Computer Science and Statistics. Jeju National University, Korea. ({jhlee,glpark}@jejunu.ac.kr)
Received : January 18, 2017; Accepted : January 30, 2017

than running fossil fuel vehicles [11]. The number, 600, does not work everywhere, but it is meaningful for us to think about the utilization ratios of energy sources such as coal, oil, water, and wind to generate electricity [9].

In this paper, we examined the generation capacity of renewable energy sources, the bidding amount of the renewable energy sources, and the utilization coefficients. We used the data provided by the Korea Power Exchange (KPS) [12], which operates Korea' electricity market and provides statistical data about electric power [13]. We examined the state of electricity generation from renewable energy sources. We focused on the generation capacity of the power plants participated in the market, the electric power trading amount, and the utilization coefficient from March, 2015 to February, 2016. In this paper, the utilization coefficient use the amount of bidding instead of the amount of generation. And, it means the ratio of real generated energy by bidding to the maximum generated energy [13]. By showing the annual changing amounts in electric power trade and the utilization coefficients, we can provide a way to use our renewable energy source more efficiently in the near future.

2. Correlation Analysis among Renewable Energy Sources

This section describes how to prepare each part of the final manuscript more specifically. Your manuscript should be typed double-spaced in two-column format on one side of a sheet only, with margins of about 1.5 cm on left and

The electric power statistics information system (EPSIS) has provided various kinds of monthly data about electric power information for 17 provinces since 2001. Among the 17 provinces, Sejong-si was newly included a few years ago. Thus, this paper excluded the Sejong-si data for our analyses. There are 11 types of renewable energy sources such as solar, bio, wind, hydro, small hydro, fuel cell, and so on.

In this section, we analyzed the correlation among the 11 renewable energy sources in terms of the generation capacity of renewable energy sources because a few research works suggested a merging method that controls two or more renewable sources together at the same time. When we figure out the relationships among the renewable energy sources, we can develop a new method to generate two or more sources at the same time. Table 1 shows the correlation coefficients (*Co.*) and their significances (*P*).

According to Table 1, most of renewable energy sources have positive correlation with other sources. For example, hydro source has positive relations with wind, small hydro, fuel cell, and ocean sources. Also, solar source has positive relations with bio (gas), bio (others), wind, small hydro, fuel cell, and solid wastes. For several cases, there exist negative relations with each other. When we consider the correlations among resources, more efficient management about resources will be achieved in the near future.

In other words, it is important for us to expect the constant amount of power generation for the renewable energy sources. To achieve this goal, many researchers have developed hybrid methods that merge several renewable energy sources together at the same time [14][15]. If we know the correlation among renewable energy sources, we can succeed in managing the renewable energy sources in a hybrid way. For example, two or more energy sources can be combined in a hybrid system such as wind or small hydro turbines [15][16].

Table 1 The correlation analysis among renewable energy sources

		A	B	C	D	E	F	G	H	I	J
B	*Co.*	.13**	1	-.02	.61**	.05*	.02	.18**	.03	.01	.03
	P	.00		.39	.00	.02	.34	.00	.18	.63	.19
C	*Co.*	-.02	-.02	1	-.03	-.05*	-.17**	-.01	-.01	-.07**	.01
	P	.31	.39		.19	.04	.00	.83	.58	.003	.73
D	*Co.*	.16**	.61**	-.03	1	.02	.02	.24**	.11**	.11**	.05*
	P	.00	.00	.19		.36	.50	.00	.00	.00	.02
E	*Co.*	.29**	.05*	-.05*	.02	1	.42**	.28**	-.04	-.07**	.19**
	P	.00	.02	.04	.36		.00	.00	.10	.003	.00
F	*Co.*	-.04	.02	-.17**	.02	.42**	1	.24**	.08**	.17**	-.07**
	P	.07	.34	.00	.50	.00		.00	.001	.00	.00
G	*Co.*	.53**	.18**	-.01	.24**	.28**	.24**	1	.24**	.16**	.47**
	P	.00	.00	.83	.00	.00	.00		.00	.00	.00
H	*Co.*	.19**	.03	-.01	.11**	-.04	.08**	.24**	1	.78**	.06*
	P	.00	.18	.58	.00	.10	.001	.00		.00	.01
I	*Co.*	.003	.01	-.07**	.11**	-.07**	.18**	.16**	.78**	1	-.07**
	P	.88	.63	.00	.00	.00	.00	.00	.00		.00
J	*Co.*	.73**	.03	.01	.05*	.19**	-.07**	.47**	.06*	-.07**	1
	P	.00	.19	.73	.02	.00	.00	.00	.01	.00	
K	*Co.*	.06**	.03	-.08**	.09**	-.11**	.31**	.20**	.56**	.55**	-.14**
	P	.01	.16	.00	.00	.00	.00	.00	.00	.00	.00

