Energy Conservation by Introducing “Top Runner Transformer 2014”

Submitted by: Japan Electrical Manufacturers’ Association
Reducing Losses in Power Distribution through Improved Efficiency of Distribution Transformers (EWG 05 2015A)

Energy Conservation by Introducing “Top Runner Transformer 2014”

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Introduction

For the Energy Conservation Law Specified Equipment Transformer, the target fiscal years were 2006 for oil-immersed transformers and 2007 for molded transformers. Improvement of 32.8% in energy consumption efficiency over the old products was attained.

To develop new technologies and new materials for the next generation to enhance the function and performance of equipment, the second criteria were notified in March 2012, which started a new transformer called Top Runner Transformer 2014.

In this presentation, we will explain the background of Top Runner Transformer 2014, the outline of the second criteria, and its energy conservation effect.
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REASON AND BACKGROUND OF ESTABLISHMENT OF THE SECOND CRITERIA
Reason and Background of Establishment of the Second Criteria

What is the Energy Conservation Law (Act on the Rational Use of Energy)?

- The Energy Conservation Law was established in 1979 triggered by the oil crisis. The purpose is to take measures needed for streamlining the energy use in factories, transportation, buildings, machinery and appliances for effective utilization and securing of fuel resources and to contribute to sound development of the national economy.

Introduction of the Top Runner Standard

- In the revised Energy Conservation Law following the 1997 Kyoto Conference for global warming prevention, “the Top Runner Standard” was established to promote improvement of energy conservation performance for each high energy-consumption equipment, and 31 items are designated currently. Distribution transformers were designated as the target equipment in 2002, and “the Top Runner Standard” has been applied since 2006.
2 SPECIFIED EQUIPMENT
Definition in “the Act on the Rational Use of Energy”

Specified equipment

Equipment for which further energy conservation is obligated by “the Act on the Rational Use of Energy” (total 31 items as of March 2017)

Top Runner “method”

Method to determine the energy conservation standard, in which the performance of the product with the highest energy conservation performance among existing products (the top runner) becomes the standard
Three Requirements of Specified Equipment

Specified equipment is defined in the government ordinance as the equipment satisfying the following three requirements:

- Act on the Rational Use of Energy (last revision: Law No. 74 of June 24, 2011)
- Article 78 of Chapter 6 Equipment for Machinery and Appliances

- Machinery and appliances used in large quantity
- Machinery and appliances consuming a considerable amount of energy
- Machinery and appliances for which improvement in energy consumption efficiency is particularly required

Transformers were designated as the specified equipment because they satisfied these three requirements.
Target Items of the Top Runner Program (31 items)

1. Passenger car
2. Truck
3. Air conditioner
4. Television receiver
5. Video tape recorder
6. Lighting equipment
7. Copier
8. Computer
9. Magnetic disk unit
10. Electric refrigerator
11. Electric freezer

12. Space heater
13. Gas cooking appliance
14. Gas water heater
15. Oil burning water heater
16. Electric toilet seat
17. Vending machine
18. Transformer
19. Jar type rice cooker
20. Microwave oven
21. DVD recorder
22. Routing equipment
23. Switching Routing equipment
24. Combined machine
25. Printer
26. Electric water heater (heat pump water heater)
27. Three phase induction motor
28. Compact self-ballasted LED lamp
29. Heat insulator
30. Sash
31. Double glass

31 items are designated as specified equipment.
What is the Top Runner method?

The Top Runner method is the method that demands a high efficiency using the highest efficiency of the products currently sold as the standard and also considering the future prospective of technology development.
Explanation of Designations

**Specified equipment transformer**

Transformers for which the target standard should be attained according to the notification “Criteria for Judgment of Manufacturers Concerning Improvement of Transformer Performance,” in which products not having attained the target yet are also included.

**Top Runner Transformer**

Designation defined by the Japan Electrical Manufacturers' Association as the name of transformers that satisfy the first criteria in specified equipment transformers.

