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Energy Saving by Reducing No Load Loss of Distribution Transformers

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In Japan about 16 million units of distribution transformers are in service. These transformers are expending a huge amount of energy in the form of "no load loss" and "load loss." Among these losses, "no load loss" is major. "No load loss" can be saved dramatically by changing these transformers to "amorphous transformers" (i.e., amorphous metal-based transformers). This paper estimates the scope of the possible energy saving and reduction of CO2 emissions by the adoption of "amorphous transformers" in Japan and in China.
Keywords: Distribution transformers, no load loss, load loss, amorphous transformers, energy, CO2 emission

1. Introduction

Distribution transformers in Japan are classified into two major types: that is, pole-mounted transformers in the possession of the power companies, and industrial transformers in the possession of the owners of plants and buildings. A huge number of distribution transformers are now in operation, with the former type of transformers totaling about 12 million units and the latter type of transformers totaling about 4 million units. Two kinds of power loss are occurring at these transformers: that is, "no load loss" and "load loss." Although these losses are not significant in terms of wattage (W) per unit, they cause a tremendous amount of power loss on a macro scale because they happen continuously without cessation at all of the transformers over a long period of about 30 years. A greater part of these losses is represented by no load loss, and it is possible to reduce such no load loss dramatically through the adoption of amorphous transformers which use amorphous alloy as the core material of the transformers.

In this paper, I will explore the possibility of making such reduction in Japan and give an overview of the possibility of reducing such losses in China.

2. Power Loss of the Distribution Transformers in Japan and the Possibility of Reducing Such Loss

2.1 Pole-mounted Transformers

(1) Number of Units, Number of Years of Service and Capacity of the Pole-mounted Transformers in Service

As of the end of March, 2005, there are pole-mounted transformers with a total capacity of 290 million kVA in service in Japan. (Reference 1) p33)

The Yearbook of Machinery Statistics (Reference 2)) published by the Ministry of Economy, Trade and Industry contains a record of production (capacity and unit number) of pole-mounted transformers (standard transformers for power companies) for each year.

According to the record, the pole-mounted transformers with a total capacity of 290 million kVA are nearly equal to the aggregate amount of the total capacities of the pole-mounted transformers produced in 1973 to 2005.

From this, it can be inferred that the average use period of pole-mounted transformers is about 33 years.

Since the total number of units of the pole-mounted transformers produced during the 33-year period from 1973 to 2005 was on the level of 11.7 million units, it can be estimated that about 12 million units of transformers are in service in Japan at present and that the average capacity of the transformers is 24.7 kVA.

(2) Load rate of Pole-mounted Transformers

From Reference 1) (p63), it can be seen that the total usage of power distributed through these pole-mounted transformers and underground transformers to meet requirements for electric light power and low-voltage power in 2005 was 322 billion kWh.

If we divide this by the total amount of 316 million kVA for the capacities of the pole-mounted transformers and the underground transformers and by the total hour number of 8,760 hours in a year, we get the annual numerical average load rate of 11.7% for these transformers. Based on this value, I estimated that the annual numerical average load rate for the pole-mounted transformers is 14% after making an addition to take into account a conversion from a numerical average load rate to an average equivalent load rate and making a correction to take into account the power factor and V wire connection.

(3) Present Status of Power Loss of Pole-mounted Transformers

The power loss that is occurring at these pole-mounted transformers was estimated by the following method:

i. The number of units of transformers produced in each year of standards, total capacity of the transformers, and the average capacity of one unit were calculated to reflect the changes in the standards of transformers in the years of standards.
ii. The standard value of the loss of a theoretical pole-mounted transformer having the average capacity as mentioned in i. above was calculated proportionally from the standard value of an actually delivered transformer.
iii. The power loss was calculated for a transformer adopted in the year of standards corresponding to the standard value of the loss of a theoretical pole-mounted transformer as calculated in i. above from the number of units as calculated in i. above and the load rate mentioned in (2) above. Then, the power loss having occurred over the 33-year period was summed up.

The value of the power loss of the pole-mounted transformers as calculated by the above method was 10.2 billion KWh/year in all as shown in column a. of Table 1.

(4) Loss That Would Occur When all Transformers Are Replaced with the Existing General-Purpose Type

The loss that would occur when all the 12 million units of the pole-mounted transformers now in service are replaced with the existing general-purpose type of pole-mounted transformers was calculated proportionally in the same manner as described in (3) above.

As a result, the value of the power loss that would result in the case of replacement with the existing general-purpose type was estimated to be a total of 6.7 billion kWh/year as shown in column b. of Table 1.