A. Utilization coefficient of solar energy
B. Utilization coefficient of bio (gas)
C. Utilization coefficient of bio (LFG)
D. Utilization coefficient aof bio (others)
E. Utilization coefficient of wind
F. Utilization coefficient of hydro
G. Utilization coefficient of small hydro
H. Utilization coefficient of fuel cell
I. Utilization coefficient of ocean
K. Utilization coefficient of solid waste (saprophagous)
Co. = *Pearson coefficient*, $* : \alpha < .05$, $** \; \alpha < .01$

3. Analysis of Annual Changes of the Renewable Energy Sources

This section describes the annual changes in the total amount of the generation capacity of the power plants participated in the market, the electric power trade, and the coefficient of utilization for the 16 provinces for 10 years. Table 2 shows the grand means and the standard deviations for the total amount of the generation capacity of the power plants participated in the market, the electric power trade, and the coefficient of utilization.

According to Table 2, we found that trading amount of electric power continuously has increased for 10 years. On the other hand, the coefficient of utilization has increased until 2011, but the curve has maintained the similar utilization coefficients after 2011. One more thing is the standard deviations for the mean of the total utilization coefficients shrank gradually as time went on. In fact, due to the weather conditions, the monthly amounts of renewable energy sources were quite different. It is natural that the standard deviations of the means of the total generation capacities are quite big as shown in Table 2. However, in the utilization coefficients, the small standard deviation means the monthly utilization coefficients are similar to each other. Thus, there exists a gap in pattern between generation capacity and the utilization.

Table 2 The grand mean of the total bidding amount, the generating capacity and the utilization coefficient for renewable energy sources

Duration	Year	The mean of the total bidding amount (MWh)		The mean of the total generation capacity (MW)		The mean of the total utilization coefficient (%)	
		M	SD	M	SD	M	SD
2006.3-2007.2	2006	351,195	222,233	4,240	355	11.14	6.66
2007.3-2008.2	2007	436,534	153,801	4,566	28	13.06	4.60
2008.3-2009.2	2008	395,128	112,862	4,821	136	11.24	3.20
2009.3-2010.2	2009	452,811	135,006	5,127	139	12.10	3.60
2010.3-2011.2	2010	760,404	143,017	5,598	230	18.58	3.19
2011.3-2012.2	2011	1,024,658	249,289	6,150	114	22.74	5.37
2012.3-2013.2	2012	1,042,998	78,591	6,422	80	22.27	1.78
2013.3-2014.2	2013	1,192,052	118,131	7,231	407	22.60	1.95
2014.3-2015.2	2014	1,408,520	62,706	8,040	166	24.00	.72
2015.3-2016.2	2015	1,472,332	53,802	8,833	220	22.79	.89

We examined if the coefficients of utilization for renewable energy sources statistically decreased annually. In order to prove it, we performed a regression analysis with the coefficients and years. As a result, the coefficients drew a parabolic curve between year and the coefficients as shown in Table 3 (F=51.60, p<0.001, df=2, R^2=.05). It means that the utilization coefficients were increasing at some point, but decreasing after that point. And, it is statistically meaningful.

