수용가 냉방부하를 고려한 하절기 주상변압기 최대부하 추정

論 文
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Peak Load Estimation of Pole-Transformer in Summer Season Considering the Cooling Load of Customer

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Abstract - In this paper, we propose a method for estimating the peak load of pole-transformer in summer season considering the degree of cooling load possession in customer. The cooling load of customer is selected as the most reliable parameter of peak load in summer season. The proposed estimation method is restricted to the aspect of load management for pole-transformer. The main concept of proposed method is that the error of peak load estimation using load regression equation reduces with considering the degree of cooling load possession in customer. We propose an index for estimation of cooling load possession in each customer. The proposed index is defined as cooling load possession in customer (CLPC) and obtained from the increment of monthly electric energy. The membership function for deciding the uncertainty of cooling load possession in customer is used. The database of pole-transformer in Korea Electric Power Corporation (KEPCO) is used for case studies. Through the case studies, we verify that the proposed method reduces the error of peak load estimation than the conventional method in domestic.

Key Words : Load management, Cooling load, Peak load estimation, Monthly electric energy

1. Introduction

According to the social framework changes information and industrialization society, weather sensitive load and information processing equipment have been very rapidly increased. The customer power demand shows various patterns. Also, the load management of pole-transformer has become seriously because the failure of pole-transformer has been increasing by various load pattern. Above of all, cooling loads have largely effect on the failure of pole-transformer due to the pattern change of customers' power demand in summer season [1].

The main subject of the load management of pole-transformer(P. Tr.) in utilities can be divided into the peak load estimation and development of overload decision standard [2]. Through the peak load estimation for next summer season, utilities decide the capacities of pole-transformer and the time of replacement. And also, the overload decision standard is used for failure prevention of pole-transformer. Dallas Power & Light Co. estimates the peak load by K factor that is adjustment proportional factor according to electric energy of transformer. They are not considering the customer type. However, Cleveland Electric Illuminating Co. estimates the peak load of pole-transformer by classifying into residential and commercial, and application bounds. In Portland General Electronic Co., they manage the pole-transformer by each capacity. The over load limit is fixed the 175[%] of each transformer capacity. These methods have merits of showing direct and clear result for the specific topology and operation philosophies of each utility, because the pole-transformer is the equipment that reflects the pattern of customer in each utility. However, these methods are not considering the effect of cooling load for peak load estimation in summer season. Therefore, we need a enhanced estimation method considering the characteristics of customer and cooling load that is largely affected the load pattern of customer in summer season.

In this paper, we propose a method for reducing error which is computed at applying load regression equation (LRE) by analyzing the monthly electric energy and cooling load possession. The membership function for the settlement uncertainty degree of cooling load possession is used. For the input data of membership function, we use electric energy[kWh] that is increased from April to August. The increased monthly electric energy[kWh] is used to know information of degree of cooling load

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possession in customer (CLPC) and average of cooling load possession (ACLP). The field data of Korea Electric Power Corporation (KEPCO) is used for enhancing the accuracy and reliability of data. These data is constructed to database and divided as two types. One is acquired from load management equipment of pole-transformer in 1997~1999. The other is monthly electric energy of customer in 1996~1999. The former data are used to adjust load regression equation. From the latter one, we can obtain the information of the number of customers, monthly electric energy and degrees of cooling load possession. Through the result of case study, we verify that the proposed method can largely reduce the error in comparison to conventional method of peak load estimation in domestic.

2. Peak Load Estimation of Pole-Transformer in Domestic

2.1 Regression Analysis

Regression analysis provides the basis for estimating the values of a variable from the values of one or more other variables [3]. In regression analysis, the method of least mean squares (LMS) is most generally applied a curve-fitting technique. We assume that a quadratic regression equation may be written as (1). The a_0, a_1 and a_2 in (1) represent the coefficient of regression equation.

$$I_i = a_0 + a_1x_i + a_2x_i^2 + e_i \tag{1}$$

The basic concept of LMS method is shown in (2). The S_r in (2) represent the square sum of error between real and estimation value. The object of regression analysis is finding the coefficient a_0, a_1 and a_2 that minimizing S_r. We substitute Eq. (3) for Eq. (2) by partial derivatives with respect to a_0, a_1 and a_2 [2].