**Top Runner Transformer 2014**

Designation defined by the Japan Electrical Manufacturers' Association as the name of transformers that satisfy the second criteria (target fiscal year: 2014) in specified equipment transformers.
Designation and Logo of Transformers

Designation: “Top Runner Transformer 2014”
Industry common designation of transformers conforming to the second criteria (target fiscal year: 2014)

**Logo:** marked on transformer body, catalog, etc.

Energy conservation mark in green
3 REGULATIONS AND LEGISLATION
For Diffusion: Standardization

Issue and revision state of standards related to specified equipment transformers

1. September 2014 Revision of JEM Standard conforming to the second criteria
   • JEM1500 “Standard energy consumption efficiency of oil-immersed transformer conforming to specified equipment”
   • JEM1501 “Standard energy consumption efficiency of molded transformer conforming to specified equipment”

2. May 2013 Revision of JIS for specified equipment
   • JIS C 4304 6kV oil-immersed distribution transformer
   • JIS C 4306 6kV molded distribution transformer

<Main changes>
   • Reflection of the second criteria
   • Consistency with IEC
   • Improvement in maintenance (oil-immersed transformer)
For Diffusion: Legislation

Legislation and institutionalization state related to specified equipment transformers

   - Criteria
   - Marking, etc.
   - Measuring method for energy consumption efficiency

2. February 2013, Law on Promoting Green Purchasing, Basic Policy on Promoting Procurement of Environmental Conservation Products (cabinet decision)
   - Specified procurement items in Fiscal 2013 and their criteria
     (Transformers whose energy consumption efficiency satisfies the second criteria of the Energy Conservation Law are designated as the specified procurement items. As no tolerance is defined, attention is needed.)
Operation of Specified Equipment

- **Target fiscal year**
  April 2014 (for both oil-immersed and molded transformers)

- **Judgment procedure for conformance to the standard**
  1. Report of annual production (or import) volume, energy consumption efficiency, and weighted average by class
  2. Report of improvement measures when not having attained the conformance

- **Marking**
  1. Marking on catalog, etc.
  2. Marking on product
THE OUTLINE OF THE SECOND CRITERIA

NOTIFICATION OF MINISTRY OF ECONOMY, TRADE AND INDUSTRY NO. 71 OF MARCH 30, 2012
“CRITERIA FOR JUDGMENT OF MANUFACTURERS CONCERNING IMPROVEMENT OF TRANSFORMER PERFORMANCE”
Application Target

To improve the efficiency in wider range, not only the standard specifications defined in JIS, etc. but non-standard specifications are targeted.

Excluded products are selected according to the following criteria:
1. Models used for special application (original specifications, special load)
2. Models whose market share is extremely small
3. Models for which measuring methods have not been established technically

[Scope of the target]
Voltage
   Primary: high voltage such as 3.3kV, 6.6kV
   Secondary: low voltage 100V - 600V
Capacity
   Single phase: 10kVA - 500kVA
   Three phase: 20kVA - 2000kVA

[Excluded products]
1. Gas-insulated transformer
2. H-type dry transformer
3. Scott-connected transformer
4. Multi-winding transformer (3 windings or more)
5. Single phase of 5kVA or less, or more than 500kVA
6. Three phase of 10kVA or less, or more than 2000kVA
7. Molded light and power common-use transformer
8. Products with secondary voltage of less than 100V or more than 600V
9. Air cooling or water cooling transformer
10. Pole transformer

For distribution transformers, 98.6% of them is targeted.
Classes for Setting a Target

Classes are determined considering physical quantities and functions closely related energy consumption efficiency (total loss). For transformers, indexes are model, frequency, the number of phase, and capacity.

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Phase</th>
<th>Rated freq.</th>
<th>Rated capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Oil-immersed transformer</td>
<td>Single</td>
<td>50Hz</td>
<td>500kV or less</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>Single</td>
<td>60Hz</td>
<td>500kV or less</td>
</tr>
<tr>
<td>III-1</td>
<td></td>
<td>Three</td>
<td>50Hz</td>
<td>500kV or less</td>
</tr>
<tr>
<td>III-2</td>
<td></td>
<td>Three</td>
<td>50Hz</td>
<td>more than 500kV</td>
</tr>
<tr>
<td>IV-1</td>
<td></td>
<td>Single</td>
<td>60Hz</td>
<td>500kV or less</td>
</tr>
<tr>
<td>iV-2</td>
<td></td>
<td></td>
<td>60Hz</td>
<td>more than 500kV</td>
</tr>
<tr>
<td>V</td>
<td>Molded transformer</td>
<td>Single</td>
<td>50Hz</td>
<td>500kV or less</td>
</tr>
<tr>
<td>Vi</td>
<td></td>
<td>Single</td>
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</tr>
<tr>
<td>VIII-2</td>
<td></td>
<td></td>
<td>60Hz</td>
<td>more than 500kV</td>
</tr>
</tbody>
</table>

Classification is the same as the first criteria.
Standard Load Ratio for the Target Standard Value

Basic policy

- When the standard load ratio is set, the followings have to be considered: (1) the value corresponds to actual use conditions, and (2) a sufficient energy conservation effect is attained even if there is a change in the actual load ratio.

