ABSTRACT

The EU ecodesign regulation for power transformers is currently under revision. While no option for reducing energy losses can be ignored in light of the European Green Deal, there are concerns about what impact stricter minimum energy performance standards could have on costs and material use. To what extent do alternative design strategies or a systems approach to material use change how this subject is viewed? And how far will a decline in energy losses compensate for the extra capital investment? The European Copper Institute (ECI) conducted a quantitative comparison between various scenarios and design strategies.

KEYWORDS:

energy efficiency, materials, losses, cost, total cost of ownership, EU regulations

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Improving energy and material efficiency in distribution transformers

Assessing the impact of stricter minimum energy performance standards on cost and material use

Tier 3 MEPS cost-benefit analysis

With its Green Deal, presented in December 2019 [1], the EU aims to fight climate change and environmental degradation while safeguarding economic growth at the same time. These goals can be achieved and reconciled by a shift from fossil fuels to low-carbon electricity and by sustained efforts to improve energy efficiency. In this context, any additional efficiency gain in the electricity grid would be welcome.

The ongoing revision of the EU ecodesign regulation for power transformers could be a good opportunity to tighten its minimum energy performance standards (MEPS) from the Tier 2 minima to more stringent Tier 3 values. Improving energy efficiency, however, increases unit cost and weight if all other parameters are kept the same. The energy transition already impacts capital costs and material use substantially, which raises the legitimate question of whether making transformer MEPS more stringent is worth the effort, especially since transformers are already highly efficient.

A reasoned answer to this question requires a life-cycle evaluation and systems perspective. In the end, what does it mean for total cost of ownership (TCO) and energy system material use? Declining energy losses in a transformer translate into savings of material and land use for generation infrastructure as well as

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for upstream transmission and distribution networks. Moreover, alternative material and design choices hold the potential to uncouple energy efficiency from transformer weight. In a quantitative comparison between various scenarios and material choices, the European Copper Institute (ECI) sheds light on these questions.

Investigating four regulatory scenarios

The ECI study investigated the impact of stricter MEPS on a typical distribution transformer with nominal ratings as shown in Table 1.

In an initial general assessment, sixteen different permutations were considered, combining no-load loss reductions (A0) of 10%, 15%, 20%, and 25%, in turn with load loss (Ak) reductions of 0%, 5%, 10%, and 15%. Combining a 10% no-load loss reduction with a 0% load loss reduction corresponds to ecodesign Tier 2 and was taken as the base case.

Following this initial assessment, four scenarios were selected for further investigation, corresponding to cases 3, 4, 5, and 6 in Table 2. All other scenarios were ignored because a quick assessment revealed an inappropriate balance between load losses and no-load losses, insufficient loss reduction, excessive capital costs, or a combination of these drawbacks.

The study used professional design software to develop two transformer designs, one with aluminium windings and one with copper windings, for each of the four selected Tier 3 scenarios as well as a Tier 2 transformer, resulting in a total of 10 transformer designs.

The results revealed the changes in volume for the entire transformer and in the mass of each of the transformer materials. Note that not all material masses increase with increasing energy efficiency. In particular, the weight of the tank and its oil content diminish in some of the scenarios because of the reduced cooling needs associated with lower energy losses.

To derive the unit cost from the material masses, material prices were assumed to be as in Table 3, based on in-house research by the European Copper Institute.

To calculate the lifetime cost of the losses in the transformer, its root mean square (RMS) load was assumed to be 30% [2, 3, 4], its lifetime 40 years [2, 3], the electricity price €0.13/kWh [2] and the annual interest rate 2%.

