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Driving down energy losses in transformers

With some 5 percent of global electrical energy being consumed by transformer losses, energy efficiency has become one of the main drivers of transformer technology evolution and regulation.

Miguel Cuesto
Miguel Oliva
ABB Transformers
Cordoba, Spain

miguel.cuesto@es.abb.com
miguel.oliva@es.abb.com

Kai Pollari
ABB Transformers
Vaasa, Finland

kai.pollari@fi.abb.com

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Energy demand and availability are intertwined with a nation's economic growth and welfare. This symbiosis is reflected in many countries by the relentless escalation in energy requirements driven by thriving economic activity and increasing population. At present, electric power satisfies a large proportion of this demand and new factors, such as electric vehicles and renewable energy sources, are expected to increase this share.

In this context, electrical equipment efficiency plays a vital role, especially in transformers, where losses account for some 5 percent of global consumption – more than the electricity demand of the continent of Africa.

ABB is at the forefront of the energy efficiency revolution and provides technologies right along the electrical energy value chain that typically pay for themselves within a few years through lower energy costs. Transformers are key links in this energy value chain.

In fact, energy efficiency has become one of the main drivers of transformer technology evolution and regulation. For example, a major initiative being implemented by major economies in support of a more efficient use of energy is the so-called minimum energy performance standard (MEPS) for transformers →2-3. Transformer MEPSs differ by country and region and have to be normalized to provide a comparison →3. In 2017, The first global reference document for transformer efficiency and related metrics was published (IEC 60076-20 TS).

Advantages of energy-efficient transformers

Efficiency improvements in transformers can lead to significant energy and emissions savings, while bringing net economic benefits because the marginal cost is spread over the lifetime of the equipment. Energy-efficient transformers also provide extra capacity, potentially lower electricity bills, reduce peak loading and related pollution at power plants, and enhance energy security and reliability.

ABB pursues many technical solutions for enhancing transformer energy efficiency. These range from better core construction techniques to lower-loss core and conductor materials. Winding design and utilization of magnetic shields and other solutions to decrease load losses can also have a considerable impact. Efficiency also comes from how the system is configured and how products, technology and knowledge can be combined to deliver a stronger and smarter grid – for example, by transmitting energy more efficiently by using higher voltages, both AC and DC, or by using products that make more efficient use of the network, such as:

- Better interconnections.
- FACTS (Flexible Alternating Current Transmission Systems).
- Reactors or phase-shifting transformers.
- Transformers specifically designed to simplify renewable energy generation and integration: solar and wind transformers; collector transformers, and AC and HVDC units for local connection to the grid.

New transformer technology and materials, and physical modeling and simulations can also deliver designs that lower losses or give the same losses but with less material or improved transportability.

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01 With rising concern over climate change, it is more important than ever to use energy efficiently. As 5 percent of global energy is consumed by losses in transformers, any measures that reduce these losses will have a major positive impact on the world's energy consumption.

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02 Examples of current initiatives for energy efficiency.

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03 Example of MEPS (normalized) for three-phase liquid-filled transformers [1]. Efficiency at 50 percent load, using the IEC definition of rating and efficiency.

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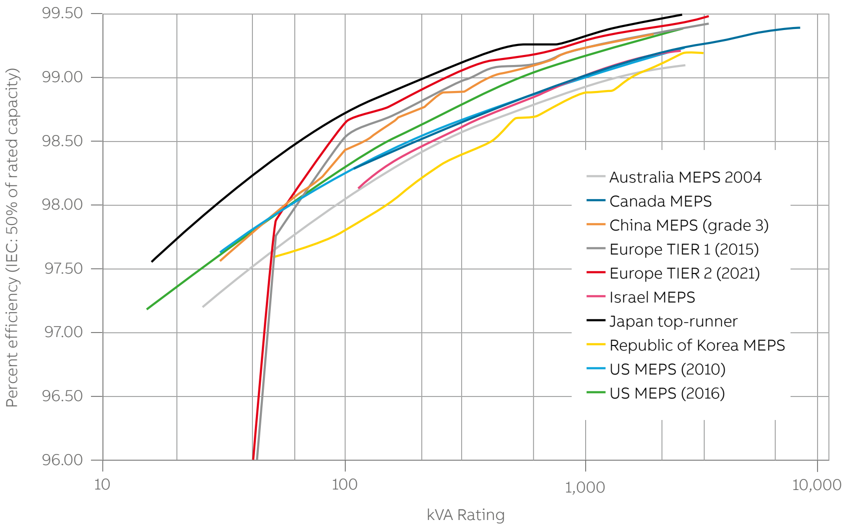
04 Example of the use of 3-D tools for optimized use of magnetic shunts to reduce tank wall losses. Green areas show where leakage flux is successfully collected; blue shows where it is not.

