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A Study on the Effective Utilization Plan through Field Investigation and Analysis with Power Transformers in Domestic Areas

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Abstract

Korea is highly dependent on foreign countries for energy while at the same time having a high energy-consumption industrial structure. Therefore, logical improvements in energy use efficiency and nationwide energy saving are becoming more and more important in coping with the worldwidehigh oil prices and environmental issues such as listed in the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Consequently, a study was conducted on the average annual load factor in domestic areas to set a reasonable and reliable technology standard plan for high-efficiency transformers. The average annual load factor in Korea was discovered to be 18.4[%] classified by industry. This factor is expected to be used in arranging a domestic standard for a minimum efficiency system for transformers, and in reviewing and supplementing the standard transformers plan for the High Energy-Efficiency Appliance Certification.

The expected effect from the establishment of the technology standards plan for highly efficient transformers is the expansion of the manufacturing and distribution of highly efficient transformers that are suitable for domestic use. These will lead to electricity cost savings for users, strengthening the related industries'market competitive powers and the effective reduction of greenhouse gases on a national level by drastically reducing loss from transformers, which accounts for a large portion of the total electric supply losses.

Key Words : Power Transformer, Load factor, Effective utilization

1. Introduction

Korea has a high dependence on foreign countries for energy while also having a high energy-consumption industrial structure. Therefore, the logical improvements in energy use efficiency and nationwide energy saving are becoming more important to cope with high global oil prices and environmental issues such as listed in the Kyoto Protocol to the United Nations Framework Convention on Climate Change.

Therefore, since 2000, the Korean government has been enforcing High Energy-Efficiency

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Appliance Certification for transformers as one step to saving energy.

In spite of this operation and the ripple effect of the High Energy-Efficiency Appliance Certification, there has been controversy on whether the magnetic domain-controlled transformers that are not compatible with current high efficiency technology standards are equally efficient or more efficient than the compatible transformers under real operations, as claimed by some.

The research on the annual load factors of transformers must review objective and reasonable standard technology standards, since the transformers' annual load factors(or the annual usage rate) have risen as one of the critical factors in the controversy[2-3].

The efficiency of transformers is improving thanks in part to new material technology such as amorphous cores and magnetic domain miniature grates as well as to the improvement of computer performance. The size of the transformers is also decreasing. Thus, if the distribution of highly efficient transformers is expanded to the national level, the load loss and the no load loss will be effectively reduced compared with those of traditional transformers.

The objectives of this study are to propose a logical plan of use for transformers by investigating the utilization of transformers and to preliminarily examine the expected effect of electric power demand management. To achieve these objectives, the average annual load factor was found through a nationwide sampling of end users and through previous studies as well as by determining the actual domestic distribution of transformers, and studying the technology trends in transformers at home and abroad.

2. Research Subjects

The total number of the end user subjects that are receiving high voltage[1] was 140,381 at the end of December, 2005. Of these, the number of customers that received electric capacity under 1,000[kW], which permits them to have electricity safety management agents, was 120,986. The number of customers that received more than 1,000[kW], and thus had resident electricity safety managers, totaled 19,413.

ㅇ Classification of City Size(utilization of the Population Census by the National Statistical Office[6])

Large cities: Special Cities, Metropolitan Cities: population greater than one million

- Midsize cities: population lies between one half million and one million
- Small cities: cities under a half a million

In classifying end customers with less than 1000[kW] by industry, the primary and secondary industries had the largest number of customers accounting for 65,333(54.01[%]). Multi-story buildings and apartment houses accounted for 23,933 customers(19.78[%]), public and educational institutions accounted for 20,679 customers (17.09[%]), and, finally, the tertiary industries, the smallest group, accounted for 11,023 customers (9.11[%]).

In classifying end customers with more than 1000[kW] by industry, multi-story buildings and apartment houses had the highest percentage at 39.95[%](4,756 customers), 35.44[%](6,880 customers) was in the primary and the secondary industries, 15.59[%](3,026 customers) was in

1) Since the end customers that possess low voltage electric equipment receive electricity supplies from resident and commercial transformers, they do not own transformers on an individual basis.

public and educational institutions, and finally the lowest, 9.02[%](1,751 customers), was in the tertiary industries.

o Classification of Industries

In the classification of transformers by industry, Business Type 1(the primary and the secondary industries) had the most transformers at 734(43.23[%]), 418 transformers(24.62[%]) were in Business Type 4, and 247 transformers(14.55[%]) were in Business Type 2.

