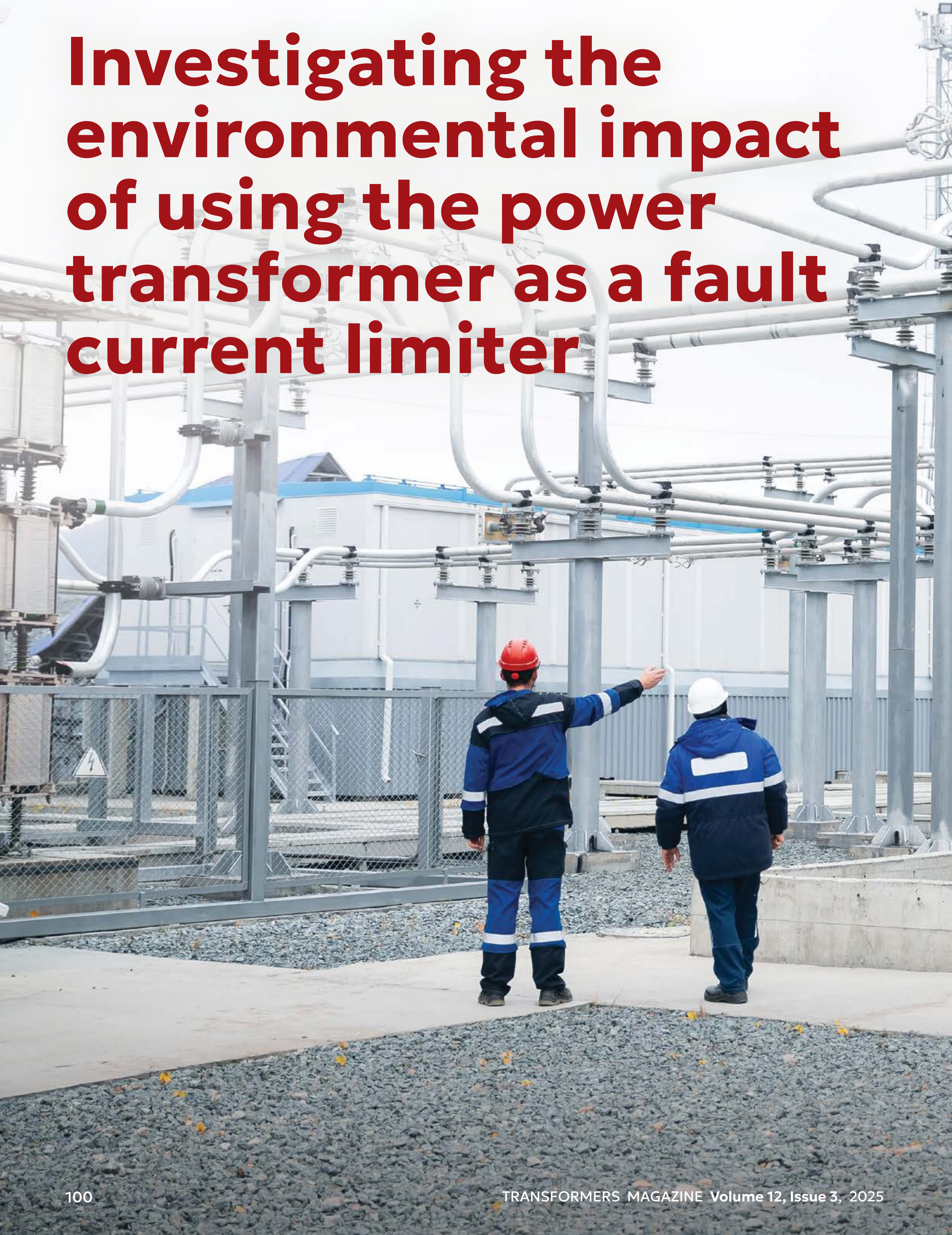
Investigating the environmental impact of using the power transformer as a fault current limiter



