United to reduce global transformer losses - Around the world, day and night

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Energy is literally moving today's world, day and night, everywhere, with a direct correlation to both people's welfare and economic progress in both advanced and developing countries.

The world's energy consumption is expected to rise significantly in the coming years, especially in regions such as Asia, where strong economic growth and rising living standards are driving higher demand. The U.S. Energy Information Administration's 2019 Energy Outlook forecasts a 50 % increase in global energy consumption between 2018 and 2050 with increasingly shifts towards electricity [1].

All end-user sectors, industry, transportation, commercial and residential will drive the consumption increase with an increasing share of electricity led by different factors such as the urbanization of a growing population, higher accessibility in developing regions, the consolidation of a data driven society, increased product demand and further electrification of transport driven by electrical mobility.

Renewables will become the leading

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source of primary energy supply, accounting for most of the growth in future electricity generation, with solar and wind power dominating. The increased share of renewables will help the decarbonization of the energy sector, contributing to a significant carbon intensity reduction.

However, the increase in energy demand will mean that the global carbon dioxide (CO_2) emissions will continue to grow in the coming decades. Using renewable and clean energy sources will, therefore, not suffice on their own to decarbonize the global energy system, and further means of fast reduction in emissions are needed to keep fighting climate change.

For example, many countries and companies around the world are setting targets to reach net zero – which implies balancing emissions by absorbing and offsetting an equivalent amount from the atmosphere. But, reducing the carbon emissions in the first place must be the main global effort and there is a lot more that can be done with existing proven, more efficient, end use technologies that are not sufficiently used or prioritized.

UN Sustainable Development Goals include goal 13 to "take urgent action to combat climate change and its impacts", reminding us that greenhouse gas emissions must begin falling by 7.6 % each year starting in 2020 to limit global warming. In the context of the Sustainable Development Goals, the United Nations present energy efficiency as the key contributor to match economic growth and competitiveness along with sustainable development and a reduction of carbon emissions.

In addition, energy efficiency contributes to lower baseload and peak electricity demand, reducing the need for additional power generation and transmission assets as well as reducing consumer energy bills at the same time.

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Both energy efficiency and renewable energy are two of the main pillars of the sustainable energy transition and together can provide over 90 % of the energy-related carbon emission reductions that are required, using technologies that are safe, reliable, affordable and widely available [2].

The International Energy Agency (IEA), in its Energy efficiency 2019 report states that energy efficiency continues to deliver multiple benefits, supported by technical efficiency gains and digitalization [3]. However, energy efficiency is not only about technology: Regulations and policies to enable their widespread uptake are critical, as is the implementation of strategic market transformation programs, energy management systems and financing schemes; all of which play an important role to drive and expand the adoption of efficient technologies and solutions.

Energy efficiency and transformers

Since electricity will have a higher grow pace than the total energy consumption, the energy efficiency of the generation, transmission and distribution systems, and thus the transformers, will have an increasingly important role.

Modern transformers are one of the most energy-efficient devices, with efficiencies exceeding 99 % in many cases.

Transformer's efficiency is related to their losses that depend on the design, materials and construction, as well as on the loading and other operating parameters, such as the voltage levels, harmonics, or power factor of the load.

But the reason why they are important in reducing the energy losses and improving the efficiency of the overall system comes from the transformer application itself within the electrical system.

Transformers are used along the overall electricity value chain, sequentially converting the voltage levels from the generation source until reaching the consumer, first to increase it for more efficient transmission to reduce it subsequently for consumption. They are present in all

those steps from the generation stations, high voltage transmission substations until reaching the sub-transmission and distribution level stations closer to the consumer.

There are millions of transformers installed worldwide, operating continuously, day and night, with power passing through an average of 4 - 5 of them before being consumed, with an approximately 5 % of global electricity being lost in transformer losses [4].

Any efficiency gain has then a multiplier effect, which is the reason why energy efficiency is one of the main drivers in transformer technology evolution.