Table 1. The nominal ratings of a typical distribution transformer

Rated power	630 kVA
Rated frequency	50 Hz
Number of phases	3
Short circuit impedance	4%
MV winding Um	Um ≤ 24 kV
LV winding Um	Um ≤ 1,1 kV
Type	liquid-immersed

Table 2. Nine different combinations of reductions in no-load losses (A0) and load losses (Ak) that could be introduced with Ecodesign Tier 3 MEPS

Cases	Ak	Ak-5%	Ak-10%	Ak-15%
A0-10%	Tier 2	1		
A0-15%	2	3	4	
A0-20%		5	6	7
A0-25%			8	9

Cost, mass, and energy savings

In identifying the significant trends arising from the exercise, it is interesting to compare Tier 3 scenarios #3 (A0-15%, Ak-5%, designated Tier 3a) and #6 (A0-20%, Ak-10%, designated Tier 3b) with the base case of Tier 2 (A0-10%, Ak-0%) for both aluminium and copper designs. Table 4 displays the main results of this comparison for metal mass, total mass,

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system mass, volume, total cost of ownership, and energy savings.

An increase in capital costs is seen when shifting to Tier 3, mainly due to larger quantities or higher quality of materials.

Over time, this upfront investment is compensated by the reduction in the net present value of the energy losses, resulting in a TCO that remains relatively constant, as seen in Figure 1. This means that the introduction of Tier 3 MEPS would not have a significant negative economic impact over the long term.

Transition to Tier 3 can result in either more or less material use in the transformer itself, depending on the conductor material used and other design choices, as seen in Figure 2.

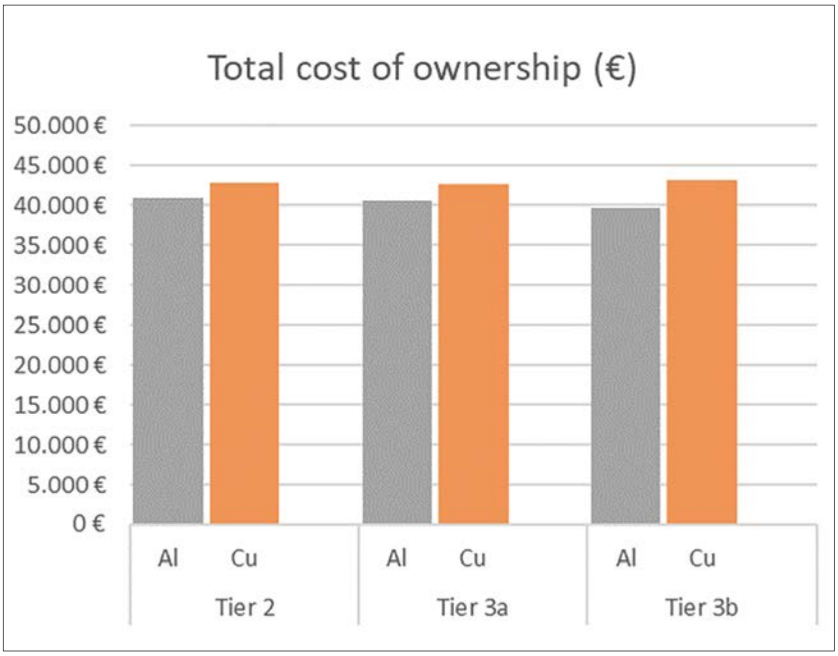

Figure 1. Comparing the Total Cost of Ownership between Tier 2, Tier 3a, and Tier 3b scenarios for both aluminium and copper designs

Table 3. Prices of the main materials used in a distribution transformer

Material	Cost per kg
Aluminium	€6.00
Copper	€12.00
Magnetic sheet (quality M070 = 0.70 W/kg at 1.7 T)	€5.50
Oil	€2.00
Tank + cover	€4.50

Table 4. Main results of the comparison between Tier 3 scenarios #3 (Tier 3a) and #6 (Tier 3b) with the base case of Tier 2 for both aluminium and copper designs

Summary for a 630 kVA transformer	Aluminium			Copper		
	Tier 2	Tier 3a	Tier 3b	Tier 2	Tier 3a	Tier 3b
	(A0-10%) (Ak)	(A0-15%) (Ak-5%)	(A0-20%) (Ak-10%)	(A0-10%) (Ak)	(A0-15%) (Ak-5%)	(A0-20%) (Ak-10%)
Mass of metals transformer (kg)	2004	2203	2295	1679	1851	2125
Total mass transformer (kg)	2370	2590	2730	1941	2131	2425
Mass of metals system (transformer + wind generation) (kg)	3167	3304	3335	2842	2952	3165
Total mass system (transformer + wind generation) (kg)	10547	10332	10037	10118	9873	9732
Inside volume (m^3)	0.74	0.81	0.88	0.43	0.49	0.56
Total cost of ownership (€)	40822	40540	39657	42875	42678	43155
Energy savings compared to Tier 2 (kWh/year)	0	444	888	0	444	888

