Electricity Energy Savings Evaluation of Inverter DSM Program based on the Measurement and Estimation

Hoi-Cheol Kim, In-Soo Kim, Jong-Bae Park and Joong-Rin Shin

Abstract - The impact evaluation of a DSM program is a very important issue since the results are used to determine the sustainability of a program. In general, to estimate the impacts of a DSM program it is required to measure the electricity usage changes before and after a program. Since the measurement-based approaches cost highly, most of the conventional evaluations are based on the average figures. However, estimation of the average-based impacts can lead to both distorted results of over/under estimation of kW and kWh savings and non-optimal DSM planning. In this paper, we have developed a new multi-point measurement approach which can evaluate kW and kWh savings of a DSM program more exactly. To do this, the saving rate and operating rate are defined and set as the function of load factor of a customer, and these rates are incorporated with the conventional diffusion function of Bass to project the future impacts of a DSM program. The case study is performed on the inverter program of Korea by using the suggested approach.
Keywords - DSM, Impact Evaluation, Inverter Program, Measurement and Verification

1. Introduction

The electricity demand in Korea has rapidly increased along with a steady economic growth since 1970s while the construction of traditional generating units to meet the demand has been limited due to the difficulty of site acquisition, public acceptance, finance and environments, etc. Therefore, Korea has positively propelled demand side management (DSM) activities since 1980s to reduce investment costs of generating units and to save supply costs of electricity through the enhancement of whole national energy utilization efficiency.

However, most of DSM activities are concentrated on Load Management (LM) programs based on tariff systems. In order to overcome policies centered on LM and to promote DSM activities (especially, Energy Efficiency programs), the Government amended "National Energy Utilization Act" in 1995 that electric utilities should invest and execute Load Management as well as Energy Efficiency (EE) programs simultaneously based on the cost-effectiveness. According to the Act, a reasonable and systematic Measurement and Verification (M&V) method should be implemented which can verify the cost-effectiveness of a DSM program. This M&V method requires the construction of database based on metering, the standard methodology and calculation programs or tools and so on.

The conventional impact evaluation methods of a DSM program are based on the statistical and engineering methods. The statistical evaluation methods include the statistical comparison method (SCM), simple comparison method (SICM), conditional demand model (CDM) and statistical adjusted engineering (SAE). Benson Bronfman et. al. have applied a SCM to evaluate utility DSM programs [1], and Bruce Mast et. al. have applied a SAE method to estimate electricity savings from commercial lighting rebate program [2].

Engineering methods cover the engineering algorithm (EA) and engineering simulation (ES) [4]. M. W. Gustafson et. al. have applied an engineering method to evaluate the potential effectiveness of a direct air conditioner load control program [3].

The conventional evaluation approaches have some shortcomings as follows. Statistical evaluation method has difficulty in gathering all data required. Also, engineering evaluation method has a possibility of declining accuracy because of introducing average concept of measurement data.

In this paper, we propose a novel engineering monitoring methodology reflecting saving rate (SR) and operating rate (OR) by measuring multi-operating-points of a DSM program. The suggested method can be usefully used when evaluating the appropriateness of a DSM program and diagnosing the potential estimation and cost-effectiveness. In this paper we have performed the impact evaluation of an inverter program of Korea that has shown excellent energy savings effects by controlling the speed of the motor demand. Also, the potential savings of the inverter program can be estimated by using the suggested model combining the SR and the OR with the conventional diffusion model for future projections.

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Hoi-Cheol Kim and In-Soo Kim are with the Dept. of Demand Side Management, Korea Energy Management Coporation.
Jong-Bae Park and Joong-Rin Shin are with the Dept. of Electrical Engineering, Konkuk University.

2. Demand Side Management (DSM) in Korea

The DSM activities in Korea has its origin in the mid-1980'. Until the early 1970s, the main resources for accommodating electricity demand was fossil-fuel power plants. The capacity reserve margin reached up to 56% at that time so the initial introduced DSM program was off-peak tariff system. Since then, social criticisms stemmed from the consecutive oil shock and excess supply capacities were the cause of delaying the construction of power plants, which resulted in the power shortage situations. The capacity reserve margin recorded 7.8% in 1975, 3.9% in 1976, 9.2% in 1977, and 7.7% in 1978. These figures imply that the reserve margins is under normal conditions. To cut the peak demand, the tariff system of 'Time-of-Use (ToU)' was first introduced in the late 1970s.