- Business Type 1: primary and the secondary industries(agriculture and fishery, metal-working/machinery/construction/food/electric /electronic industries)
- Business Type 2: tertiary industries(department stores, shopping centers, marketplaces, hotels, and large lodging houses)
- Business Type 3: multi-story buildings, apartment houses, building complexes, broadcasting and communications industries, insurance businesses, storage and warehousing businesses
- Business Type 4: public institutions, educational institutions, performance spaces, hospitals, universities, libraries, the military and gyms

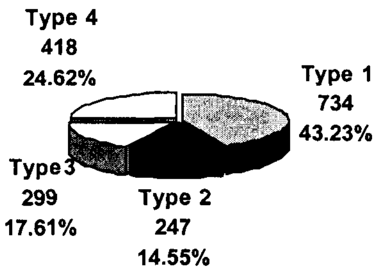

Fig. 1 Classification by industry

A detailed sample distribution of the end users throughout Korea is shown in Fig. 1.

Targeting this sampling frame, the random sample in Fig. 1 was sampled by stratified allocation to insure a certain level of reliability (95[%]±5[%] margin of error) and to attain samples that can represent the whole subject.

Table 1. Distribution of sampling

Classification	Under 500[kW]				Under 700[kW]			
Type	1	2	3	4	1	2	3	4
Number	123	26	28	38	113	22	37	39

Classification	Under 1000[kW]				Over 1000[kW]			
Type	1	2	3	4	1	2	3	4
Number	98	18	38	28	334	66	103	105

Classification	Over 3000[kW]				Over 5000[kW]			
Type	1	2	3	4	1	2	3	4
Number	18	18	20	20	10	9	9	10

3. Methods and Research Process On Actual Conditions

3.1 Theoretical Inquiries

3.1.1 Load Factor

A load factor (A) is the ratio between the average electric power and the maximum electric power over a certain period and differs profoundly from the ratio (B) [load capacity[kVA]/transformer capacity[kVA]] that is used to review the efficiency of transformers.

$$Load\ Factor = \frac{Average\ Electric\ Power}{Maximum\ Electric\ Power} \times 100(\%)$$

When the maximum electric power in the load factor (A) is regarded as a transformer capacity, which is a customer's maximum complex electric power, the formula can be written as below.

$$T.C \geq \frac{S.E.C \times \dfrac{Demand\ Factor}{Diversity\ Factor}}{100}$$

$T.C$: Transformer Capacity

$S.E.C$: Sum of Equipment Capacity

$$Load\ Factor(A) = \frac{Average\ Electric\ Power}{\dfrac{S.E.C \times \dfrac{Demand\ Factor}{100}}{Diversity\ Factor}}$$

$$= \frac{Average\ Electric\ Power \times Diversity\ Factor}{S.E.C \times \dfrac{Demand\ Factor}{100}}$$

From the formula above, it can be observed that the load factor is directly proportional to the diversity factor and is inversely proportional to the demand factor.

The load factor (B) used in this study is a ratio between the load factor supplied by a certain transformer and the capacity of the transformer equipment. It is also a coefficient that shows the level of the load a transformer is operating under compared to the equipment capacity.

This load factor is critical in deciding the efficiency of a transformer.

$$Load\ Factor(B) = \frac{Load\ Capacity}{T.C} \times 100(\%)$$

3.1.2 The Equivalent Load Factor of a Transformer

The electric power supplied by a transformer is not generally constant but changes continuously, rotating in a similar pattern every year by time/day and night/day/season. The load level differs a great deal between late night and the afternoon, weekdays and weekends, and the seasons.

A formula is thus needed that converts this fluctuating load factor of the transformer over a certain period into an equivalent load factor as shown below.

$$Pe = \frac{P_1^2T_1 + P_2^2T_2 \times P_{i1}^2T_i \cdots P_K^2T_K}{T_1 + T_2 \times T_i + \cdots T_k} = \sqrt{\frac{\sum_{j=1}^{k} P_j^2 T_j}{\sum_{j=1}^{k} T_j}}$$

P : Load Factor by Time

T : Supply Time of Same Electric Power

3.1.3 The Selection of the Demand Factor and the Capacity of the Transformer

In deciding the capacity of the transformer that provides customer equipment with electric power, it is usual to select a transformer which has a supply capacity within a certain level of the customer's equipmentcapacity and the reasons are as follows. Since each employment condition of customer equipment varies and not all customer equipment is used at the same time, it is not necessary to have a transformer that possesses the same level of capacity with that of the customer equipment.

Therefore, the selection of capacity when installing a transformer is usually decided as below based on the "compound maximum capacity"which is an assumed "maximum demand electric power".

$$T.C = \frac{\sum E.C(kW) \times Demand\ Factor}{Diversity\ Factor \times Power\ Factor}(kVA)$$

$E.C$: Equipment Capacity

Selecting the capacity of transformers is greatly affected by demand factors classified by business type, the characteristics of each demand load and the applied method of operation conditions. Consequently, these factors greatly affect the load factor employed in reviewing the efficiency of an operating transformer.