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ABSTRACT

The demand for electrical energy is growing rapidly. Renewable energy resources, such as solar and wind, are growing fast as these low emission sources are key milestones on the pathway to net zero emissions by 2050. As more and more generations are added, the associated fault currents increase. When transformers are operated in parallel to enhance the reliability of the system, the fault current increases as well. To deal with fault currents, there are different types of fault current limiters (FCL). One traditional measure to limit the short-circuit fault current is to increase the impedance of the transformer. This article investigates the environmental implications of this fault current limiting method. The environmental performance of a 62.5 MVA 154/33.6 kV transformer at 12% impedance is compared against a 62.5 MVA 154/33.6 kV transformer at 20% impedance in terms of tons of carbon dioxide equivalent emissions.

KEYWORDS:

fault currents, fault current limiter, environmental impact, environmental performance, power transformer, carbon footprint

Electricity will become the core of the energy system and will play a key role across all sectors, from transport and buildings to industry, thereby increasing the fault current levels

1. Introduction

The world has seen considerable economic growth in recent decades, and consequently, the demand for electrical energy has increased manifold. To reach net zero emissions by 2050, annual clean energy investment worldwide will need to more than triple by 2030 [1]. Electricity will become the core of the energy system and will play a key role across all sectors, from transport and buildings to industry. It is clear that because of this demand, the fault current level will be increasing. Thus, electrical utilities would need to continuously upgrade their systems to handle the demand. The fundamental problems with high fault currents are:

- High mechanical dynamic stress.
- High thermal stress.
- The need for sophisticated and higher rated circuit breakers.

There are different types of fault current limiters (FCL) employed by utilities – a) permanent impedance increase during nominal and fault conditions, b) condition-based impedance increase: small impedance at nominal load and fast increase of impedance during fault. CIGRE Technical Brochure 239 [2] presents the state of the art, functional specifications, system demands and testing of FCLs, while CIGRE Technical Brochure 497 [3] presents the feasibility of FCLs in power systems. There are different types of FCLs – traditional current limiting reactors, which have been in service for many years now, while newer technologies, superconducting FCL, solid state FCL, and hybrid FCL have completed the substantial research and development phase and are anticipated to be used in commercial applications soon. [4] presents a comparative table of the newer technologies, which shows that most of the technologies are in the medium voltage range. A successful testing and demonstration project for a 10 MVA, 11 kV FCL was published in [5].

Typically, impedance values are specified in IEC 60076.5 [6]. However, when voltage levels rise, the fault current levels also rise, which in turn means larger high impedance transformers are required. Also, when transformers are operated in parallel to enhance the reliability of the system, the fault current increases at the secondary side, so high impedance transformers are required as well.

This article will compare the outcomes of total life cycle carbon emission assessment for the 62.5 MVA 154/33.6 kV transformer at 12% and 20% impedance values

This article investigates the environmental implications of the practice of limiting fault current using high impedance transformers. The environmental performance of a 62.5 MVA 154/33.6 kV transformer at 12% impedance is compared against a 62.5 MVA 154/33.6 kV transformer at 20% impedance in terms of tons of carbon dioxide equivalent emissions for countries with a predominantly fossil based electricity mix.

2. Ideal requirement for FCL

The ideal FCL characteristics can be summarized as follows:

- Low impedance during normal operation (low voltage drop across the device)
- Low losses
- Adequate current limiting performance
- Compatibility with existing or planned protection schemes.
- No deterioration of the limiting behavior during the useful life
- High reliability
- Low maintenance requirements
- No risk for personnel
- Low impact on the environment

In practical installations, such an ideal FCL is not achievable, and different design compromises have to be made. With higher impedance, a higher voltage drop is introduced, requiring a higher voltage to produce the full load current. Low impact on the environment is also a requirement. Since higher impedance transformers are still specified by the end users, especially under parallel operation to achieve security of supply, this article will compare the outcomes of total life cycle carbon emission assessment for the 62.5 MVA 154/33.6 kV transformer at 12% and 20% impedance values.