Regulations play an important role, especially related to the adoption of energy-efficient technologies. For transformers, there are minimum energy performance standards (MEPS) which are applied in many countries. Fig. 1 provides a normalized comparison of existing MEPS plotting transformer efficiency vs. rating.

However, many countries, particularly the fast growing developing and emerging economies, still do not have these types of minimum performance regulations, which is where United for Efficiency "U4E", led by the United Nations Environment Programme, is playing an important role. U4E is a public-private partnership led by the United Nations Environment Programme (UN Environment) and other major agencies, including the United Nations Development Programme (UNDP) aiming to help countries to become much more energy efficient to limit the pace of climate change.

U4E focus is on five product categories, including power distribution transformers, with the purpose of accelerating and encouraging the uptake of energy-efficient electrical products.

For transformers, the focus has been on the distribution side, being the most numerous and with comparative lower efficiency values. The estimated impact associated with the adoption of more energy-efficient distribution transformers globally would imply savings of 750 TWh in 2040, meaning an avoidance of more than 450 million tonnes of greenhouse gas emissions.

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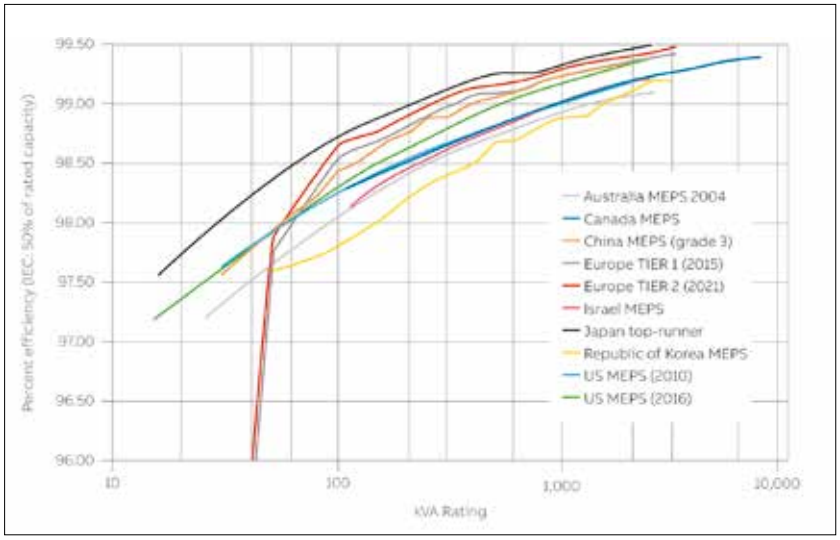

Figure 1. MEPS (normalized) for three-phase liquid filled transformers; efficiency at 50 percent load

Hitachi ABB Power Grids has been supporting U4E in a collaborative effort along with other institutions to create a model that assesses the impact and benefits for relevant countries of moving toward energy-efficient transformers, providing technical expertise and knowledge about appropriate energy efficiency levels and metrics and also supporting the development of the U4E transformer policy guide, model regulations, as well as model procurement guidelines and technical specifications.

A high-level summary of those model regulations and guidelines are presented below.

Accelerating the global adoption of energy-efficient transformers [5]

The increase in global electricity demand will be directly associated with an increase in the number of transformers, especially on the distribution side, meaning that the potential savings associated to more energy-efficient distribution transformers are huge (i.e., an annual growth rate of 3.7 % would imply more than doubling the number of transformers between 2015 and 2040).

Table 1 presents a projection of world's electricity consumption and the proportion of losses attributable to power and distribution transformers. The table also shows the energy and CO_2 savings that would result from all countries adopting or updating minimum energy performance standards (MEPS) for transformers or the best available technologies (BAT) starting in 2020.

Additionally, an energy-efficient transformer is also very appealing for the user on a life-cycle cost basis, given its non-stop operation and long service life with overall reduced losses, meaning reductions in peak loading and lower electricity bills.

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The reference TCO calculator [6] helps in computing the total cost of ownership of different transformers with different level of losses, the payback time of those more efficient transformers and the associated reduction of CO_2 emissions.