04a Large blue areas indicate this design is poor at leakage flux collection, so there will be high loss in the tank.

04b The prevalence of green indicates high collection of leakage flux and lower losses in the tank.



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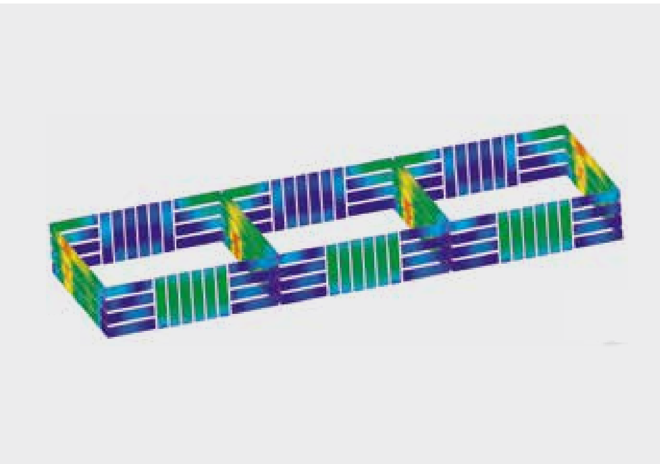
Other techniques improve overall cost-effectiveness and performance:
- Transformer intelligence via digitalization – ie, the collection of monitoring and service data to better use the existing assets and increase their availability and life expectancy.
- Transformer life cycle management.
- Reusing or recycling materials at the end of life.

Battling the losses by design
Transformer losses have three main components: load losses, no-load losses and auxiliary losses.

Load losses
Load losses are created by current circulation along the windings and will vary with the transformer load. Regardless of the type of transformer, 2-D and 3-D software tools, together with ABB expertise, allow the designer to minimize these losses, especially those that cannot be calculated easily – ie, the losses due to leakage flux (also called stray losses). These losses can be reduced with magnetic shunts, which are basically collectors or shields that avoid leakage flux going to areas like the tank walls, where the flux would create even higher losses →4.

No-load losses
No-load losses are the losses created in the transformer magnetic circuit due to the magnetic flux circulation through it. These losses are incurred from the very first moment that the transformer is energized and do not depend on the transformer load level. The use of new and more efficient electrical steels reduces these losses. The electrical steel specific losses, defined as losses per unit mass at certain conditions, range roughly from 1.22 to 0.70 W/kg, meaning that depending on the type of material selected, the no-load losses can be reduced by up to 57 percent from one case to another. Furthermore, there are ongoing developments in the field of amorphous electrical steels to further reduce losses. The use of these amorphous materials is, however, currently limited to small transformers.

Auxiliary losses
Auxiliary losses are the losses from the transformer control cabinet and accessories – ie, mainly cooling equipment such as fans and pumps. Even for a certain level of load plus no-load losses, there can be significant differences in terms of transformer internal temperatures that will determine the dimensions of the cooling equipment and therefore its energy consumption.



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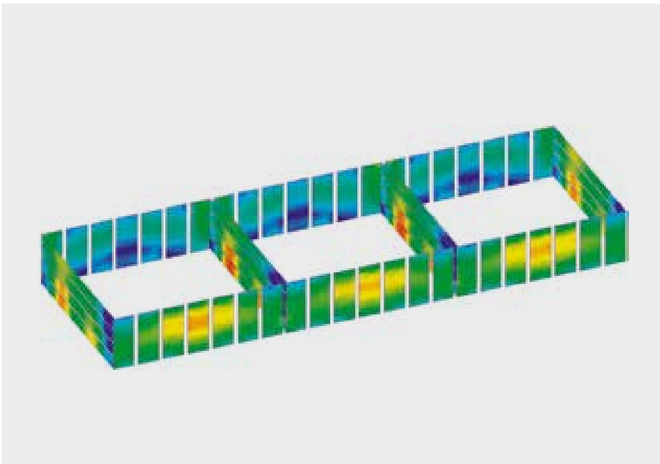

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05 ABB's Effilight traction transformer.