Table 3 The regression analysis of the utilization coefficients with years

Model	Unstandardized Coefficients		Standardized Coefficients	t	*Sig.*
	B	Std. Error	Beta		
(Constant)	9.16	1.70		5.37	<.001
X	5.80	.71	.79	8.14	<.001
X^2	-.42	.06	-.63	-6.58	<.001
(X: year)					

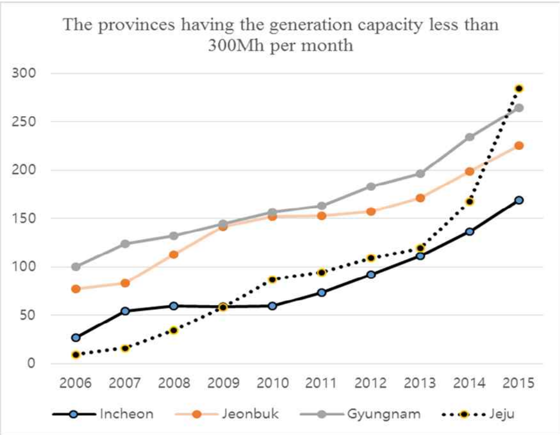
4. Regression Analysis

This section describes the annual changes in the total amount of the generation capacity and in the mean of the utilization coefficient. We divided 16 provinces into 3 groups according to the generation capacity as shown in Fig. 1, Fig. 2, and Fig. 3.

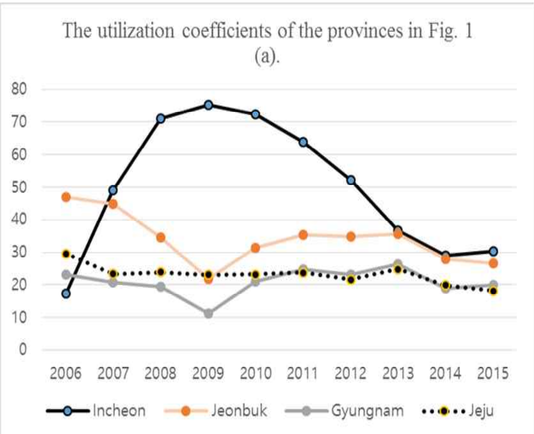
In fact, the metros such as Seoul, Daegu, Gwhangju, Daejoen, and Ulsan had low generation capacities. Thus, we exclude these 5 metros in this region analysis. We figured out the relationship between the generation capacity and the utilization coefficient by comparing their values. The figures in the following described the annual changes of the provinces having the generation capacity less than 300Mh, less than 1100Mh, and greater than 1100Mh respectively in terms of the generation capacity and the utilization coefficient.

In the Fig. 1 (a), the generation capacities for all the cities have increased. Among the cities, Jeju had the noticeable increase in the generation capacity. In the Fig. 1 (b), 2009 had the biggest gap among the cities. The utilization coefficient patterns among the cities were quite different. However, all curves have fallen since 2013.

Gyunggi, Gangwon, Chungbuk, and Chungnam had the generation power less than 1100Mh. In Fig. 2 (a), Chungnam showed the remarkable increase in the generation capacity. However, even though Chungnam's utilization coefficient was the highest, the utilization coefficient of Chungnam have dropped since 2011. On the other hand, Chungbuk's generation capacity decreased in 2015. In Fig. 2 (b), the utilization coefficients are shown. The curve patterns are similar to those in Fig. 1 (b). The utilization coefficients have been reduced since 2011.