(5) Loss That Would Occur When all Transformers Are Replaced with the Amorphous Transformers

It is the pole-mounted amorphous transformer ("AMDT") having a core made of amorphous alloy that shows the highest efficiency and involves the least power loss out of all the pole-mounted transformers now in service. (Refer to Fig. 1.)

AMDT began to come into widespread usage in the second half of the 1990s, and it is estimated that about 350,000 units of AMDT are in service in Japan.

The loss that would occur when all of the 12-million pole-mounted transformers now in service are replaced with AMDT was calculated by the same proportional method as described in (3) above. As a result, the power loss in this case was estimated to be a total of 2.3 billion kWh/year as shown in column c. of Table 1.

From the above calculations, it was found that if all of the pole-mounted transformers now in service are replaced with AMDT, it would be possible to reduce power loss by 7.9 billion kWh/year, but that if the replacement of the pole-mounted transformers now in service with the existing general-purpose type is continued, it would only be possible to reduce power loss by no more than 3.5 billion kWh/year. In other words, there would be a difference of 4.4 billion kWh/year after 30 years between the two cases.

Fig. 1

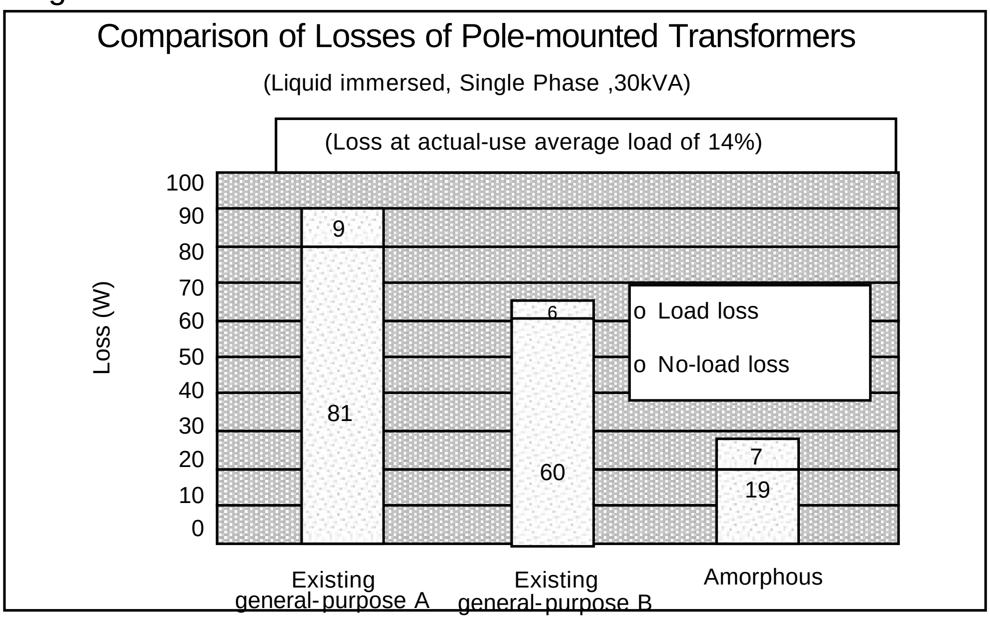

Table 1 Present Status of Power Loss of Pole-mounted Transformers and Possibility of Energy Saving
(Unite: billion kWh/year)

	No-load Loss	Load Loss	Total
a. Loss under present conditions	9.3	0.9	10.2
b. Replacement with existing general-purpose transformers	6.0	0.7	6.7
c. Replacement with amorphous transformers	1.7	0.6	2.3
d. Difference between a. and b.	3.3	0.2	3.5
e. Difference between a. and c.	7.6	0.3	7.9
f. Difference between b. and c.	4.3	0.1	4.4

(Number of units in service: 11.7 million units; average capacity: 24.7 kVA/unit)

2.2 Industrial Transformers

(1) Number of Years of Service of Industrial Transformers

There are no statistics based on an actual survey as to the number of units and capacity of the industrial transformers in service, and they have to be estimated from other data. In this case, it is necessary to estimate the average number of years of service of the industrial transformers first.

According to a survey of the Japan Electrical Manufacturers' Association in 1991, the average expected time of replacement of industrial transformers in use is 26.2 years for oil-immersed transformers and 25.7 years for cast resin transformers, both of which are shorter than the time (28 to 35 years) given by other similar surveys. (Reference 3) p39)

However, in the final summary (Reference 4)) prepared by the Transformer Judgment Standards Subcommittee of the Advisory Committee on Energy and Natural Resources in April, 2002 in relation to the application of the Top Runner Scheme under the Law concerning Rational Use of Energy to industrial transformers, the aforementioned time of 26 years was adopted.