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For European policy making, the balance of material use should be addressed at the system level, including the electricity generation infrastructure needed to generate the energy losses to the equation and the transformer itself. In its investigation, ECI made a first step towards such a systems approach, making the assumption that losses in the transformer are generated by onshore wind turbines. The relevant data were obtained from the Renewable Energy Materials Properties Database (REMPD) from the US Department of Energy (DOE), which is a consolidated data repository on wind and solar plant material use.

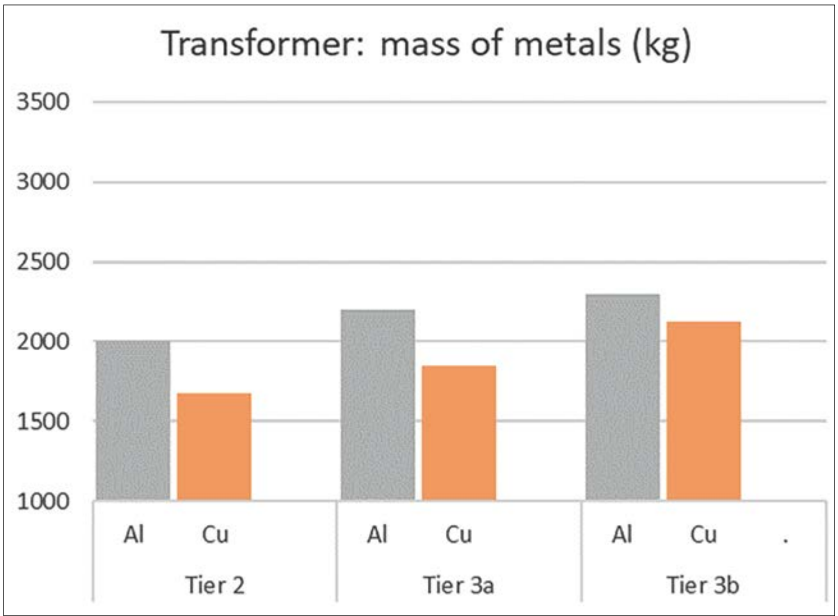

Figure 2. Comparing the mass of metals (kg) in the transformer between Tier 2, Tier 3a, and Tier 3b scenarios for both aluminium and copper designs

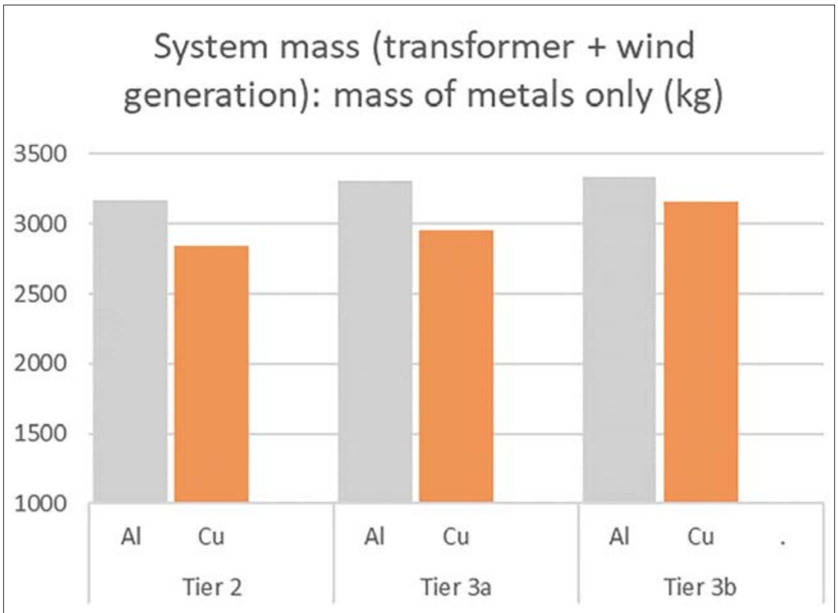

Figure 3. Comparing the mass of metals (kg) in the entire system, including the transformer and the generation capacity needed to supply the transformer losses, between Tier 2, Tier 3a and Tier 3b scenarios for both aluminium and copper designs