Starting with the construction of nuclear power plant named 'GoRi-1', the large-scaled power plants began to participate in electricity supply to meet the increasing demand of electricity which also led to the over capacity periods. The capacity reserve margin reached up to about 61% in 1986. However, it was down to around 20% in 1989. And after 1980s, economic growth has given an effect on the pattern of consumptions and resulted in the changes of the season of peak demand into winter from summer.

Afterwards, the air-condition demand in summer has worked as an important factor of peak demand in Korea. There were several DSM programs to cut summer peak demand including tariff system for the period of summer vacation and maintenance. The following Table 1 shows the roles of each organization associated with DSM activities in Korea.

After 1990, as reserve margin remains under 10% load management programs for peak-cutting are introduced in Korea as follows. Voluntary program for electricity savings launched in 1995, load-shift rebate program such as ice-storage cooling system in 1991, high efficient lighting programs in 1993, high efficiency vending machine and inverter program in 1999.

Table 1 Roles of each organization associated with DSM

Organization	Role
Government (MOCIE*)	- Deciding and delivering the goal of DSM policy, basic direction and investment level - Investigation on the results and performance
Electric Power Corp. (KEPCO**)	- Development of DSM programs and operation of programs - Securing finances regarding DSM
Consumer (Including ESCO)	- Participating in DSM programs

**MOCIE: Ministry of Commerce, Industry & Energy*
***KEPCO: Korea Electric Power Corporation.*

According to the 5th long-term generation expansion plan (from 1999 thru 2015) announced by the Government, it will drive more powerful DSM policy, setting up the goal of cutting 5.42 million kW by load management and 2.01 million kW by efficiency improvement. The total sum is up to 7.43 million kW which accounts for 10% of the maximum power consumption in 2015 [5].

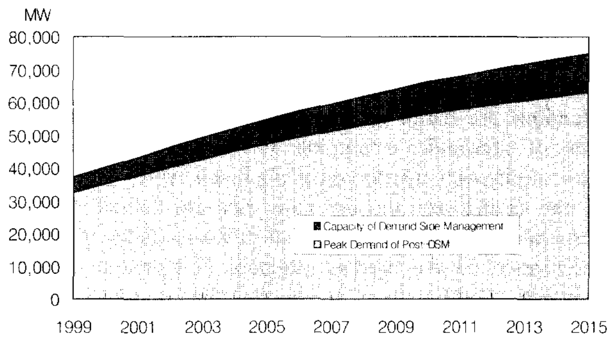

Fig. 1 Prospects of DSM in the future

3. Diffusion Model of High-Efficient End-User

To estimate the potential amount of a DSM program (in our case, inverter program), it is necessary to consider market characteristics of high-efficiency appliances which require the estimation of diffusion rate on each one. To do this, we have applied Bass' diffusion model for the estimation of diffusion rate in the market.

First, we have divided customers for a new product into several adoption types as Innovator (product purchase by external influence) and Imitator (product purchase by interior influence). The well-known diffusion model [6] is derived form the hazard function as expressed in eq. (1).

$$\frac{f(t)}{(1-F(t))} = p + qF(t) \tag{1}$$

Equation (1) states the conditional probability of adoption, and it is the basic premise underlying the diffusion process of any high-efficiency product.

$$mf(t) = n(t), \quad mF(t) = N(t) \tag{2}$$

$$n(t) = \frac{dN(t)}{dt} = p[m - n(t)] + \frac{q}{m}N(t)[m - N(t)] \tag{3}$$

Diffusion capacity in season [s, s+1] (in case study, we have considered only 1 season in a year) can be represented as the cumulative adoption function N(s) expressed in eq. (4), and the integral denotes the adoption probability in season s.

$$N(s) = m\int_{s}^{s+1} \frac{p(p+q)^2 e^{(p+q)t}}{(p+qe^{-(p+q)t})^2}\,dt \tag{4}$$

where,

m	: potential market size
p	: coefficient of innovation
q	: coefficient of imitation
$n(t)$	: market penetration amount at time t
$N(t)$	: cumulative market penetration amount until time t
$f(t)$	: adoption probability at time t
$F(t)$	: cumulative adoption probability until time t.