3.2 Methods and Research Processes on Actual Conditions

The electric power supplied by a transformer is not generally constant but changes continuously upon the passage of time such as days and nights or seasons. Thus, to determine the annual load factor of a transformer, the most accurate determination is made when measuring it over a period longer than a year.

Nevertheless, due to the problems of time, labor costs, the availability of manpower and equipment, and difficulty in mobilizing large amounts of equipment, it was, in practice, impossible for this study to measure the annual factor of each transformer a given customer owns for an entire year.

Therefore, a different approach was taken as below to deduce the annual load factor for each transformer of end customers through out the nation.

First, the subject customers used as the sample classified by business type were determined by 65 tech special teams from each Korean Electrical Safety Corporation station. The basic data of each transformer were collected by determining and drawing a single line diagram of the sample subject in field studies. The current electric power usage of each transformer was calculated simultaneously by using the CT and PT of the high-tension side or measuring the load electric power of the low-tension side.

After determining the annual electric power usage of the sample subject end customers, the annual electric power supplied by each transformer was inferred by dividing the annual electric power usage based on current electric power supply for each transformer. Lastly, the annual load factor for each transformer was determined on the basis of the inferred value above.

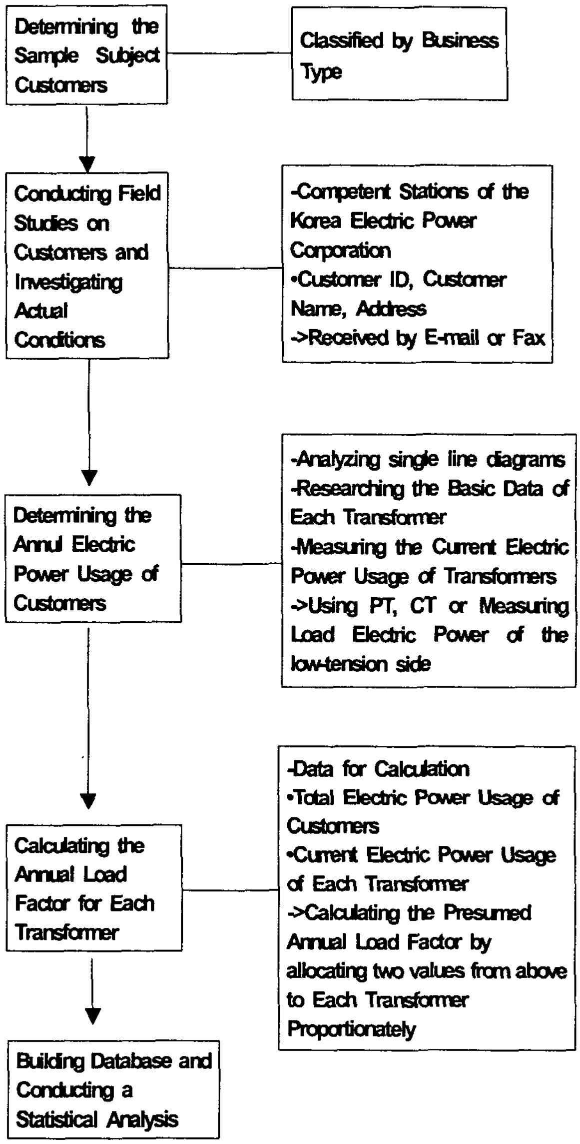

Fig. 2. Flow diagram for Investigation of Utilization of Power Transformers

4. Analysis of Results

As a result of the nationwide investigation on transformers, the subjects of investigation were 743 end customers and 1,698 transformers 2.28 transformers were allocated for each customer. The main analysis is as follows.

4.1 Analysis of the Investigated Samples

o Customers

According to the analysis of the 743 end customers investigated, Business Type 1(the primary and secondary businesses) had the highest percentage at 40.11[%](298 customers), while Business Type 2(the tertiary businesses) had the lowest percentage at 9.56[%](71 customers) among end customers with usage less than 1,000[kW].

o Transformers

According to the analysis of the 1,698 transformers investigated, Business Type 1 displayed the highest percentage at 43.23[%](734 transformers), with 24.62[%](418 transformers) for Business Type 4, 17.61[%](299 transformers) for Business Type 3 and the lowest at 14.55[%](247 transformers) for Business Type 2.

4.2 Annual Load Factor

o Total

The estimated value for the average annual load factor of the population transformers based on the entire sample is 18.4[%]. The confidence interval of the population's annual load factor is 95[%](17.8, 19.1).

o Annual Load Factor Classified by Business Type

When stratifying the samples by business type, the percentage of Business Type 1(the primary and secondary businesses) was the highest at 20.9[%]. It was 19.1[%] for Business Type 2(the tertiary businesses) while the lowest at 15.1[%] was for Business Type 4 such as public institutions. The difference in the load factors between Business Type 1 and Business Type 2 was 5.84[%].