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06 Examples of efficiency comparison between the classic solution and ABB's Effilight.

06a Comparison of transformer efficiency as a function of the output power. Roof-mounted 1.1 MVA, 15 kV, 16.7 Hz to 25 kV 50 Hz traction transformer. Effilight offers a significant improvement in terms of efficiency compared to the classical technology in the case of bi-system traction transformers too.

06b Typical efficiency vs. weight curve for a roof-mounted 1.1 MVA, 15 kV, 16.7 Hz traction transformer. Increasing efficiency always requires increasing weight. Since Effilight offers a significant reduction of weight at equal efficiency, it is possible to get drastically improved efficiency compared to the classical technology at the same weight.

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07 The ABB transformer efficiency portal – an ABB Web site that provides a transformer cost and energy efficiency calculator and information on all aspects of transformer efficiency.

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Reference
[1] The Clean Energy Ministerial (CEM) and the International Partnership for Energy Efficiency Cooperation (IPEEC), "SEAD Standards & Labelling Working Group Distribution Transformers Collaboration. Part 1: Comparison of Efficiency Programmes for Distribution Transformers," 2013.

Tools such as computational fluid dynamics (CFD) modelling are used to calculate these temperatures, for liquid-filled or air cooled (dry-type) transformers, and thus allow the correct specification of the cooling equipment.

Transportation industry case study: Effilight® traction transformer
One case that exemplifies ABB efforts toward energy efficiency in transformers is the Effilight® traction transformer →5.

Over half the world's trains are powered by ABB traction transformers. Traditionally made of iron and copper, traction transformers are among the heavier components on a train. These transformers use oil for insulation and cooling, as oil has excellent electrical insulating properties and high reliability.

ABB's Effilight traction transformer opens up new opportunities in rail vehicle design by reducing the weight of onboard components and ensuring more energy-efficient rail networks, two of the rail industry's priority objective →6.

The benefits for the user are related to:
- Reliability and proven lifetime
- Optimization of weight, losses and energy consumption (energy costs represent around 10 percent of all rail operator expenses)
- Design flexibility (the possibility to have the same part for different mounting positions)
- Life cycle cost reduction, in terms of investment and maintenance.

The first commercial order for Effilight is for 42 units on 21 trains, the initial step of a long-term relationship intended to deliver and install up to 600 traction units for 300 trains by the end of 2024.

United for efficiency
In 2016, in line with its commitment to support transformer energy efficiency, ABB became a founding partner of the so-called United for Efficiency (U4E) group. U4E is a public-private partnership led by the United Nations Environment Program (UN Environment) and other major agencies, including the United Nations Development Program (UNDP). The program

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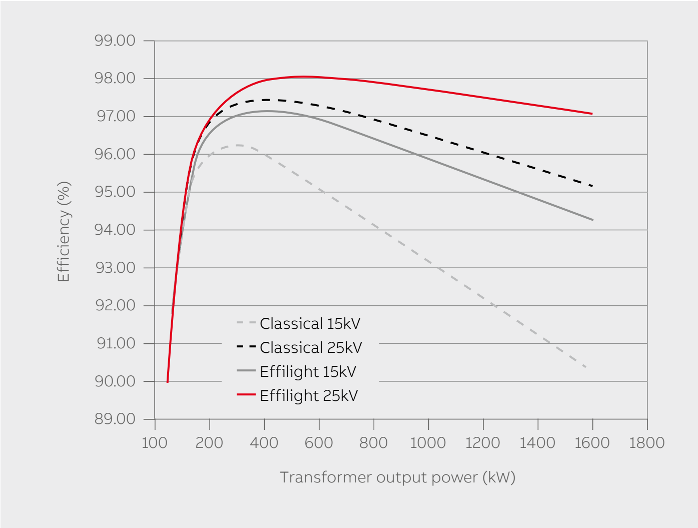
Based on an innovative approach to mechanical integration, this major advancement of a proven technology offers unprecedented energy-efficient and lightweight transformers with a smart combination of lower losses and less use of materials.

Effilight uses a unique and patented cell design that reduces the quantity of oil needed by up to 70 percent, without compromising functionality. The technology enables unprecedented weight reduction (up to 20 percent) and energy savings (up to 50 percent) for train manufacturers and rail operators thanks to a unique approach that keeps the oil exactly where it is needed around the windings.

essentially aims to help countries and economies become energy-efficient through collaboration with international companies. This collaboration includes helping governments develop and implement national and regional strategies to improve their energy efficiency – an important element in the goals of the Paris Climate Agreement, agreed in 2016, to limit the pace of climate change.