$$S_r = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (I_i - a_0 - a_1x_i - a_2x_i^2)^2 \tag{2}$$

$$\begin{aligned} \frac{\partial S_r}{\partial a_0} &= -2\sum (I_i - a_0 - a_1x_i - a_2x_i^2) = 0 \\ \frac{\partial S_r}{\partial a_1} &= -2\sum x_i\,(I_i - a_0 - a_1x_i - a_2x_i^2) = 0 \\ \frac{\partial S_r}{\partial a_2} &= -2\sum x_i^2\,(I_i - a_0 - a_1x_i - a_2x_i^2) = 0 \end{aligned} \tag{3}$$

The values of a_0, a_1 and a_2 can be determined from the general solution of Eq. (4).

$$\begin{aligned} \sum I_i &= a_0 n + a_1\sum x_i + a_2\sum x_i^m \\ \sum x_i I_i &= a_0\sum x_i + a_1\sum x_i^2 + a_2\sum x_i^3 \\ \sum x_i^2 I_i &= a_0\sum x_i^2 + a_1\sum x_i^3 + a_2\sum x_i^4 \end{aligned} \tag{4}$$

2.2 Peak Load Estimation of Pole-Transformer

The object of peak load estimation in domestic is the load forecasting of next summer season. The conventional method of peak load estimation in domestic is composed as four steps.

Step 1) We need the peak load ($\hat{I}_t$[A]) of pole-transformer at present, 12 months ago and 24 months ago, respectively. It is shown in (5). The peak load [A] is obtained from the regression function between the electric energy[kWh] and the peak load[A]. The simple regression model as Eq. (6) is used [1,2].

$$kW_t = V \times \hat{I}_t \times 10^{-3} \tag{5}$$

where,

t: t point of time (month)

kW_t: Load[kVA] of pole-transformer i at time t

$\hat{I}_t$: Peak current[A] of sample pole-transformer i at t

V: Second side voltage[V] of pole-transformer

$$\hat{I}_t = a_0 + a_1X_t \tag{6}$$

where,

$\hat{I}_t$: Estimation value of peak load[A] for sample pole-transformer at t point

a_0 , a_1: Regression coefficient

X_t: Monthly electric energy[kWh] of sample pole-transformer at t point

The regression coefficients a_0 and a_1 are decided using the data that obtained from the pole-transformer in field [4]. Table 1 shows the regression coefficients of pole-transformer in summer season, 1986 [2]. The regression coefficients were calculated by each area due to the difference of load characteristics.

Step 2) In this step, we calculate the average customer load[kW] of pole-transformer at present, 12 months ago and 24 months ago, respectively. It is shown in (7). We already know the kW_t(t= present, 12 and 24 months ago) at step 1.

$$kW_{c,t} = \frac{kW_t}{N_t} \tag{7}$$

where,

$kW_{c,t}$: Average customer load [kW] of pole-transformer at time t

N_t: Total number of customer at time t

Step 3) The result of step 2 is used for calculating the rate of load increase as (8). The R is the load increase rate and the subscript 4, 2, 0 are the present point of time, before 12 and 24 months from present point.

$$R = 1 + \frac{1}{3}\left(\frac{kW_{c,2}}{kW_{c,0}} - 1\right) + \frac{2}{3}\left(\frac{kW_{c,4}}{kW_{c,2}} - 1\right) \qquad (8)$$

Step 4) Finally, we estimate the peak load of next summer season in present as (9).

$$kW_6 = kW_4 \times R \qquad (9)$$

Through the above mentioned steps, we find the importance of peak load ($\hat{I}_t[A]$) using load regression equation in step 1. If the estimation has large error then the whole estimation procedures is wrongly. In this paper, we propose the peak load estimation method to reduce the error of peak load ($\hat{I}_t[A]$) estimation using load regression equation.