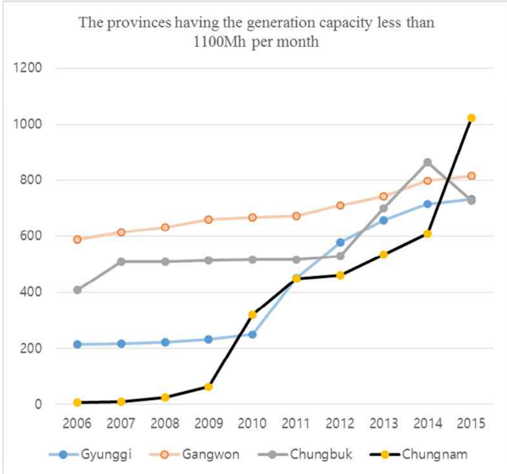
(a) The generation capacities



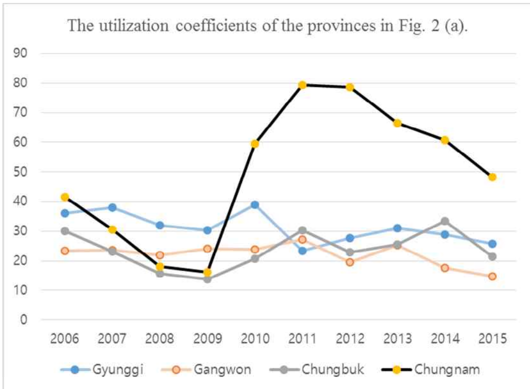
(b) The utilization coefficients

Fig. 1 Annual changes in 4 Provinces (Generation Capacity 〈 300Mh)

In Fig. 3 (a), Jeonnam and Gyungbuk had generation capacities greater than 1100Mh. Like other cities, the generation capacities of Jeonnam and Gyungbuk have increased for 10 years. However, for the utilization coefficient, the two cities had different patterns as shown in Fig. 3 (b). The utilization coefficient of Gyungbuk has increased even though the coefficient was less than 20. On the contrary, the utilization coefficient of Jeonnam reduced compared with the one in 2006. Compared with the cities which had lower generation capacities, the utilization coefficients of Jeonnam and Gyungbuk were low.



(a)The generation capacities



(b)The utilization coefficients

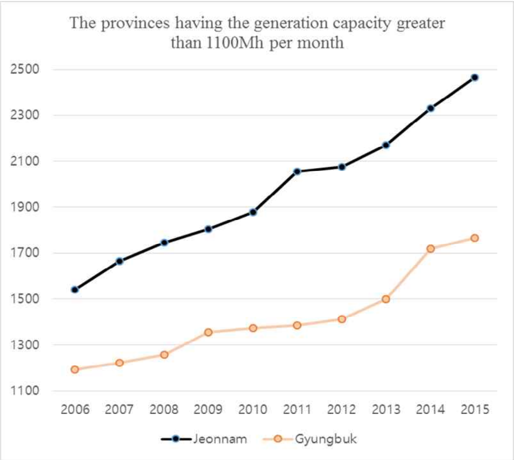
Fig. 2 Annual changes in 4 Provinces (Generation Capacity 〈 1100Mh)

One common phenomenon is that the generation capacity was increasing as time went on for all provinces. The changes in the utilization coefficients were different. Also, we can also find out another common phenomenon. Unlike the pattern found in the generation capacity, the provinces' utilization coefficients were generally decreasing except Gyungbuk.

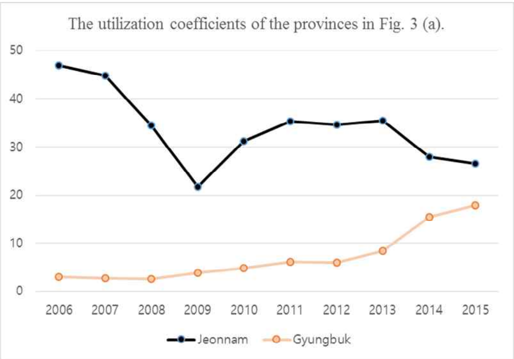
In particular, the provinces such as Incheon, Chungnam, and Jeonnam, whose slope about the generation capacity was steep, had a fallen shape of utilization coefficient curve. The curves seem that the utilization coefficients are decreasing as time goes on. In this paper, the utilization coefficient use the amount of bidding instead of the amount of generation. And, it means the ratio of real generated energy by bidding to the maximum generated energy [13]. In summary, the utilization and the capacity formed an imbalance on dealing the power.

We analyzed this result with the diffusion of innovations theory [17]. This theory tried to explain the relations between new ideas and widespread technology in society [18]. In the process of diffusion about new products and new ideas, the diffusion of demand occurs. The participants in a market have different characteristics and different preferences. For example, some people are early adopters, who adopt new products and new ideas earlier than others. Other people are late laggard, who purchase the products or adopt the ideas after most people adopted.