The partnership focuses on five product categories, including distribution transformers and electric motors (both with ABB representation), with the aim of accelerating and encouraging the uptake of energy-efficient electrical products.



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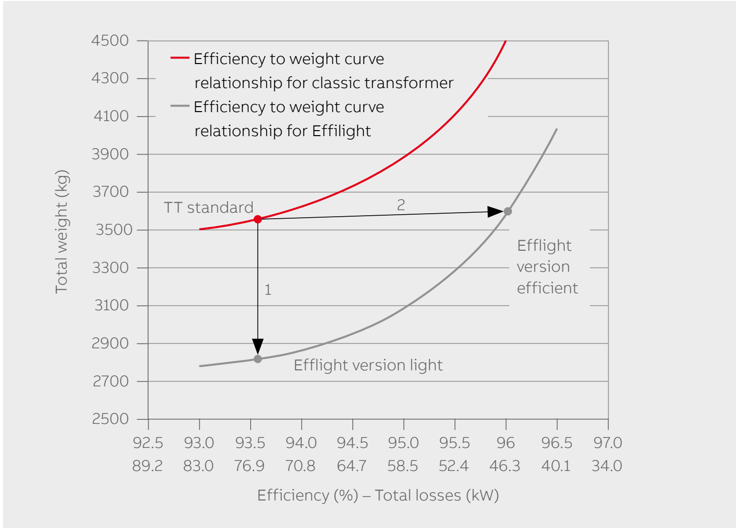

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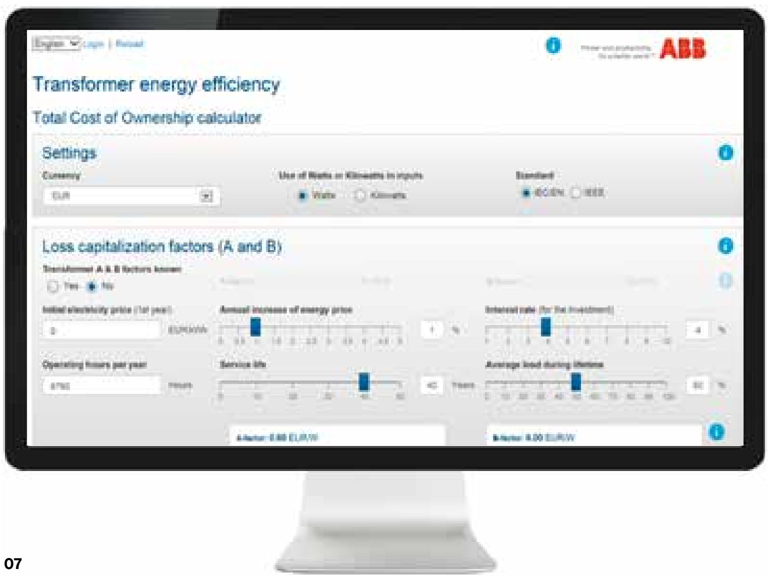
There are two main phases of ABB contribution from the transformers side: the first phase (now concluded) consisted of supporting UN Environment in creating a model that assesses the impact and benefits for relevant countries of moving toward energy-efficient transformers. Here, ABB also provided technical expertise and knowledge about appropriate energy efficiency levels and metrics.

The second phase (global outreach, now starting) will focus on distribution transformers. ABB will develop training packages and tools to support countries and regions in their transition to energy-efficient products and will provide the training. ABB will also foster interregional collaboration to promote energy-efficient products.

ABB is the first transformer manufacturer to join this initiative.

ABB transformer efficiency portal
ABB has a dedicated Web page for transformer efficiency that contains a blog and links to relevant articles and Web pages →7. The Web page also includes a useful online tool for calculation of transformer total cost of ownership (TCO). The tool also compares transformers with different initial costs and loss values from the following aspects:
- TCO with payback time on marginal cost.
- Energy consumption.
- CO_2 emission impact (in kg of CO_2) with the equivalent number of trees needed to compensate the extra emissions caused by the transformer with lower efficiency.

As energy demands rise, ever more attention will be paid to the efficiency of equipment throughout the power network. By innovating on all fronts and by adopting an open, proactive stance to the ongoing evolution of the energy world, ABB will contribute significantly to the evolution of a highly energy-efficient power infrastructure. ●



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