The database lists the types and quantities of materials required per megawatt (MW) of generation capacity (values for onshore wind: steel 143 kg/kW, cast iron 12 kg/kW, composites and polymers 29 kg/kW, other metals and alloys 19 kg/kW, concrete 404 kg/kW, road aggregate 613 kg/kW, and other materials 3 kg/kW). Assuming that onshore wind turbines have an annual productivity of 2500 hours full load equivalent and a lifespan of 20 years, material use for onshore wind generation infrastructure ranges between 400 and 900 kg per MWh per year.

Figure 3 shows the aggregated impact on metal use when adopting such a systems approach.

Figure 4 shows the same aggregated impact, but this time taking all materials into account. A 4% to 8% net material use reduction can be observed when introducing Tier 3 MEPS for transformers compared to a continuation of Tier 2.

These figures show that a transition towards Tier 3 MEPS could be compatible with the potential future introduction of material efficiency requirements (MMPS). Computed with an aggregated EU level distribution transformer capacity of 1250 GVA, the EU-wide material savings potential of Tier 3 MEPS for transformers ranges between 0.8 and 1.6 million tonnes.

The annual energy savings for a 630 kVA transformer would be 440 kWh for scenario Tier 3a and 888 kWh for scenario Tier 3b. Extrapolating the latter figure to the EU level, the Tier 3b scenario represents an annual electricity savings potential of 1.8 TWh.

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system-wide, long-term impact that could be expected when introducing Tier 3 MEPS for power transformers. Since the results are largely positive, a more far-reaching investigation assessing the impact of such regulatory evolution is desirable. Such an investigation should include a sensitivity analysis of input parameters such as material prices and the load factor, as well as a Life Cycle Assessment (LCA).

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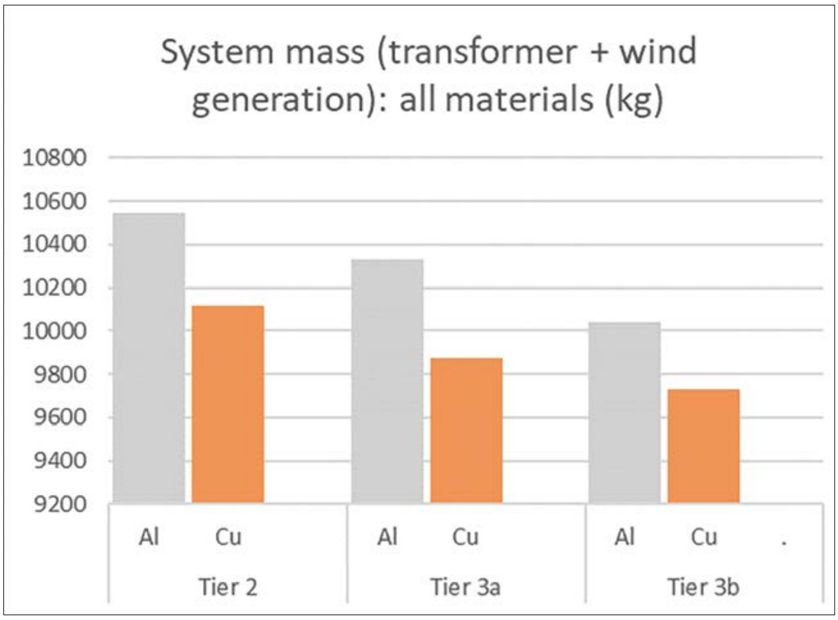

Figure 4. Comparing the mass of all materials (kg) in the entire system, including the transformer and the generation capacity needed to supply the transformer losses, between Tier 2, Tier 3a, and Tier 3b scenarios for both aluminium and copper designs

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