Energy-Efficient Distribution Transformers: a Hidden Opportunity for Large Scale Energy Savings

Benoit Lebot
International Energy Agency - OECD
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Energy Efficient Transformers: an opportunity for significant energy savings

Energy saving transformers can save 100 - 150 TWh / year of electricity in OECD countries, equivalent to more than 70 million tonnes of CO2 emissions.

Despite this significant potential energy saving, high efficiency transformers may not have yet reached their rightful place as an energy saving option in national energy efficiency policies. Since almost all IEA countries are concerned, distribution transformers appear to be a attractive candidate for an internationally co-ordinated energy efficiency initiative and a worthwhile area for R&D, demonstration and promotional efforts.

The IEA Secretariat would like to encourage information sharing, analyses of further technical and policy issues, and eventually stimulate more energy efficient policy in the field.

Distribution Transformers: an essential component in any electricity grid

Losses in electricity supply systems depend on the voltage level. They are minimised by transmitting electricity at as high a voltage as possible, consistent with demand load levels. Distribution transformers reduce it to the level required by users, are therefore an essential component in transporting electricity economically from the power station to the final customer. To reduce the voltage to the desirable level, distribution transformers do consume some electricity, only a small portions of the electricity passing through them, but in a permanent manner. The resulting standby power losses account for up to 2% of the total electricity production. Distribution transformers present a range of energy efficiency. Promoting the most energy efficient transformer technology, when replacing old equipment, can generate significant amount of energy savings.

The present paper proposes an overview of the context, some elements of the technology, an estimation of potential savings, a summary of policy proposed by IEA Member Countries to promote low-loss distribution transformers. It proposes an avenue for a possible international co-ordinated effort.

Background

Transformers (excluding those used in small appliances) can be divided into three groups: generation, transmission and distribution. The first two types are used in the transmission network linking electric generators with the distribution network, which provides power to end users. Distribution transformers are by far the most numerous and convert high-voltage electricity to lower voltage levels for use in home and businesses.

The main reasons for considering an initiative on energy-efficient transformers are given below.

The large number of distribution transformers in use and the fact that all electric power generated world-wide continuously passes through them implies that even small improvements in transformer efficiency can result in substantial energy and greenhouse gas savings.

Despite high average efficiencies (from 95 to 99.75%), transformers have a significant environmental impact because they continuously consume power. This might be considered as a 2nd standby loss, after the standby power loss in electrical equipment.

The energy losses in electricity transformers fall into two components : no-load losses or iron losses (resulting from energising the iron core; this phenomenon occurs 24 hours per day, 7 days per week, over the lifetime of the transformer, 30 years in average) and load losses (arising when providing power to a user, from the resistance of the coils when the transformer is in use, and for eddy currents due to stray flux). Transformers may lose 1 to 2% of energy transformed as heat when they are lightly loaded.

Electricity distribution transformers have a relatively long life (estimates range from around 30 years to as much as 50 years for lightly loaded or refurbished transformers), and individual transformers accumulate substantial losses over their working life.

In several OECD countries, electricity networks are responsible for purchasing most of the transformers, while the cost of transmission and distribution losses are passed on to consumers. As a result, little market incentive exists to purchase efficient transformers.

Distribution transformers are used all over the world to distribute power from large power stations to millions of end-users. In the OECD area, there are over 60 million distribution transformers (Australia 590,000 units, European Union 4 million units, Japan 13 million units, USA 40 million units). There are 3.3 million units in China.

In most electricity grid, up to 2% of total electricity generated is estimated to be lost in distribution transformers, representing nearly one-third of overall system losses. This represents about 5.5 TWh in Australia (resulting in 5.4 million tonnes of CO_2 in 1998), 90 TWh in China, 50 TWh in European Union countries, 32 TWh in Japan and 61 TWh in United States (resulting in annual greenhouse emissions of 45 million tonnes of CO_2). For comparison, in the European Union, to compensate the energy losses in distribution transformers, it takes about eight largest nuclear stations.