4. Diffusion Process of High Efficiency Appliances

To estimate diffusion capacity of a high efficiency appliance, we have set 3 categories by product adoption patterns, that is, New Adoption (NA), Substitute Adoption (SA), and Alternative Adoption (AA) [7-10].

The New Adoption (NA) capacity in s season is expressed as eq. (5), and (FC-RCs) term implies potential market size to be acceptable by customers. New adoption for a high efficiency appliance is diffused through diffusion model and diffusion of a high efficiency appliance supposes in state that is not before considering point s=0.

$$NA_s = (FC - RC_s)\int_s^{s+1} \frac{p(p+q)^2 e^{(p+q)t}}{(p+qe^{-(p+q)t})^2}\,dt \qquad (5)$$

When the life cycle (l) of existing appliances is ended up, the appliances are substituted with new high efficiency ones. These are expressed as the Substitute Adoption (SA) capacity as given in eq. (6).

$$SA_s = (\Delta RC_s + \frac{\Delta AC_s}{\eta})\int_s^{s-1} \frac{p(p+q)^2 e^{(p-q)t}}{(p+qe^{(p-q)t})^2}\,dt \qquad (6)$$

where,

$$\Delta RC_s = RC_{s-l} - RC_{(s-l)-l}$$

$$\Delta AC_s = AC_{s-l} - AC_{(s-l)-l}$$

$$\eta = \textit{efficiency enhancement rate}$$

Here, ΔRC_s implies possible and substitutable capacity in s season considering existing life cycle in eq. (7), and ΔAC_s means appliance capacity that is selected by high efficiency appliances already in s season. Therefore, $\Delta RC_s + \Delta AC_s/\eta$ term means all capacity of existing appliance that life cycle has expired in s season. Although the life cycle of existing appliances did not end, Alternative Adoption (AA) capacity selected to alter high efficiency appliances is expressed as the following eq. (7).

$$AA_s = \sum_{i=1}^{l-1}(\Delta RC_{s-i} + \frac{\Delta AC_{s-i}}{\eta})\int_s^{s-1} \frac{p(p+q)^2 e^{(p+q)t}}{(p+qe^{-(p+q)t})^2}\,dt \qquad (7)$$

where,

RC : the total capacity in peak load to be adoptable by high efficiency appliances,

AC : already adopted appliance capacity by high efficiency appliances.

The three results in a targeted period constitute the diffusion capacity for high efficiency appliances in s season and is expressed as the following eq. (8).

$$DC_s = NA_s + SA_s + AA_s \qquad (8)$$

5. Estimation of Saving Rate and Operating Rate in the Variable Load Factor

In the conventional approaches, the kW and kWh savings of a DSM program are evaluated based on average load factor and constant operating rate figures due to the measurement and cost constraints. However, that kind of approaches can lead to the distortion of the DSM impacts. Therefore, a more sophisticated approach is required to evaluate the impacts. In this research, we have introduced the Saving Rate (SR) and the Operating Rate (OR) as a function of load factor, and these are based on the multi-points measurements and the curves are generated using a regression analysis as given in eq. (9) and (10).

$$SR(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \qquad (9)$$

$$OR(x) = b_0 + b_1 x + b_2 x^2 + b_3 x^3 \qquad (10)$$

The restrictive operating zones such as the minimum and maximum load factors are considered for practical treatments of a DSM program. The operating time in each load factor cannot exceed Total Operating Time (TOT). The following 2 figures show examples of the regression

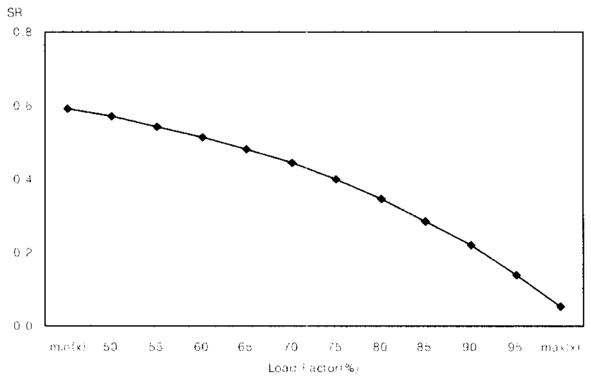

Fig. 2 Estimated graph for SR

curves for SR and OR. Therefore, Potential Capacity in Peak Load (PCPL) is determined by using eq. (11) and (12) when the load factor is x.

$$PCPL(x)_{RC}\,|_x = RC \cdot SR_x \cdot OR_x|_{x=const} \tag{11}$$

$$PCPL(x)_{AC}\,|_x = AC \cdot SR_x \cdot OR_x|_{x=const} \tag{12}$$

Potential energy savings can be easily calculated if we consider Total Operating Time (TOT).