According to the theory, the characteristics of the market participants form a bell-shaped demand curve. In other words, since there exists a temporal gap between innovators and adopters, it forms a step function between time and the amount of demand. While the supply draws a linear increasing curve, the demand draws a step curve. As a result, the gap between demand and supply occurs due to the early period of the product life cycle. In an industrial market, it is important that manufacturing and marketing should be synchronized and coordinated.



(a)The generation capacities



(b) The utilization coefficients

Fig. 3 Annual changes in 2 Provinces (Generation Capacity > 1100Mh)

5. Conclusions

This paper examined if there is any phenomenon for generating electricity from renewable energy sources and utilizing them in Korea. We examined the generation capacity of renewable energy sources, the bidding amount of the renewable energy sources, and the utilization coefficients. We use the data provided by the Korea Power Exchange (KPS) [13]. We examined the state of electricity generation from renewable energy sources. We focused on the generation capacity of the power plants participated in the market, the electric power trading amount, and the utilization coefficient from March, 2015 to February, 2016.

From our research, the utilization coefficient for renewable energy has been decreasing since 2011, whereas the total amount of energy power trade has been increasing for 10 years.

Jeju-do established a plan to accomplish the 'Carbon Free Island Jeju by 2030 Plan' [19]. According to this plan, all running vehicles in Jeju-do will be 100% electric cars by 2030. However, it is not meaningful to generate electricity for EVs without utilizing renewable energy sources. We can find some reasons for low utilization coefficient of renewable energy sources. The one is due to the increased amount of electricity, the share of renewable energy seems to be reduced. Secondly, the trading market for renewable energy has not been active so far.

The research about the adoption of renewable energy sources is new and innovative at this moment. The diffusion of innovations theory suggested by Rogers [17] defined the innovations as the communication process among components of a society via a certain path across time [17]. Rogers divided users as 5 groups such as innovators, early adopters, early majority, late majority, and laggard by using means and standard deviations of a normal distribution [17].

Scientific and technological knowledge have brought innovations that made new products and new strategies by adding values to the traditional resources, technologies, knowledge, and processes [20]. Also, these innovations are regarded as the essence of the development by bringing the enhancement of the economic and social conditions and the environmental sustainability. In other words, many researchers recognized the innovations as an interaction between individuals who possess various kinds of knowledge and organizations in a political, economic, and institutional context

[20]. The diffusion process of innovations is not linear.

For protecting the global warming, it is necessary to change the use of electric power from the traditional energy power. Thus, many researchers and administrators have prepared many technologies and policies for smart grid. At the same time, renewable energy has been treated as important sources for successful smart grid era. However, from the analyses of this research, we found that the most of practical works have focused on the supply-oriented policies. In the near future, industrial marketing for demand management will be necessary for the renewable energy sources.

References

[1] K. S. Kim, Y. T. Yoo, and G. S. Jang, "The Necessity of Renewable Energy according to New Climate System Negotiation," Electric World, vol. 65, no. 1, pp. 10-16, 2016.

[2] S. K. Sul, "Guest Editorial on the Special Section on Control Issues on Electric Power System," International Journal of Control, Automation, and Systems, vol. 6, no. 4, pp. 467-467, 2008.

[3] A. Feliachi, "On the control of re-structured electric power systems," International Journal of Control Automation and Systems, vol. 3, no. 2, pp. 363-375, 2005.

[4] V. T. Minh and J. Pumwa, "Simulation and control of hybrid electric vehicles," International Journal of Control, Automation and Systems, vol. 10, No. 2, pp. 308-316, 2012.

[5] J. B. Cao and B. G. Cao, "Neural network sliding mode control based on on-line identification for electric vehicle with ultracapacitor-battery hybrid power," International Journal of Control, Automation and Systems, vol. 7, no. 3, pp. 409-418, 2009.