Power generation is one of the largest contributors to toxic emissions and global warming (SO_x, NO_x and greenhouse gas emissions) in OECD countries. Initiatives to reduce emissions, and meet agreed climate change and global warming targets, are often similar to those aimed at improving energy efficiency. Most countries have programme involving the electricity industry to help meet the global warming targets set in the Kyoto Protocol.

Newly privatised utilities are reported to show less interest in longer-term problems. They usually require more rapid paybacks on their investment compared to the public sector network operators they have replaced.

Distribution utilities, when managing transformers and other equipment, try to minimise capital expenditure, particularly through assets management.

The existing stock of distribution transformers is ageing, with many transformers over 40 years old. In several OECD countries, the age profile of the power transformer stock is widely regarded as a cause for concern.

The main sources of distribution losses are transformers and cables, unmetered and unbilled supplies.

According to the size of the commercial and domestic sectors, as much as 75% of all electricity generated in several OECD countries is consumed at low-voltage. This proportion is likely to increase, since domestic and small commercial loads grow while heavy industry declines. This suggests that distribution transformer losses will grow.

A recent study performed for the European Commission[1] estimates that about 22 TWh per year could be saved in the European Union through the use of energy-efficient distribution transformers (representing 3% of the European commitment to reducing carbon emissions), worth 1,171 million euro at 1999 prices. In Japan, the Top Runner Programme extended to distribution transformers, could save about 24 TWh per year. In the United States, the potential is about 45 TWh per year ; in this country alone a 0.01 percent gain in the average efficiency of utility transformers installed in a single year would produce an energy savings of 2.9 TWh. In China, the potential saving is about 47 TWh per year.

The environmental benefits of energy-efficient transformers are very high. A 400 kW transformer, typical for urban distribution, has lifetime losses equivalent to 125 – 184 tonnes of CO_2 emissions. Electricity losses cost two to three times more than the original purchase price of the transformer. An energy-efficient transformer could reduce CO_2 emissions to 56 tonnes (figures for The Netherlands).

In Europe, if all electric appliances and end uses were turned off, six of the largest nuclear power stations would be still needed to compensate for transformer losses, and another six for standby power losses from electronic equipment.

Transformers could emerge as a major focus for energy efficiency initiatives in OECD countries, comparable with electric motors, domestic appliances, etc. They are potentially capable of making a similar contribution to reducing carbon emissions and achieving global warming goals.

Technical considerations

Technical solutions exist to reduce transformer losses by 75% at minimum (when replacing with modern transformers) or even by 90% (when replacing transformers over 30 years old). Energy-efficiency can be improved with better transformer design (selecting better, lower-core-loss steels; reducing flux density in a specific core by increasing the core size; increasing conductor cross-section to reduce current density; good balancing between the relative quantities of iron and copper in the core and coils; and so on.), or by the adoption of amorphous iron transformers world-wide (distribution transformers built with amorphous cores can reduce no-load losses by more than 70% compared to the best conventional designs).

High-efficiency transformers are available and already used by the utility industry. Producing energy-efficient transformers is not a technical challenge. The technology is available in all OECD countries.

Economic considerations

Transformers use well-established technologies and designs, and equipment can be manufactured in relatively low-cost facilities. For this reason the manufacturing sector – working in close relationship with its utility customers, supplying mainly power cables, transformers and switch-gear has always been very price competitive.

Utility's investment in energy-efficient distribution transformers has an economic payback time between 1.4 and 8 years, and an internal rate of return between 70% and 11%.

There are a variety of additional cost savings and benefits associated with energy-efficient transformers. They include:

- reduced physical size (unit dimensions);
- reduced transformer heating, hence lower need for additional cooling or insulation (hence reduced variable costs such as coolants, ageing insulation materials);
- reduced noise levels;,
- longer operating lifetime.
- Low-loss transformers also better withstand electronic (harmonic) loads.