3. Transformers under consideration

For this study, two transformers with identical requirements, optimized designs for different impedances, are evaluated as listed in Table 1. The impact of increasing the impedance on limiting the fault current is listed in Table 2.

4. Design outcome comparison

4.1 Transformer efficiency outcomes

The transformer loss outcomes for the two different designs are listed in Table 3.

4.2 Transformer component mass outcomes

The outcome of the two design variations is shown in Table 4.

Table 1. Major Design Parameters for the comparison study

	Design 1		Design 2	
Rating	50 MVA ONAN/62.5 MVA ONAF			
Phases	3-phase			
Impedance	12%		20%	
Voltages	154 kV/33.6 kV			
Max Flux density	1.63T			
Tapping	154±12*1.25%			
Sound Power Level	82 dBA			
BIL	HV: 650 kV, LV: 170 kV			
Max No Load Loss	30 kW			
Max Load Loss	250 kW			
Capitalization Factors	No Load Loss Factor (A) = \$7500/kW Load Loss Factor (B) = \$2500/kW			
Temperature Limits	Ambient	Top Oil Rise	Winding Temperature Rise	Hot Spot Rise
	45°C	55K	60K	73K

Table 2. Reduction in short circuit current comparison: Design 1 vs Design 2

	Design 1	Design 2
Rating	50 MVA ONAN/62.5 MVA ONAF	
Nominal Voltage	154 kV/33.6 kV	
Impedance	12%	20%
LV Full Load Current	1074 A	1074 A
Short Circuit Current (SCC) (rms)	8.95 kA	5.37 kA
SCC Under N-1 contingency	17.9 kA	10.74 kA
SCC Under N-2 contingency	26.85 kA	16.11 kA

There is almost 3% increase in the weight of the copper windings, and a marginal increase in the weight of the tank steel requirements by 2%

Table 3. Transformer loss values for the different designs

Parameters	Design 1 X = 12%	Design 2 X = 20%
No Load Loss (kW)	21	17
Load Loss (kW)	203	269
Total Loss	224	276
Peak Efficiency Index (PEI) Design output	99.79%	99.78%
K_{PEI}	32.2%	24.6%

The material carbon footprint for Design 2 (X=20%) is 226 tCO_{2e} compared to Design 1 (X=12%) of 220 tCO_{2e}, which is only 2.75% increase overall

The percentage variation of different components is shown in Figure 1. The major components with the highest contribution are Steel (electrical steel and carbon steel), copper windings, oil, contributing almost ~90% of the total weight of the transformer. As seen from Figure 1, there is almost 3% increase in the weight of the copper windings, and a marginal increase in the weight of the tank steel requirements by 2%.

Table 4. Main Component Mass Outcomes for the two designs

Component Mass	Design 1 X = 12%	Design 2 X = 20%
Core coil assembly (kg)	45,000	42,100
Radiators and conservator (kg)	7,895	9,275
Oil (kg)	18,945	19,000
Tanks, turrets and bushings (kg)	14,865	16,415
Total weight (kg)	86,705	86,790

Environmental impact comparison

Overall, the material carbon footprint for Design 2 (X=20%) is 226 tCO_{2e} compared to Design 1 (X=12%) of 220 tCO_{2e}, which is only 2.75% increase overall. Figure 2 shows that the material carbon footprint for a high impedance transformer is marginally higher than that of a lower impedance transformer.

Figure 2 also shows that the operational carbon footprint for a high impedance transformer is almost 18.6% higher than a lower impedance transformer (under 50% load factor, with a Grid Emission Factor = 0.669 and considering a lifetime of 35 years).