Table 1 Load regression coefficients of pole-transformer in summer season

Area	Electric Energy[kWh]	a	b
Commercial	under 2,000[kWh]	0.0680	0
	2,001~10,000[kWh]	0.0438	48.0
	over 10,000[kWh]	0.0197	287.0
Residential	under 1,000[kWh]	0.1010	0
	1,001~7,500[kWh]	0.0422	59.0
	over 7,500[kWh]	0.0166	260.0
Farming & Fishing	under 500[kWh]	0.1199	0
	over 500[kWh]	0.0339	43.0

3. Proposed Method of Peak Load Estimation

3.1 Database Construction and Data Analysis

The regression coefficients of Table 1 were estimated about 15 years ago, when the power demand was little. However, the power demand has been increased from 56,310[GWh] in 1986 to 193,470[GWh] in 1998. Also the cooling load had been increased from 267,012 in 1986 to 991,494 in 1998 [3]. Because of rapid increase of power demand and cooling load, the regression coefficients of Table 1 are necessary to be readjusted. For enhancing the reliability of load regression coefficients, the load data of Korea Electric Power Corporation (KEPCO) in 1997~1998 is used. We acquire the field load data using the load management equipment [4]. The load management equipment is installed the 264 pole-transformer of 11 branch offices of KEPCO. Fig. 1 illustrates the installation location of measurement device in Seoul.

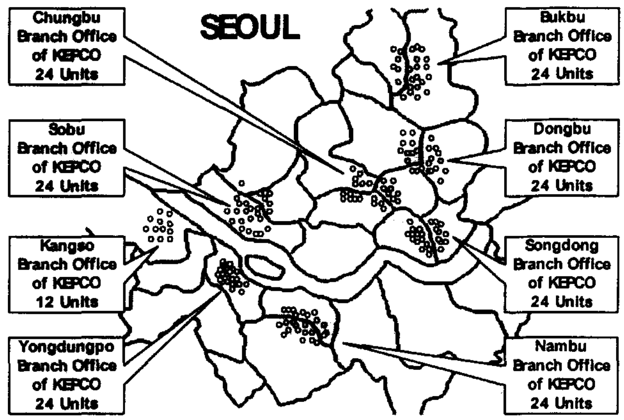


Fig. 1 Installation location of measurement device (Seoul)

The measured data that relate the status information data (for examples; current, voltage, power factor, electric energy and temperature) of sample P. Tr. and the customer information data (for examples; the monthly electric energy [kWh] of each customer, contact power of each customer and each customer kind) of sample P. Tr. are constructed the database system for P. Tr. load management. Fig. 2 simply illustrates the process of database construction. The data acquisition is carried out using notebook computer. We use the Oracle (for Windows NT) for database management system. The data is obtained from September 1997 to August 1998. Fig. 2. Procedures of DB construction for P. Tr. load management.

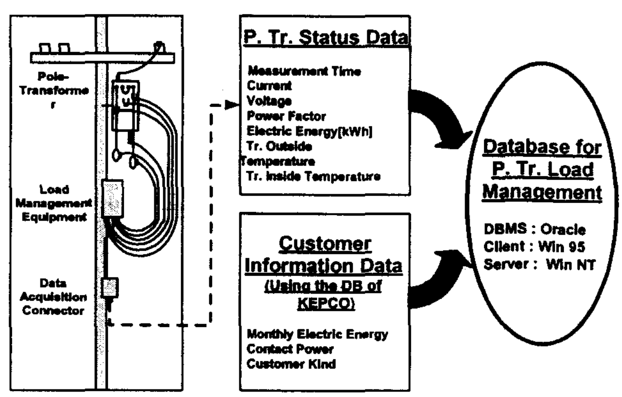


Fig. 2 Procedures of database construction for P. Tr. load management

3.2 Causes of Peak Load Variation

In domestic, the peak load estimation mostly depend on the linear load regression equation. Table 2 shows the fitness of each regression model between peak load[A] and electric energy[kWh] of residential pole-transformer in February 1998. We find that the quadratic load regression model is the fittest regression model [4].