- In JIS C 4620 “Cubicle Type High-voltage Power Receiving Facilities,” which is a standard for high-voltage power receiving facilities, the application scope is a capacity of 500kVA or less per transformer. On the other hand, main application of the transformers with a capacity of more than 500kVA is power sources in middle or large scale factories of extra-high voltage consumers.

- Survey of load ratios in 2010

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Daytime</th>
<th>Nighttime</th>
<th>Average</th>
<th>After improving power factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>500kV or less</td>
<td>36.4%</td>
<td>9.7%</td>
<td>26.6%</td>
<td>11%-42%</td>
</tr>
<tr>
<td>more than 500kV</td>
<td>47.1%</td>
<td>29.6%</td>
<td>39.3%</td>
<td>34%-54%</td>
</tr>
</tbody>
</table>

- It needs to be considered that the setting is based on the actual load ratio on one hand, and an energy conservation effect is attained over the entire range of the load ratio on the other. An effective energy conservation standard is determined by selecting an intermediate value as the standard load ratio.

**Standard load ratio**
The standard load ratio for each capacity is determined as follows:

- 500kVA or less: 40%
- more than 500kVA: 50%

*The standard load ratio is the same as the first criteria.*
Energy consumption of transformers is considered as “total loss (W),” and the target standard value is derived by the Top Runner method in which the most excellent property existing currently at the standard load ratio is determined as the target value.

E: Standard energy consumption ratio (W)
* Standard load ratio
  500kVA or less: 40%
  more than 500kVA: 50%

kVA: Rated capacity of transformer (kVA)

Semistandard specification product
Treated using the calculation formula of the target standard value of standard energy consumption efficiency for each class multiplied by the following value.

Oil-immersed transformer:  1.10
Molded transformer:  1.05

<table>
<thead>
<tr>
<th>Classification</th>
<th>Calculation formula of target standard value of standard energy consumption efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Type</td>
</tr>
<tr>
<td>I</td>
<td>Oil-immersed transformer</td>
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</tr>
<tr>
<td>III-2</td>
<td>Oil-immersed transformer</td>
</tr>
<tr>
<td>IV-1</td>
<td>Oil-immersed transformer</td>
</tr>
<tr>
<td>IV-2</td>
<td>Oil-immersed transformer</td>
</tr>
<tr>
<td>V</td>
<td>Molded transformer</td>
</tr>
<tr>
<td>VI</td>
<td>Molded transformer</td>
</tr>
<tr>
<td>VII-1</td>
<td>Molded transformer</td>
</tr>
<tr>
<td>VII-2</td>
<td>Molded transformer</td>
</tr>
<tr>
<td>VIII-1</td>
<td>Molded transformer</td>
</tr>
<tr>
<td>VIII-2</td>
<td>Molded transformer</td>
</tr>
</tbody>
</table>
Improvement Effect in the Target Fiscal Year

Improvement effect in the target fiscal year

The improvement ratio of the energy consumption efficiency (total loss (W)) in the target fiscal year is expected to be 12.5% compared to the current target standard value on the precondition that the shipment volume and composition by class are the same as those in fiscal 2009.

<Outline of calculation>

1. The energy consumption efficiency (total loss (W)) per unit obtained from the target standard value of the transformers shipped in fiscal 2009 with the weighted average by shipment volume is:
   \[ 596.1 \text{ W/unit} \]

2. The energy consumption efficiency (total loss (W)) per unit obtained from the target standard value of the transformers expected to be shipped in the target fiscal year with the weighted average by shipment volume is:
   \[ 521.8 \text{ W/unit} \]
   * The precondition is that the shipment volume and composition are the same as those in fiscal 2009.

3. Improvement ratio of the energy consumption efficiency is:
   \[ \frac{596.1 \text{ W/unit} - 521.8 \text{ W/unit}}{596.1 \text{ W/unit}} = 12.5\% \]

The Top Runner Transformer 2014, combined with the first criteria, will contribute to improvement of 43% in the energy consumption efficiency.
Target Fiscal Year

Basic policy

• Model changeover of a transformer is mostly done when the efficiency standard in laws, standards, specifications, etc. is changed. It is generally done every 7 to 8 years. To enhance the energy consumption efficiency substantially, improvement in the efficiency of transformers at least once or twice is required.

Target fiscal year

• The target fiscal year of transformers is determined as the year when 8 years have passed since fiscal 2006, which is the target fiscal year of the current standard for oil-immersed transformer, i.e., the target fiscal year is determined to be fiscal 2014 (April).