The U4E guidelines support the development and implementation of a national efficient transformers strategy with guidance meant to be flexible rather than prescriptive

Although MEPS are supporting the efforts to transition to more efficient transformers in many countries, many others are still to take action where we may find different barriers to market transformation:

- Financial: The magnitude of the first (purchasing) cost relative to less efficient technologies. The higher relative cost of energy-efficient transformers poses an initial investment hurdle, despite favorable payback periods but also the availability (or lack) of sustainable financing schemes, including new financing options or new business models such as transformers as a service.
- Market: Structures and constraints preventing efficient transformer investments. Several reasons may be behind this barrier: the limited availability of energy efficient transformers, import costs or tariffs, split the incentives

Table 1. Electricity and CO_2 savings potential of all electric power transformers globally

	DESCRIPTION	Units	2020	2025	2030	2035	2040
ELECTRICITY SAVINGS	World electricity consumption	TWh/yr	24,222	27,516	30,875	34,100	37,352
	Baseline electricity loss by transformers	TWh/yr	1,181	1,306	1,462	1,643	1,845
	% of world electricity use	%	4.88	4.75	4.73	4.82	4.94
	Annual savings from MEPS in 2020	TWh/yr	18	113	218	325	426
	Annual savings from BAT in 2020	TWh/yr	34	209	400	595	776
	Cumulative savings from MEPS in 2020	TWh	18	390	1,267	2,678	4,610
	Cumulative savings from BAT in 2020	TWh	34	718	2,331	4,918	8,444
CO_2 SAVINGS	Baseline emissions from transformer electricity losses	MT/yr	732	817	923	1,046	1,183
	Annual savings from MEPS in 2020	MT/yr	10	66	127	190	250
	Annual savings from BAT in 2020	MT/yr	20	129	248	370	483
	Cumulative savings from MEPS in 2020	MT	10	226	737	1,562	2,693
	Cumulative savings from BAT in 2020	MT	20	441	1,438	3,045	5,240

(utilities lack incentive to invest in efficiency because the cost of losses is simply passed to their customers).
- Information and awareness: Reduced level of information about efficient transformers and their benefits (level of education, training and knowledge among policymakers, financial institutions, system designers, suppliers, operations and maintenance teams, poor promotion of efficient transformer products, business-as-usual approach and risk aversion can also be mentioned).
- Regulatory and institutional: Structural characteristics of the political and legal system which difficulties in promoting efficient transformers. Policies, regulatory frameworks, monitoring / verification, and enforcement.
- Technical: Lack of resources and infrastructure for promoting efficient transformers (like adequate or accredited testing facilities, resources to monitor, verify and enforce regulations in the market, accessibility of poor-quality refurbished transformers, type of access to new materials and technologies).

The guidelines are intended for regulatory authorities in developing and emerging economies to build a legislative framework to promote energy-efficient transformers

- The level of environmental and health and safety awareness.

An integrated policy approach is a structured approach to transform a specific market towards the adoption of energy-efficient transformers, and typically includes all of the following:

- Standards and regulations;
- Supporting policies such as education and training;
- Labelling and communications outreach to all main stakeholders;
- Monitoring, verification, and enforcement;
- Finance and financial delivery mechanisms, including incentives;
- Health and environmentally sound management measures.

The U4E guidelines support the development and implementation of a national efficient transformers strategy with guidance designed to be flexible, rather than prescriptive.

The idea behind this approach is to enable each country to consider and make decisions based on its specific priorities and circumstances. The process should involve all relevant authorities and stakeholders in jointly determining priorities and the most appropriate pathways to achieve them. It can be applied to large power and distribution transformers in both utility networks as well as those used in commercial and industrial applications.

The U4E model regulation guidelines are available to support those efforts [7].

Providing manufacturers with a set of clear, current, and correct specifications is the key to procuring high-quality, optimum energy performing transformers

Model regulation guidelines: Energy performance requirements for distribution transformers

The guidelines are intended for regulatory authorities in developing and emerging economies to build a legislative framework to promote energy-efficient transformers, or by those already having a legislative framework but who have not yet developed regulations.