Table 2 Fitness comparison of each regression model

Model / Coefficient	Linear	Logarithmic	Quadratic	Exponential
a_0	31.53	-2048.3	-47.134	8×10^{-5}
a_1	0.0213	250.86	0.0349	106.15
a_2	-	-	-5×10^{-7}	-
r^2(fitness)	92[%]	92[%]	94[%]	89[%]

We select the quadratic equation for regression model between monthly electric energy[kWh] and peak load[A]. The quadratic load regression model of pole-transformer is shown in (10). The readjusted load regression model is shown in Table 3.

$$LRE_j(X_i) = a_0 + a_1X_i + a_2X_i^2 \qquad (10)$$

where,

$LRE_j(X_i)$: Load regression equation for j area (j= residential, commercial, and so on)

X_i: Monthly electric energy[kWh] of sample pole-transformer i in j type area

a_0, a_1, a_2: Regression coefficient

Table 3 Readjusted load regression coefficient of P. Tr. in summer season

Area	Electric Energy[kWh]	a0	a1	a2
Commercial	under 10,000	159	-0.01	3×10-6
	10,001~20,000	-204.9	0.06	10-6
	over 20,000	577.6	0.01	3×10-7
Residential	under 10,000	140.4	-0.006	2×10-6
	10,001~20,000	751.8	-0.084	4×10-6
	over 20,000	-831.2	0.097	-2×10-6

Though we choose the quadratic load regression model, it has a large deviation in comparison to actual value. Fig. 3 shows the peak load deviation according to the each pole-transformer when we set peak load on the basis of quadratic load regression equation in summer.

According to the load pattern of pole-transformer, the random variable is calculated very different value. We analyze the reason that the similar electric energy[kWh] has difference peak load[A] value. Total load of each pole-transformer sums up the load of customers which are supplied power from pole-transformer. Therefore, it would be not difficult to estimate peak load if we could exactly know load pattern of customer. However, the load capacity and load pattern of each customer are very uncertainty and it is difficult for us to forecast increase and decrease load. The general causes that have an effect on load pattern of customer are economic, time, weather, irregular demand and etc. In this paper, we assume that the cooling load (air conditioner load) has largely effect on the change of customer's electric energy in summer.

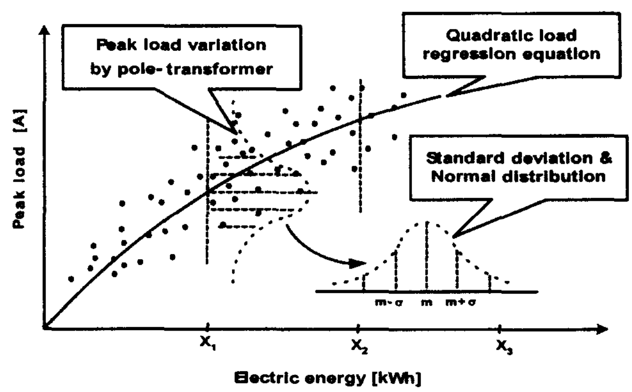


Fig. 3 Peak load[A] deviation when applied load regression equation

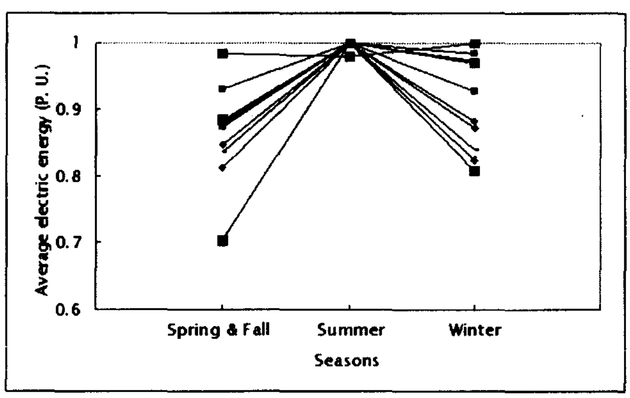
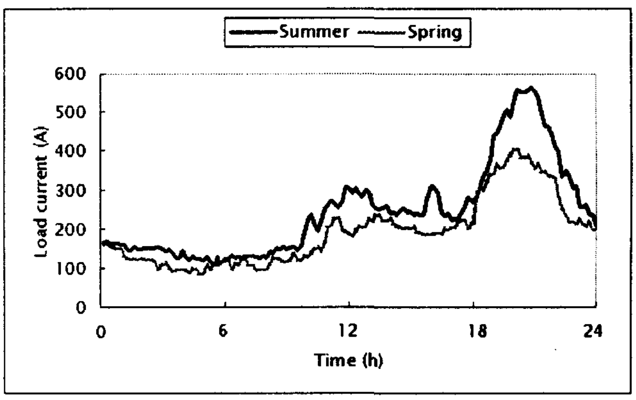