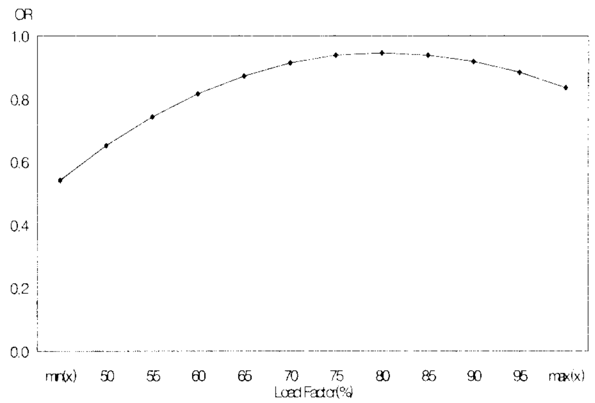

Fig. 3 Estimated graph for OR

6. DSM Monitoring Model

We propose a novel engineering monitoring methodology reflecting SR and OR based on the multi-operating-points of a DSM program. It is composed of the accurant power model that estimates potential capacity in peak load (kW base) and potential capacity in annual used (kWh base).

6.1 Estimation model of potential capacity in annual used

Estimation model for potential capacity in annual used is expressed as eq. (13) which estimates the potential capacity amount of electric energy annually consumed by an individuation appliance. It considers the change of load factor and uses methodology such as estimation model for potential capacity in peak load and other points analyzed by a year.

$$E_y = E_{RC,y} + E_{AC,y} + E_{IM,y} \tag{13}$$

Here $E_{RC,y}$ (the annual capacity to adoptable by high efficiency appliances) and RC_y (Reference Capacity) are expressed as the following eq. (14) and (15), respectively.

$$E_{RC,y} = \sum_{x=\min(x)}^{\max(x)} PCPL(x)_{RC,y} \cdot TOT \tag{14}$$

$$RC_{y+1} = RC_y - DC_y + NI \cdot RC_y \tag{15}$$

Also, $E_{AC,y}$ (the already adopted annual capacity by high efficiency appliances) and AC_y (adopted capacity) are expressed as given in eq. (16) and (17).

$$E_{AC,y} = \sum_{x=\min(x)}^{\max(x)} \eta \cdot PCPL(x)_{AC,y} \cdot TOT \tag{16}$$

$$AC_{y+1} = AC_y + \eta \cdot DC_y \tag{17}$$

where,

NI : natural increasing,
TOT : total operating time.

6.2 Estimation model of potential capacity in peak load

For the estimation model of potential capacity in peak load, we assume that the load composition by each end-user is given during the study horizon. Considering a DSM program that exchanging an old appliance, practically it does not fluctuate sharply in the load composition itself with seasonal conditions. In this paper, when system is on peak load in s season P_s (peak loads of DSM appliance) is represented as the sum of outputs from $P_{RC,s}$(peak load of load to fungible by high efficiency appliance considering variable load factor), $P_{AC,s}$(peak load of the adopted capacity of high efficient appliance) and $P_{IM,s}$(peak load of the impossible capacity for high efficiency appliance) as given in eq. (18).

$$P_s = P_{RC,s} + P_{AC,s} + P_{IM,s} \tag{18}$$

Also, $P_{RC,s}$ and RC_s are expressed as the following eq. (19) and (20).

$$P_{RC,s} = \sum_{x=\min(x)}^{\max(x)} PCPL(x)_{RC,s} \cdot CF_s \cdot DF_s \tag{19}$$

$$RC_{s+1} = RC_s - DC_s + NI \cdot RC_s \tag{20}$$

Also, $P_{AC,s}$ and AC_s (the already adopted capacity by high efficiency appliances) can be expressed as given in eq. (21) and (22).

$$P_{AC,s} = \sum_{x=\min(x)}^{\max(x)} \eta \cdot PCPL(x)_{AC,s} \cdot CF_s \cdot DF_s \tag{21}$$

$$AC_{s+1} = AC_s + \eta \cdot DC_s \tag{22}$$

where,

CF : coincident factor,
DF : diversity factor.