Based on this, the average use period of industrial transformers is assumed in this paper to be 26 years.

(2) Number of Units and Capacity of Industrial Transformers in Service

Similarly as in the case of pole-mounted transformers, the number of the units and the capacity of the industrial transformers sold in the past 26 years were calculated on the basis of the Yearbook of Machinery Statistics (Reference 2)) published by the Ministry of Economy, Trade and Industry.

In this case, all units of the oil-immersed transformers with a capacity of less than 10,000 kVA were counted in the number. As to the dry-type transformers, all units of the cast resin transformers were counted and only one third of the other types of dry-type transformers were counted to take into account the fact that transformers other than transformers for distribution use are included in the dry-type transformers.

As a consequence, it is estimated that about 4 million units of industrial transformers are now in use in Japan and the total capacity of them is 680 million kVA (2.3 times that of the pole-mounted transformers).

(3) Load Rate of Industrial Transformers

There are only a few general and comprehensive surveys conducted as to the load rate of industrial transformers. The only survey is a survey of power consumers in 290 locations carried out by the aforementioned Transformer Judgment Standards Subcommittee, and a report of the results of the survey has been given (Reference 4) PIV-57). According to the report, the average annual equivalent load rate is 33.6%.

Accordingly, the load loss of the industrial transformers was calculated by adopting this value of 33.6% for the purpose of this paper.

(4) Present Status of Power Loss of Industrial Transformers

The power loss that is now occurring at about 4 million industrial transformers in service in Japan was estimated by the same proportional calculation method as described in 2.1 (3) above for each of the individual models as classfied in the Yearbook of Machinery Statistics.

As a result, it was found that the value of power loss at the industrial transformers was estimated at a total of 34.5 billion k Wh/year as shown in column a. of Table 2.

(5) Loss That Would Occur When all Industrial Transformers Are Replaced with the Existing General-Purpose Type

The loss that would occur when all of the 4 million units of industrial transformers now in service are replaced with the existing general-purpose type was estimated by the same proportional calculation method as described in 2.1 (3) above for each of the individual models as classfied in the Yearbook of Machinery Statistics.

As a result, it was found that the value of power loss in the case where all units of the industrial transformers are replaced with the existing general-purpose type would be a total of 20.6 billion k Wh/year as shown in column b. of Table 2.

(6) Loss That Would Occur When all Industrial Transformers Are Replaced with the Amorphous Transformers

It is the amorphous industrial transformer (“AMIT”) having a core made of amorphous alloy that shows the highest efficiency and involves the least power loss out of all the industrial transformers now in practical use at the moment.

AMIT began to come into wide use in the second half of the 1990s, and it is estimated that about 40,000 units of AMIT are currently in service in Japan.

The power loss was estimated by the same proportional calculation method as described in 2.1 (3) above for each of the individual models as classfied in the Yearbook of Machinery Statistics. The losses as summed up totaled 10.6 billion kWh/year as shown in column c. of Table 2.

Table 2 Present Status of Power Loss of Industrial Transformers and Possibility of Energy Saving

(Unite: billion kWh/year)

	No-load Loss	Load Loss	Total
a. Loss under present conditions	24.2	10.3	34.5
b. Replacement with existing general-purpose transformers	12.0	8.6	20.6
c. Replacement with amorphous transformers	3.1	7.5	10.6
d. Difference between a. and b.	12.2	1.7	13.9
e. Difference between a. and c.	21.1	2.8	23.9
f. Difference between b. and c.	8.9	1.1	10.0

(Number of units in service: 4 million units; average capacity: 154 kVA/unit)

From the above calculations, it was found that if all of the industrial transformers now in service are replaced with AMIT, it would be possible to reduce power loss by 23.9 billion kWh/year but that if the replacement of the industrial transformers now in service with the existing general-purpose type is continued, it would only be possible to reduce power loss by no more than 13.9 billion kWh/year. In other words, there would be a difference of 10.0 billion kWh/year after 30 years between the two cases.

2.3 Total Possibility of Energy Saving at Distribution Transformers in Japan

Integration of 2.1 and 2.2 above gives the results as shown in Table 3.

Table 3 Present Status of Power Loss of Distribution Transformers in Japan and Possibility of Energy Saving

(Unit: billion kWh/year)

	No-load Loss	Load Loss	Total
a. Loss under present conditions	33.5	11.2	44.7
b. Replacement with existing general-purpose transformers	18.0	9.3	27.3
c. Replacement with amorphous transformers	4.8	8.1	12.9
d. Difference between a. and b.	15.5	1.9	17.4
e. Difference between a. and c.	28.7	3.1	31.8
f. Difference between b. and c.	13.2	1.2	14.4

However, it should be noted that there are variable factors involved in the values of load loss out of the above values because there are only a few surveys of the actual conditions of industrial transformers and those amorphous transformers which have a design value of a larger load loss are beginning to come into existence for use by users having transformers in service at a low load rate. Furthermore, load loss provides a much lower possibility of reducing power loss in transformers than no-load loss. Therefore, we will look mainly at the possibility of no-load loss achieving a reduction in this paper.