Fig. 4 Change of monthly electric energy of each customer for each seasons

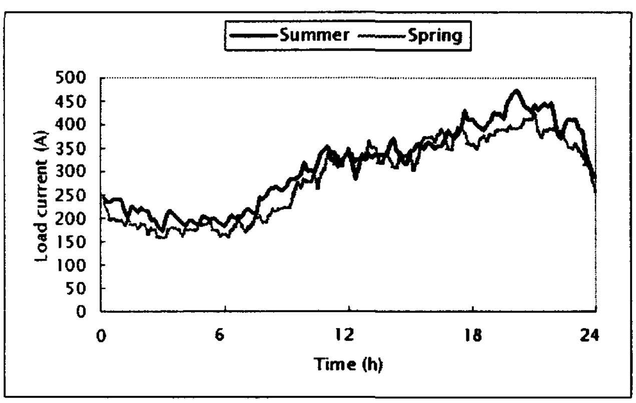
To Analyze customer's electric energy[kWh] which is supplied power from pole-transformer, we classify into two the load pattern. One is the pattern that is not changed monthly electric energy[kWh] of customer. The other is the pattern that is largely changed monthly electric energy[kWh] of customer in summer season. Fig.

4 shows the change of monthly electric energy for the residential area customer from January 1996 to December 1997. This figure shows a large difference in the change of each customer's electric energy.

Fig. 5 shows daily load pattern at residential area in spring and summer, 1998. We compare with daily load pattern of sample pole-transformer for same day and week in April and August, 1998. Fig. 5(a) shows that the peak load largely increase in summer than spring. However, the peak load of Fig. 5(b) shows similar in spring and summer season. We assume that the peak load[A] of pole-transformer in Fig. 5(a) increase by cooling load of customers because cooling load is simultaneous load [5-7] by temperature. Therefore, the estimation method of peak load in summer must considered the cooling load possession of customer.



(a) Large difference pattern of peak load



(b) Small difference pattern of peak load

Fig. 5 Comparition with daily load curve in spring and summer

3.3 Discriminating Cooling Load

In this paper, we estimate the degree of cooling load possession using the information of cooling load possession in customer (CLPC) and average of cooling load possession in pole-transformer (ACLP). For this estimation, the CLPC is formulated a membership function [8] for the settlement uncertainty degree of cooling load possession CLPC and compute the CLPC of each customer from established proper membership function for discriminating CLPC. For the input data of membership function, we used to electric energy [kWh] that is increased from April to August. The increased monthly electric energy[kWh] is used to know information of CLPC. The CLPC is defined as (11).

$$\mathrm{CLPC}(k) = \frac{(1-\nu)^2 (X_k - a)^3}{(1-\nu)^2 (X_k - a)^3 + \nu^2 (b - X_k)^3} \tag{11}$$

where,

X_k: Increased kWh of customer k from spring to summer

a : Lower limit value (=0)

b : Upper limit value

ν : Inflection point (=0.5)

Each pole-transformer is different capacity and the number of customer. For the same condition, we calculate average cooling load possession of each pole-transformer (ACLP). The ACLP of each pole-transformer defines as (12).

$$\mathrm{ACLP}(i) = \frac{\sum_{k=1}^{N_i} \mathrm{CLPC}(k)}{N_i} \tag{12}$$

where,

i : Sample pole-transformer

k : one customer of sample pole-transformer i

N_i : Total number of customer for sample P. Tr. i

3.4 Peak Load Estimation Equation

In this paper, we propose the peak load estimation equation as (13). The LRE, CLPC and ACLP in (13) are already explained in (10)~(12).