As utilities enter an era of increased competition, they must find ways to cut costs while improving the quality of service to their customers.

Despite the benefits of energy-efficient distribution transformers, it is a challenge to convince customers that, although the initial price associated with these transformers is higher, the overall cost using them can be lower.

A favourable context for co-ordinated international action

In a context where governments are trying to find ways to reduce their greenhouse emissions in a cost-effective way, eliminating unnecessary electricity losses from distribution transformers represents an interesting avenue. Moreover, the stock of distribution transformers will continue to grow –driven by e electricity market de-regulation in most OECD countries (The trend toward generating electricity at sites close to the point of use suggests a decreasing need for transmission across long distances, but will increase the need for smaller transformers in the network.) As a result, losses from distribution transformers will represent an even larger share of electricity use.

Yet, take-up of efficient transformers has been low. Markets deregulation has forced utilities to reduce capital budgets. Since energy losses are directly charged to customers via tariffs, reduced losses do not necessarily benefit the investor.

Several countries are facing significant growth in electricity demand. They could benefit greatly from installing energy-efficient transformers.

The environmental, energy efficiency and economic arguments for efficient distribution transformers are clearly understood by actors and decision-makers in the electricity sector, creating an increasingly positive climate for dialogue.

Existing initiatives

In Canada, Natural Resources Canada (NRCan) has proposed minimum energy performance standards for transformers. In 1997, NRCan distributed a proposal to stakeholders and has subsequently consulted widely. The proposed regulations, based on the US NEMA[1] guidelines to harmonize regulation within North America, were introduced in January 2001.

In Australia, the National Appliance and Equipment Energy Efficiency Committee (NAEEEC) is exploring the benefit of mandating minimum energy performance standards (MEPS) for electricity distribution transformers. MEPS is a government regulatory program stipulated in state and territory law that excludes from the market products which do not meet the minimum energy performance levels. The MEPS for distribution transformers, matching the Canadian standards proposed to take effect in early 2001, will come into force by approximately mid-2003. Cumulative savings by 2015 resulting from the introduction of MEPS in 2005 are estimated to be at least 346 thousand tons CO_2 and could be as high as 950 thousand tons CO_2.

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[1] The National Electrical Manufacturers Association (NEMA) had published a *Guide for Determining Energy Efficiency for Distribution Transformers* (TP-1-1996). In 1998, NEMA also publised a standard test method for the measurement of energy consumption in transformers (TP-2), and proposed a further *Standard for Labeling of Energy-Efficient Distribution Transformers*.

In the United States, the Environmental Protection Agency (EPA) has included transformers into its Energy Star labelling scheme. The Energy Star Transformer Program is a voluntary energy efficiency programme designed to encourage utilities to purchase and install high-efficiency, cost effective transformers in their distribution systems. Consideration is being given to setting minimum standards for distribution transformer losses. This programme includes information and software dissemination. Technical assistance is provided to partners to ensure that transformers are not oversized. Distribution Transformer Cost Evaluation Model (DTCEM) is available that provides a standard methodology for evaluating multiple transformer bids.

The US Department of Energy (DOE) Federal Energy Management Program also encourages government procurement of energy-efficient distribution transformers. Starting in 1998, the DOE began a process of research and consultation on the merits and potential levels for a minimum energy performance standard (MEPS). No firm implementation commitment has been made to this so far. However, industry-wide consultations are being carried out and test procedures are being developed. Possible references on which to base standards include the ANSI/IEEE standards or the NEMA standard. It is envisaged that minimum energy performance standards will be adopted for transformers by approximately mid-2003.

Mexico is among the most advanced countries in the enactment and implementation of minimum energy performance standards and energy efficiency labelling. Much of the effort has borrowed from the United States experience, although a good deal has also been developed in response to local requirements. Minimum energy performance standards and energy labelling have been implemented to reduce the growth in electricity demand. The Energy Performance Standards cover energy efficiency and safety for distribution transformers and became mandatory in 1999. They also prescribe the maximum allowed losses, which is not the case in either the United States or Canada.