From Table 3, it can be seen that a no-load loss of about 33.5 billion kWh/year is ocurring at the distribution transformers in Japan and that the replacement of these transformers with amorphous transformers involving the least no-load loss out of all the Distribution transformers available for practical use at the moment would make a power saving of 28.7 billion kWh/year possible. In contrast, it was also found that if the switchover of the distribution transformers to the energy-saving types stops at the level of the existing general-purpose type and all of the distribution transformers now in service are replaced with the transformers of the existing general-purpose type level, then the power loss will only be reduced by no more than 15.5 billion kWh/year, and as a result, there will be a difference of 13.2 billion kWh/year in the amount of power loss after 30 years.

The difference of 13.2 billion kWh/year in the amount of power loss accounts for 1.2% of the total power requirements of 1,070.0 billion kWh/year (including in-house power generation) (Reference 1) p45, 49). If this is converted to the amount of CO2 emissions*, it is equivalent to a reduction of 7.3 million tons of CO2/year, accounting for 0.59% of the energy-derived CO2 emission amount of 1,230 million tons/year in 2003 (Reference 5) p225). (*: Converted with the amount of CO2 emission per 1 kWh assumed to be 0.555 kg-CO2)

3. Power Loss of the Distribution Transformers in China and the Possibility of Reducing Such Loss

It is said that the production of distribution transformers in China is 240 million kVA/year (about 7 times that of distribution transformers in Japan). It is also said that the average capacity of the distribution transformers in China is on the 200-kVA/unit level (Reference 6))

Based on this, on the assumption that the capacity of all the distribution transformers produced and installed in China for one year is 200 kVA/unit, a comparison was made between the case in which all of them are S9 Standards transformers of the general-purpose type and the case in which all of them are SH11 Standards transformers using amorphous cores to reduce no-load loss, as follows:

- Number of units produced annually: 240 million kVA/year divided by 200 kVA/unit = 1.2 million units
- Rating of S9 Standards transformers: Load loss = 2,600 W; No-load loss = 480 W
- Rating of S H 11 Standards transformers: Load loss = 2,600 W; No-load loss = 120 W
- Difference in power loss between 200-kVA S9 Standards transformers and 200-kVA S H 11 Standards transformers is 360 W/unit.
- Calculation of energy-saving possibility:
  0.36 kW/unit x 8,760 h/year x 1.2 million units/year x 30 years
  = 113.5 billion kWh/year
  (4.6% of the 2005 power requirements of 2,470 billion kWh/year)
- Calculation of the possibility of reducing CO2 emissions:
  Assuming that the amount of CO2 emission per kWh in China is about 1 kg-CO2/kWh, then an energy saving of 113.5 billion kWh/year is equivalent to a CO2 emission reduction of 113.5 million tons-CO2/year. This represents a 2.7% reduction of the amount of CO2 emission of 4130 million tons-CO2/year in China in 2003 (Reference 5) p225)

4. Summary

It has been found that the reduction of no-load loss at the distribution transformers through the adoption of amorphous transformers will open up the following possibilities of energy savings and CO_2 emissions reductions on the global scale in Japan and China:

- Japan:
  Energy-saving scale: 13 billion kWh/year (about 1% of power requirements)
  CO_2 reduction scale: 7 million tons-CO_2/year (about 0.6% of total emissions)
- China:
  Energy-saving scale: 113.5 billion kWh/year (about 5% of power requirements)
  CO_2 reduction scale: 110 million tons-CO_2/year (about 3% of total emissions)

The useful life of a transformer is as long as about 30 years. However, if a decision is immediately made to switch the distribution transformers over to amorphous transformers, there is a very realistic possibility of attaining energy savings and CO_2 reductions of such scale as mentioned above, within this 30 year period.

Conversely, if transformers of the existing general-purpose type involving much no-load loss continue to be installed, that will have an adverse effect that will reach the next generation after 30 years. It is hoped that the amorphous transformers will come into wider use as rapidly as possible.

Further, information on the actual status of the load rate of distribution transformers is essential for pressing ahead with the adoption of transformers of the energy-saving type and the adoption by users of proper models of transformers. However, the amount of such information available at the moment is extremely small.

It is hoped that a further investigation will be carried out from now on into the actual status of the load rate of distribution transformers.

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