$$PL_j(i) = LRE_j(i) + f(ACLP(i)) \times S \tag{13}$$

where,

$PL_j(i)$: Peak load [A] of sample pole-transformer i for j type area

$LRE_j(i)$: Estimation value of sample pole-transformer i by LRE of j type area

$f(ACLP(i))$: Regression equation between ACLP and random variable

S: Sample standard deviation in bound

Fig. 6 describes the methodology for peak load estimation of each pole-transformer. At first, we construct the relational database tables, which are needed for performing the load data analysis. The next following we analyze the data necessary for LRE, CLPC, ACLP values. And finally, we calculate the peak load of each pole-transformer using peak load estimation equation.

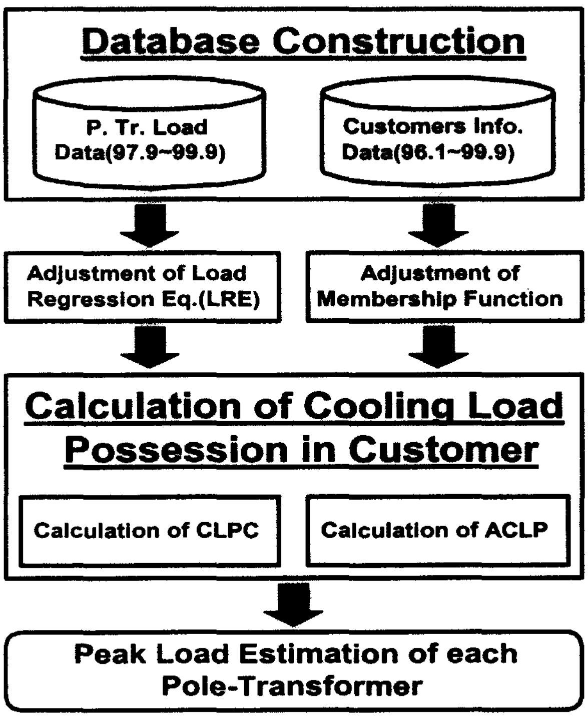


Fig. 6 Block diagram of methodology for peak load estimation

4. CASE STUDIES

For the case studies, the data of residential area is used. We use the 16 sample pole-transformer which are between 15000 and 25000[kWh] of monthly electric energy at residential area in summer, 1998. We compared with the peak load estimation method in domestic (conventional method) and peak load estimation method which is proposed in this paper. Also, we use the data which is monthly electric energy[kWh] of residential customers in 1996~1999. For determining the CLPC, we need determinating of criteria value to b in (11). For this reason, we must know average monthly electric energy of air conditioner.

We assume that the average using time of air conditioner is 4.93[hr] [9] and the average rated capacity of residential cooling load is 1.75[kW] [6]. From this assumption, the value of b is selected 280. We research the cooling load(air conditioners) in residential customer and compare with the sum of CLPC according to changing b. The number of surveying customer is 47 and the surveying date is March 2000. Table 4 shows the number of customer which possess cooling load and sum of CLPC. The result of Table 4 shows that the assumed b is properly.

Table 5 shows the calculation procedures of CLPC for a sample pole-transformer in residential area. The capacity of the sample pole-transformer is 100[kVA] and the total number of customer is 32.

Table 4 Research for discrimination cooling load (air conditioners)

State / Sample P. Tr.	Peak Load [A]	No. of customer	No. of customer that possess cooling load (surveying result)	Sum of CLPC (calculation result)
9721B8741 (75[kVA])	459	24	10	10.15
9721C8421 (50[kVA])	381	20	6	6.09

Table 5 Calculation of each customer CLPC for sample transformer

Customer No.	Normal kWh	Summer kWh	Increase kWh	CLPC
05381035080450000004	127	433	306	1.000
05381035080460000003	173	185	12	0.000
1138103512109566****	1032	1555	523	1.000
11381035121100000004	165	338	173	0.809
...	...	...	...	...
113810351221615****	780	1141	361	1.000
Sum (30 customer total)	11664	18224	6696	14.83

Fig. 7 shows the regressive correlation of ACLP and random variable in residential area. For this case, we select the logarithmic regression model, which is the fittest regression model between ACLP and random variable.