In Europe, CENELEC has, for ten years, applied a voluntary standard for transformer losses for each of the harmonised distribution transformer sizes: HD428 for oil-cooled transformers and HD538 for dry-type transformers. However, HD428 allows for different levels of efficiency, none of which are technically challenging. Purchasers are allowed to choose loss evaluation techniques, effectively determining their own standard. The current national standards of European Union countries and major utilities are based upon HD428. There are no plans to create a European Standard (EN) from HD428.

However, discussions have already taken place between the European Commission (DG TREN), COTREL (Industry Representatives) and EURELECTRIC to discuss the possibility of voluntary agreements or a European Directive on reducing losses from distribution transformers through a minimum standard.

In Japan, transformers will be added to the Top Runner scheme in 2002. For a given equipment, the energy efficiency target to be met by the whole market is set at the level of today's best available equipment (the Top Runner). Therefore, the specified performance level for transformers is based on the performance of the best currently marketed equipment and short-term technology development. The Amorphous Industrial

Transformers (AMIT) is actually the most efficient but standards will be set at a lower level.

China banned some transformers (referred to as S7) in January 1999, and moved the market effectively to the S9 level (about 30% higher losses than OECD state-of-the-art).

Possible actions at international level

Several OECD countries are developing policies to promote energy-efficient distribution transformers.

However at the present stage, few OECD countries have formal national energy efficiency plans in place for distribution transformers, although these are being drafted to help fulfil global warming commitments.

The savings potential from distribution transformers may appear too small and too difficult to achieve to be considered at national level. However, for the OECD, potential savings can be estimated at 150 TWh per year, representing an emission savings of 75 million tonnes of CO_2. This is equivalent to about 30% of the European Union's Kyoto commitments.

Both utilities and non-utility purchasers are difficult to influence. However, the transformer market is extremely competitive and the sector involves a limited number of professional buyers, already reasonably aware of the arguments for energy efficiency. An energy-efficient transformers initiative could help partners of the supply chain to be receptive to arguments for these transformers, provided that benefits issuing from the promotion of such equipment are clearly demonstrated.

In developing countries, where help is needed in electricity generation, in energy efficiency and in standard utility operational expertise, the potential savings are greater than those in the OECD region.

Current efforts to promote energy-efficient distribution transformers could accelerate and benefit from a co-ordinated approach.

Possible roadmap for the IEA

IEA is well placed to co-ordinating an initiative on energy-efficient distribution transformers. The successful introduction of a world-wide initiative on energy-efficient transformers would strongly reinforce the existing national programmes.

The IEA Secretariat is keen to open and maintain a dialogue with several stakeholders in order to discuss the issue of electricity losses due to distribution transformers and explore the possibility of organising international collaboration to facilitate domestic efforts. A number of issues still need to be debated and refined, such as the magnitude of the electricity waste in various economies and the related CO_2 emissions, existing technical solutions and their cost-effectiveness, and the various policies that could be used to tackle the problem. Discussions could help to produce recommendations targeted to policy makers.

An initiative on energy-efficient distribution transformers could be linked to the IEA Ad-Hoc Group of Experts on Electric Power Technologies. The aim of the initiative could be to facilitate setting high transformer standards and stimulate programmes for replacement of older transformers.

Conclusion

Distribution transformers appear to be a attractive candidate for an internationally co-ordinated energy efficiency initiative and a worthwhile area for R&D, demonstration and promotional efforts.

The majority of OECD countries are currently developing strategies to decrease greenhouse gas emissions. The potential for reducing losses from distribution transformers could be considered as an element of world-wide strategies to address energy efficiency, global warming and environmental impacts.

The energy-efficient transformers initiative could impact the world market, benefiting to economies outside those of the OECD.

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