• For molded transformers, the target fiscal year was set with a different period from oil-immersed transformers. However, to improve the energy consumption efficiency promptly, as with oil-immersed transformers, the target fiscal year for molded transformers is determined to be fiscal 2014 (April).

While the period from the final decision to the target fiscal year was 4 years (molded: 5 years) for the first criteria, the period is as short as 2 years and 3 months for the second criteria.
Measuring Method of the Energy Consumption Efficiency

The energy consumption efficiency of transformers is considered as the “total loss (W).” No-load loss (W) and load loss (W) are measured according to the method specified in JIS C 4304 and JIS C 4306, and the total loss is calculated by the following formula.

Total loss (W) = No-load loss (W) + \( \left[ \frac{m}{100} \right]^2 \times \text{Load loss (W)} \)

In the above formula, the following values shall be used as ‘m’: m: standard load ratio

- Transformers with a capacity of 500kVA or less: 40 (%)
- Transformers with a capacity of more than 500kVA: 50 (%)

The measuring method is the same as the first criteria.
Marking

Marking items
As with the marking items for the energy consumption efficiency of transformers of the current standard, the items a) to j) shown below shall be marked on catalogs showing information related to performance and materials provided by manufacturers, etc. for selection of products.

a) Product name and model
b) Type (structure) of transformer (oil-immersed or molded)
c) Rated capacity (kVA)
d) Number of phase
e) Rated frequency (Hz)
f) Rated primary and secondary voltages (V)
g) Energy consumption efficiency (total loss (W))
h) Standard load ratio (%)
i) Name of standard (standard (JIS or JEM) or semistandard)
j) Name of representative or trade name of manufacturer, etc.

The marking items are the same as the first criteria. It is prescribed that the marking is enforced in April 2014. Overall renewal of catalogs, etc. (or collection of old catalogs) is required.
STRUCTURE AND CONSUMPTION ENERGY OF TRANSFORMERS
Structure of Transformer

- Tank
- Terminal
- Coil
- Iron core

**Oil-immersed transformer**

**Molded transformer**
Consumption Energy of Transformers
Loss Reduction

Loss and technology to reduce loss

<table>
<thead>
<tr>
<th>Loss</th>
<th>Site of loss</th>
<th>Main cause of loss</th>
<th>Characteristics</th>
<th>Technology to reduce loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-load loss</td>
<td>Iron coil</td>
<td>Magnetic resistance of iron core</td>
<td>Always generated irrespective of load</td>
<td>Improve material</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Improve core structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Thinner iron core</td>
</tr>
<tr>
<td>Load loss</td>
<td>Coil</td>
<td>Magnetic resistance of coil</td>
<td>Proportional to the square of load current</td>
<td>Aluminum -&gt; Iron</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shorten winding length</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Thinner insulator</td>
</tr>
</tbody>
</table>

Improving iron core material

Reduction in no-load loss for higher efficiency is realized by adopting high magnetic flux density directional magnetic steel sheet with enhanced crystal directionality and domain control directional magnetic steel sheet with magnetic domains segmented by surface chase treatment, and improving iron core technology.

Representative properties of iron core material

<table>
<thead>
<tr>
<th>Type of magnetic steel sheet (JISC2553 class No.)</th>
<th>Sheet thickness (mm)</th>
<th>Iron loss (W/kg) at 1.7T, 50Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>General directional (35G130)</td>
<td>0.35</td>
<td>1.28 (100%)</td>
</tr>
<tr>
<td>Highly directional (23P090)</td>
<td>0.23</td>
<td>0.88 (69%)</td>
</tr>
<tr>
<td>Magnetic domain control (23R085)</td>
<td>0.23</td>
<td>0.83 (65%)</td>
</tr>
</tbody>
</table>

Improving coil (winding technology)

Reduction in load loss is realized by adopting copper with excellent electric conductivity as the winding conductor instead of aluminum used conventionally, and by improved technology of windings with higher density using a thinner insulator. For the coil shape, dimensions are reduced using a multiple square tube.