7. Case Study

We have performed simulations based on the inverter program applied to a paper manufacturing company in Korea. Table 2 shows the estimated coefficients of saving rate and operating rate based on measured data by the multi-points, and Table 3 shows the input data for DSM monitoring simulation.

Table 2 Estimated Parameters

	a_0, b_0	a_1, b_1	a_2, b_2	a_3, b_3
SR	0.8814	-0.1011	0.0147	-0.0012
OR	-0.0741	0.0682	-0.0061	9E-5

Table 3 Input data for DSM monitoring

RC0(MW)	RLF	CF
10,901	0.65	0.72
DF	FC(MW)	l(year)
1.08	29,956	15
TOT(hour)		NI(%)
8,160	0.03	[illegible]
p	q	
0.021	0.34	

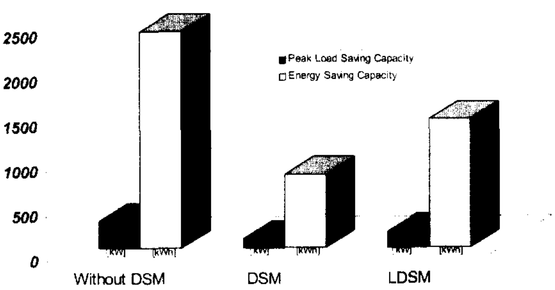

Fig. 4 Comparisons of Peak Load Demand(kW) & Annual energy consumption(MWh)

The following Fig. 4 shows the difference of the kW and kWh savings between the conventional approach (i.e., using the average load factor and constant operating time) and the suggested approach (i.e., using saving rate and operating rate by the function of load factors).

The first bars in Fig. 4 imply the peak demand and the total annual energy before inverters are installed. The second bars imply the peak and energy usage by the conventional approach (DSM in the figure), and the final bars by the suggested approach (LDSM in the figure). The differences between the conventional method and the suggested method has shown about 43% differences in kW and kWh savings. This implies that the conventional method estimated more positively.

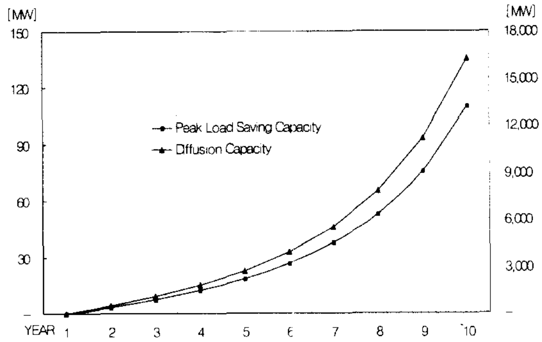

Fig. 5 Difference of Peak Load Saving Capacity and Diffusion Capacity

Next, we have applied the aforementioned diffusion model for the projection of the inverter DSM program in the future. Fig. 5 shows the diffusion capacity of the inverter program and the difference of peak load savings between the conventional method and the proposed method. The proposed method was compared with the conventional method in terms of the peak load as shown in Fig. 6.

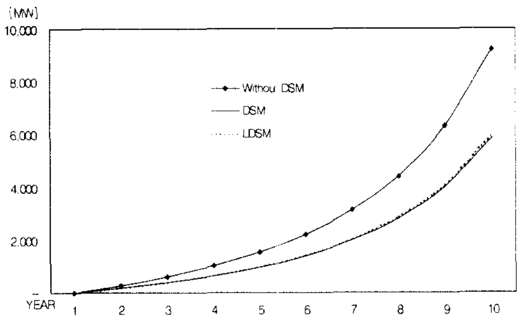

Fig. 6 Comparisons of Peak Load Saving Capacity(MW)

The proposed method was compared with the conventional method in terms of the energy usage as shown in Fig. 7.

The differences of peak load saving capacity show about 1.85% while the differences of the energy savings are about 34% between the conventional and the proposed method.