In order to compare the peak load estimation to the actual peak load, the observed error is calculated as (14).

$$\varepsilon = \left| \frac{I_j - \hat{I}_j}{I_j} \right| \times 100 \qquad (14)$$

where,

ε: Relatives error[%] for j^{th} sample P. Tr.

I_j: Actual peak load value j^{th} sample P. Tr.

$\hat{I}_j$: Estimation peak load value j^{th} sample P. Tr.

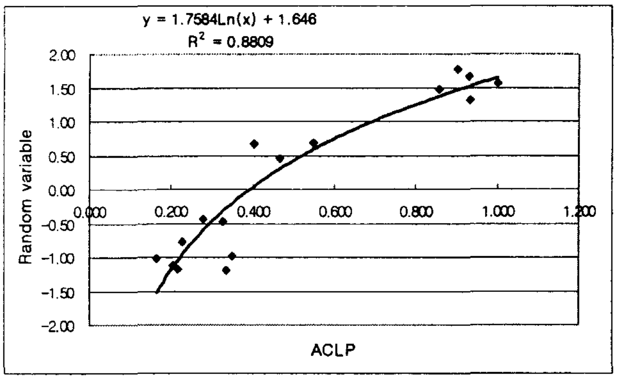


Fig. 7 Regressive correlation between ACLP and random variable

Table 6 shows the actual value, error and peak load estimation value by each method at residential area in summer. Through the case studies, we can verify that the supposed method is largely reduced the error ratio than conventional method in domestic.

Table 6 Comparison with peak load estimation by each method in summer (residential)

P. Tr. No.	kVA	Actual Peak Load [A]	Conventional method		Proposed method	
			Estimation value[A]	ε [%]	Estimation value[A]	ε [%]
1	100	493	542.80	10.10	441.10	10.53
2	75	534	674.64	26.34	596.79	11.76
3	75	332	537.77	61.98	330.10	0.57
4	75	459	630.69	37.40	555.16	20.95
5	75	399	541.55	35.73	378.28	5.19
6	50	381	530.95	39.36	390.06	2.38
7	75	515	646.78	25.59	488.41	5.16
8	75	442	607.80	37.51	383.53	13.23
9	50	351	547.81	56.07	337.32	3.90
10	100	563	526.81	6.43	550.81	2.17
11	100	469	524.80	11.90	466.04	0.63
12	75	662	615.01	7.10	665.82	0.58
13	100	576	614.40	6.67	564.63	1.97
14	100	666	628.03	5.70	697.54	4.74
15	100	711	646.01	9.14	732.86	3.08
16	100	722	648.36	10.20	723.87	0.26
			Sum	**24.20**	Sum	**5.44**

5. CONCLUSIONS

This paper propose a peak load estimation method for pole-transformer in summer season considering the cooling load of customer. For enhancing the load management of pole-transformer, we obtained the field load data using the load management equipment and constructed the database system for pole-transformer load management. We readjust the load regression equation using the database system. The quadratic model is selected for the readjusted load regression equation because it has fittest correlation between electric energy[kWh] and peak load[A]. For considering the cooling load possession in customer, we propose the index to forecast the cooling load possession of each customer using the increase rate of monthly electric energy. The membership function is used for the settlement uncertainty degree of cooling load possession. Through the case studies, we verify that the proposed method largely reduces the estimation error in comparison to the conventional estimation method of peak load in domestic.

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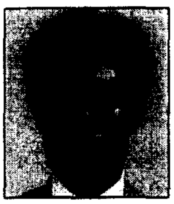

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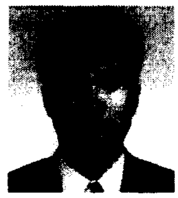

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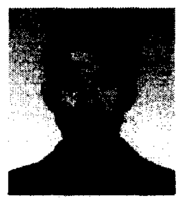

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