The model regulation includes all the key elements to regulate a transition from inefficient distribution transformers to the international best practice of energy performance levels: Definitions, scope, performance requirements, information requirements, applicable test methods and compliance criteria.

The scope covered includes liquid-filled and dry distribution transformers in the 5 – 3150 kVA rated power range, voltage Um up to 36 kV at 50 and / or 60 Hz; and continuous duty operation, addressing:

- Energy performance requirements;
- Product information reporting and labelling;
- Demonstrating compliance; and
- Market surveillance and enforcement of the requirements;

with two technical standard rating alternatives in accordance with IEC and IEEE practices.

The model guidelines are not covering other requirements that are not primarily related to energy performance that is typically covered by relevant International standards like the mechanical construction, functional performance, safety, hazardous substances, or warranty. When developing their own requirements, countries should investigate and confirm that these other requirements are covered in parallel regulations.

The model regulations include two options, to facilitate use by governments when initiating their national consultative policy-making processes.

Countries without a significant domestic distribution transformer manufacturing industry and that import almost all of them, can choose to leapfrog to a Level 2 high energy performance option, the international best practice.

Other countries that do have an industry can choose a graduated transition via a Level 1 basic energy performance option, in order to provide its industries with additional time for technology upgrading.

The U4E programme encourages countries to use the Level 2 Option because it offers greater energy savings potential and the availability of worldwide standardized products.

The policy guidance presented in this document is meant to be a starting point

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for policymakers to encourage regional harmonization where possible, lowering costs and removing barriers to trade.

An additional document is available [8] to assist in the preparation of procurement specifications for liquid immersed distribution transformers.

Procurement guidelines: Model liquid immersed distribution transformer technical specification

This model technical specification is intended to guide transformer purchasers, like utilities, in their national and international markets, as the very first step towards owning transformers that offer maximum value is preparing clear and concise specifications.

While writing any specifications, the challenge always lies in striking the right balance between being specific and generic, besides ensuring its accuracy and practicability.

Too generic or inaccurate or impractical specifications lead to confusion during the bidding stage, which can ultimately snowball into disputes and the procurement of transformers that do not fully comply with a utility's requirements. To a large extent, clarity and effectiveness of specifications also depend on the formatting of the specification document. Well-structured specifications aid in readers' understanding, thereby improving the prospects of compliance or frank discussion about non-compliances.

Providing manufacturers with a set of clear, current and correct specifications is the key to procuring high-quality, optimum energy performing transformers and lowering the total cost of ownership.

Two annexes provide sample specifications that purchasers can adopt, either as they are or to use as a baseline to adjust to their own unique specifications.

The sample technical specifications are almost ready to be used and additional comments and suggestions to each clause of the specifications are provided. A general guideline on procurement is also provided within the document.

Is energy efficiency an option?

Increasing energy efficiency is a global effort with many stakeholders involved. When it comes to transformers, regulators, manufacturers, users, and the whole industry have a role to play.

Lower loss transformers are available, supported by technology and material development.

MEPS and energy efficiency regulations are contributing but are not generally widespread. U4E is helping with a structured framework and supporting information to facilitate the global adoption of more energy-efficient transformers.

The benefits of switching to more energy-efficient transformers are significant and justified, not only looking at the economical side (payback evaluated using tools like the total cost of ownership) but also to the contribution to the overall electricity system, as lower global losses mean less generation, more grid capacity that can postpone or simply avoid investments in unnecessary capacity additions, all with the consequent reduction of CO_2 emissions and a positive impact to the environment.

Business social responsibility programs are increasingly incorporating energy efficiency initiatives that value their associated sustainability and environmental benefits, improving the companies' image and helping them to stay competitive and attractive to customers but also contributing to net-zero initiatives to avoid and offset CO_2 emissions.

Energy efficiency may be considered by some as the only an option today, but it is likely to be a necessity and the only option, for everyone, everywhere and especially for transformers that run day and night powering the world, very soon.

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