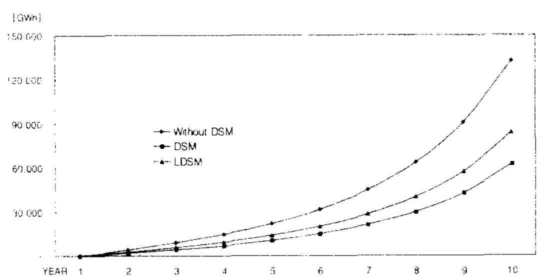

Fig. 7 Comparisons of annual energy consumption(GWh)

8. Conclusions

This paper proposes a new engineering monitoring methodology that incorporates the saving rate and operating rate by the function of the variable load factors. The kW and kWh savings by the suggested method have shown much difference compared with the conventional approach. In the case study of the Korean electricity system, the potential savings of the suggested method in the next 10 years is 1.85% less in terms of peak savings than the conventional approach and 34% less in terms of the energy.

Acknowledgement

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References

[1] Benson Bronfman, George Fitzpatrick, et al, *Handbook of Evaluation of Utility DSM Programs*, Oak Ridge National Laboratory, ORNL/CON-336, December 1991.

[2] Bruce Mast, Patrice Ignelzi, *Two-Level Regression Impact Analysis to Estimate Savings from 1993 Commercial Lighting Rebates*, Pacific Consulting Services, September 1995.

[3] M. W. Gustafson, J. S. Baylor, Gary Epstein, "Estimating Air Conditioning Load Control Effectiveness using an Engineering Model", *IEEE Transaction on Power Systems*, Vol.8, No.3, August 1993.

[4] Richard Ridege, Kirtida Parikh, Dan Viloette, *An Evaluation of Statistical and Engineering Models for Estimating Gross Energy Impacts*, Pacific Consulting Services, June 1994.

[5] *5th Long-term Generation Expansion Plan of Korea*, MOCIE Korea, 2000.

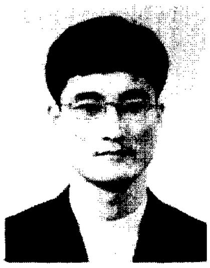
[6] V. Mahajan, Peterson, R. A., *Models for Innovation Diffusion* Sage Publications, Inc, 1985.

[7] Kim Jung-Hoon, Chang Seungchan, Hwang Sung-Wook, Kim Balho, Kim Chang-Seob, Development of Demand Side Management(DSM) Monitoring Methodology Considering the Diffusion Process of High Efficient End-Use appliances, *ICEE98 Proceeding*, Vol.1, pp.115-118, July 1998.

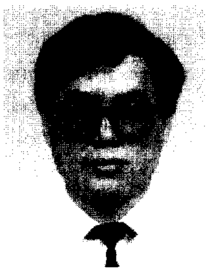
[8] *A Study on the Measurement and Evaluation(M&V) and Cost Effect Analysis of Demand Side Management(DSM)*, KEMCO Korea, 2000.

[9] *Developing Methodology of DSM Potential Estimation and Monitoring*, MOCIE Korea, 1998.

[10] *A Survey on the Electric Motor*, KEPCO Korea, 1994.



Hoi-Cheol Kim received the B.S., and M.S., from KonKuk University in 1993, 1995 respectively and all in electrical engineering. Currently, he work in the department of DSM (Demand Side Management), KEMCO (Korea Energy Management Co.) and is enrolled in a doctoral course in KonKuk University for electrical engineering



In-Soo Kim received the B.S., and M.S., from Inha University in 1983 and Yonsei University 1986, respectively in electrical engineering. Currently, he is a manager at department of DSM(Demand Side Management), KEMCO(Korea Energy Management Co.).

Jong-Bae Park received B.S., M.S., and Ph.D. degrees from Seoul National University in 1987, 1989, and 1998, respectively. For 1989-1998, he was with KEPCO, and for 1998-2001 he was an Assistant Professor at Anyang University. Currently, he is an Assistant Professor at Konkuk University.

Joong-Rin Shin received his B.S, M.S., and Ph.D. from Seoul National University in 1977, 1984, and 89, respectively in electrical engineering. His major research field in power system analysis, power system planning. Since 1990, he has been a faculty of Dept. of EE, Konkuk University. Currently, he is an Professor at Konkuk University.