In a comparison analysis of population transformers' average annual load factors based on business types, there was no statistically significant difference either between Business Type 1 and 2 or between Business Type 3 and 4. Yet, when a Business Type 1 and 2 group was compared with a Business Type 3 and 4 group, there was a significant difference between them. That is, there was a significant difference in annual factors between Business Type 1 and Business Type 3 and 4, and between Business Type 2 and Business Type 3 and 4.

Table 2. Annual Load factor for business types

Type	Annual Load Factor				
	Mean	Sample numbers	SD	SE	95[%] Confidence Interval
1	20.90	734	16.14	0.60	(19.73, 22.06)
2	19.05	247	12.42	0.79	(17.50, 20.60)
3	16.55	299	9.86	0.57	(15.44, 17.67)
4	15.06	418	12.34	0.60	(13.88, 16.24)
Total	18.43	1,698	13.98	0.34	(17.76, 19.09)

Note) SD: Standard Deviation, SE: Standard Error

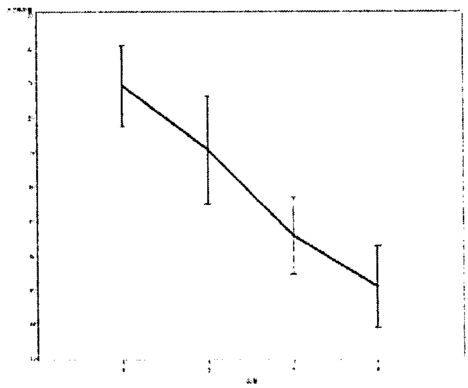

Fig. 3. Confidence Interval of Annual Load Factor of Business Types

5. Conclusion

As a result of this investigation, the estimated value of the Korean annual load factor was 18.4[%].

According to the analysis of the annual load factor based on business types, the annual load factor was the highest in Business Type 1(the primary and secondary businesses) with a percentage of 20.9[%]. It was 19.1[%] for Business Type 2(the tertiary businesses) and the lowest factor of 15.1[%] was found in Business Type 4 such as public and educational institutions.

5.1 Determination of Utilization Plan for Transformers

□ Optimum Transformer Design for Energy Savings

○ Deciding the Proper Transformer Capacity

Deciding the transformer capacity is most important from the perspective of economical efficiency and electric power savings. If transformer capacity is smaller than the load, it leads to an overload, which increases voltage drops. If an overloads continue, it shortens the transformer's lifespan by raising the temperature of the windings and depleting the insulating materials.

On the other hand, if transformer capacity is too large, it causes a huge loss of electric power because of the increased no load loss and load loss.

○ Effective Operation Methods for Transformers

To effectively operate transformers in consideration of saving energy, keeping no load loss small should be the priority. The second priority should be that the transformers operate under a capacity with the highest efficiency. As the transformer capacity grows, the loss increases since no load loss is consumed evenly regardless of load.

Thus, the methods below can be employed for the operation of multiple transformers:

- The merger and abolition operation of light load transformers by loss calculation
- Installing two transformers of large and small capacities and alternating the two upon the load conditions to minimize iron loss
- Stopping transformers at midnight and on holidays[8]

○ Selecting a High Efficiency Transformer

Transformers made of amorphous alloy or magnetic miniature graterinstead of traditional silicon steel plate have recently been developed commercially due to the development of transformer-related technology. Such transformers have smaller losses than those of traditional transformers and therefore can be selected for high efficiency.

□ Energy Savings through the Utilization of Transformers

Since 2000, theKorean government has been applying and enforcing the High Energy-Efficiency Appliance Certification for transformers.

The efficiency of transformers is improvingdue to new materials technology such as amorphous cores and magnetic miniature graters, as well as by the analysis and design technology development brought by computer performance improvement. The sizes of transformers are also decreasing. If the distribution of highly efficient transformers is expanded, more than 30[%] of the no load loss and load loss will be reduced compared to those of traditional transformers.

Currently, the Energy Efficiency Standards, the Energy-saving Labels, and the High Energy-Efficiency Appliance Certification are being enforced in Korea. For transformers, inflow transformers were selected as High Energy-Efficiency Appliances in September of 2000 as were mold transformers in December of 2001. These two kinds of transformers are being distributed for real-life use.

Since a constant expansion of highly efficient transformers benefits the whole nation, energy efficient systemsshould be enforced more firmly, such as establishing a more aggressive support system than the Prior Purchase System. Public institutions appear to abide by the system quite well due to obligatory regulations. However, to encourage the voluntary participation of the general public, effective management standards and systems that are agreeable to national circumstances should be constantly developed. Promotion should be also followed through on not only by the government, but by the Korea Energy Management Corporation and citizen committees as well.

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