[6] https://en.wikipedia.org/wiki/Renewable_portfolio_standard

[7] Z. Q. Wu, Y. Yang, and C. H. Xu, "Adaptive fault diagnosis and active tolerant control for wind energy conversion system," International Journal of Control, Automation and Systems, vol. 13, no. 1, pp. 120-125, 2015.

[8] http://www.law.go.kr/lsInfoP.do?lsiSeq=136967&efYd=20130323#0000

[9] Youngin Ahn, "How Much Are Electric Vehicles Eco-friendly," http://news.sbs.co.kr/news/endPage.do?news_id=N1002867718, 2015.

[10] http://www.newsis.com/ar_detail/view.html?ar_id=NISX20151001_0010323482&cID=10805&pID=10800, 2015.

[11] C. Kennedy, "Key Threshold for Electricity Emissions," Nature Climate Change, vol. 5, pp. 179-181, 2015.

[12] http://www.kpx.or.kr/www/index.do

[13] http://epsis.kpx.or.kr/epsis/

[14] J. H. Park, "Roles and Prospects about the Hybrid System of Renewable Energy," Electricity Journal, vol. 471, pp. 66-70, 2016.

[15] M. Liserre, T. Sauter, and J. Y. Hung, "Future energy systems: Integrating renewable energy sources into the smart power grid through industrial electronics," IEEE Industrial Electronics Magazine, vol. 1, no. 4, pp. 18-37, 2010.

[16] http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE-WG_Technological_Solutions_-_Brochure_Hybrid_Systems.pdf

[17] E. M. Rogers, Diffusion of Innovations, Simon and Schuster, 2010.

[18] https://en.wikipedia.org/wiki/Diffusion_of_innovations

[19] http://www.iclei.org/pt/details/article/jeju-island-carbon-free-by-2030.html

[20] H. K. Kwak, "Change in Agricultural Department from the Innovation Point of View," Proceedings of 2010 Winter Conference of Korean Association for Public Administration, 2010.

저 자 소 개

현 정 석(Jung Suk Hyun)

Professor Hyun received Ph.D. at Sogang University, Korea. Since 2002, he has worked for the Dept. of MIS at Jeju National University. In 2011, he was a visiting scholar at University of California, Berkeley. His research interests include behavioral decision theory and creative problem solving. He received awards of the Korean Intellectual Property Office (2012), the Best Teacher Award (2011, 2016), the Award of Enhancing University Prestige of Jeju National University (2008), Best Professor Award of Achievement in Research of Jeju National University (2007).

박 찬 정(Chan Jung Park)

Professor Park received B.S. at Dept. of Computer Science of Sogang University, Korea. She received M.S. and Ph.D. at KAIST and Sogang University, respectively. From 1990 to 1994, and also from 1998 to 1999, she worked for Korea Telecom as a researcher. Since 1999, she has worked for the Dept. of Computer Education at Jeju National University. Currently, she is a professor in Jeju National University. In 2010, he was a visiting scholar at University of California, Berkeley. Her research interests include creative problem solving, web app development, and data mining.

이 정 훈(Junghoon Lee)

Professor Lee received B.S., M.S., and Ph.D. at Dept. computer engineering, Seoul National University, Rep. of Korea. From 1990 to 1992, and also in 1996, he was a senior research engineer at Lab. of optical telecommunication, Daewoo Telecom. In 1997, he joined the Dept. of computer science and statistics in Jeju National University. From 2003 to 2005 and 2009 again, he was a visiting scholar at Dept. of computer sciences, University of Texas at Austin. His research interests include cyber-physical systems and smart grids.

박 경 린(Gyung Leen Park)

Professor Park received B.S. in Dept. of computer science from Chung-Ang University. He received M.S. and Ph.D. from computer science and engineering department at the University of Texas at Arlington, respectively. His research interests include scheduling in parallel and distributed systems, mobile computing, and telematics. In 1997, he was a visiting assistant professor at the University of Texas at Arlington. In 1998, he joined the Dept. of computer science and statistics at Jeju National University, Korea, where he is a professor. Currently, he is the director of the Smart Grid Research Center, Jeju National University