Improving iron core structure

Wound iron core structure
Change in Consumption Energy by Load

Energy consumption (total loss) = No-load loss + (Load ratio/100)^2 x Load loss

![Graph showing the relationship between consumption ratio (W) and load ratio (%). The graph illustrates how energy consumption increases with load ratio.]
6 COST-EFFECTIVENESS OF INTRODUCTION
Energy Conservation Effect (1)

Improvement in energy consumption efficiency

Comparison of energy consumption efficiency
Three phase, 50Hz, 500kVA

Standard load ratio: 40 [%]

Energy consumption efficiency at standard load (W)
Energy Conservation Effect (2)

Improvement in efficiency at all load ratios

Comparison of efficiency vs. load ratio
Three phase, 50Hz, 500kVA

Oil-immersed transformer

Molded transformer

Energy consumption efficiency at standard load (W)
## Reduction in Annual Electric Power Charge

**Formula:**
Annual power charge (yen) = Energy consumption efficiency (kW) \times 24 \text{ h} \times 365 \text{ d} \times Unit power charge (yen/kWh)

**Comparison of annual electric power charge**  
Three phase, 50Hz, 500kVA

<table>
<thead>
<tr>
<th>Product before Top Runner</th>
<th>Previous standard</th>
<th>Current standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric power charge (thousand yen)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Oil-immersed transformer**
- Product before Top Runner: 258
- Previous standard: 144
- Current standard: 131
- Annual reduction: 126 thousand yen

**Molded transformer**
- Product before Top Runner: 300
- Previous standard: 171
- Current standard: 150
- Annual reduction: 149 thousand yen

**Calculated as unit power charge = 12 (yen/kWh)**

**Standard load ratio: 40 [%]**

**Electric power charge at standard load (thousand yen)**
Energy Conservation Effect of Transformers Depending on Load Ratio

The total loss of transformers changes depending on the average equivalent load ratio. The formula for the average equivalent load ratio, $Pe$, is given by:

$$Pe = \left( \sum_{i=1}^{k} \frac{(P_i)^2 T_i}{T_1 + T_2 + \cdots + T_i + \cdots + T_k} \right)^{1/2}$$

where $P_i$ is the load at time $T_i$.

Example: Product before Top Runner, three phase, 500kVA, conforming to JIS4304

- **Load curve**
- **Time (h)**
- **Load ratio (%)**

<table>
<thead>
<tr>
<th>Load ratio (%)</th>
<th>Time (h)</th>
<th>Load curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Total loss**
- **No-load loss**
- **Load loss in rated operation**

- **$W_t = W_i + \left( \frac{Pe}{100} \right)^2 \times Wc$**

- $W_t$: Total loss (W)
- $W_i$: No-load loss (W)
- $W_o$: Load loss in rated operation (W)
- $Pe$: Average equivalent load ratio (W)
7 PROMOTION OF DIFFUSION
Basic Policy for Diffusion

The interim report of the Transformer Criteria Subcommittee recommended the followings for energy conservation:

1. **Efforts of the government**
   From the viewpoint of diffusing transformers with excellent energy consumption efficiency, the government should take measures necessary for diffusion and awareness-raising to promote the efforts of users, manufacturers, etc.

2. **Efforts of the manufacturers, etc.**
   a) Promote technological development for further energy conservation of transformers and make effort to develop products with excellent energy consumption efficiency.
   b) From the viewpoint of diffusing transformers with excellent energy consumption efficiency, make efforts to provide appropriate information so that users can choose a transformer with excellent energy conservation performance and proper capacity in addition to the catalog and instruction manual of the product. For example, show the energy consumption efficiency on a noticeable part of the material provided by manufacturers, etc. for selection of products by users.

3. **Efforts of the users**
   When purchasing a transformer, choose one with excellent energy consumption efficiency and proper capacity, and use the transformer suitably and efficiently for further energy conservation.
Efforts of JEMA

According to the recommendation shown on the previous slide, JEMA promotes the followings for diffusion of Top Runner Transformer 2014.

**Promote product development**
- Establish standard

**PR activity**
- Diffusion activity

*** Efforts other than improving the energy consumption efficiency ***

- Propose the concept of earthquake-resistance.
- Increase commonality of accessories (dial thermometer).
- Include an oil scavenging valve or plug as a standard component. (75 - 2000kVA model)
- Increase commonality of connection part of the secondary terminal.
8 SUMMARY
To All the Parties Concerned

With regard to Top Runner Transformer 2014 that contributes to environmental conservation, because a transformer is equipment used in power distribution facilities, understanding and cooperation by business entities concerning construction, electric facilities, design and distribution boards that use a transformer is important. The transformer industry wishes to hear your opinion and will work toward development and commercialization of new transformers. We appreciate it if you cooperate with us so that the users who use a transformer now or plan to use it know the importance of environmental conservation as well as the energy consumption effect, and bear a part for promotion of diffusion.
Thank you very much for your attention.

The Japan Electrical Manufacturers' Association