Conclusions

The traditional passive current limiting measure of permanent impedance increase during nominal and fault conditions by high impedance transformers increases both the material and operational carbon footprint. In this article, the environmental performance of a 62.5 MVA 154/33.6 kV transformer at X= 12% against X = 20% impedance shows

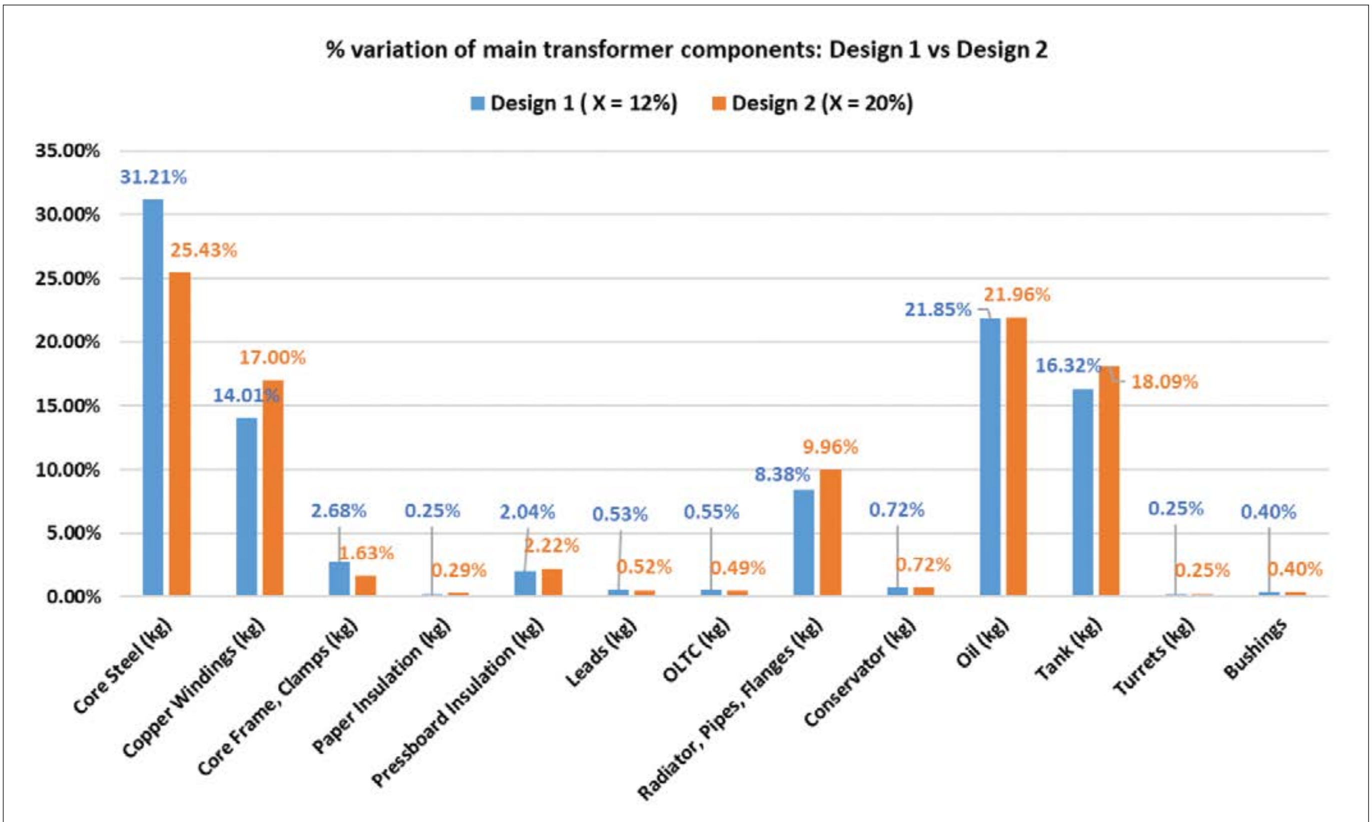

Figure 1. Percentage variation comparison of main transformer components – Design 1 vs Design 2

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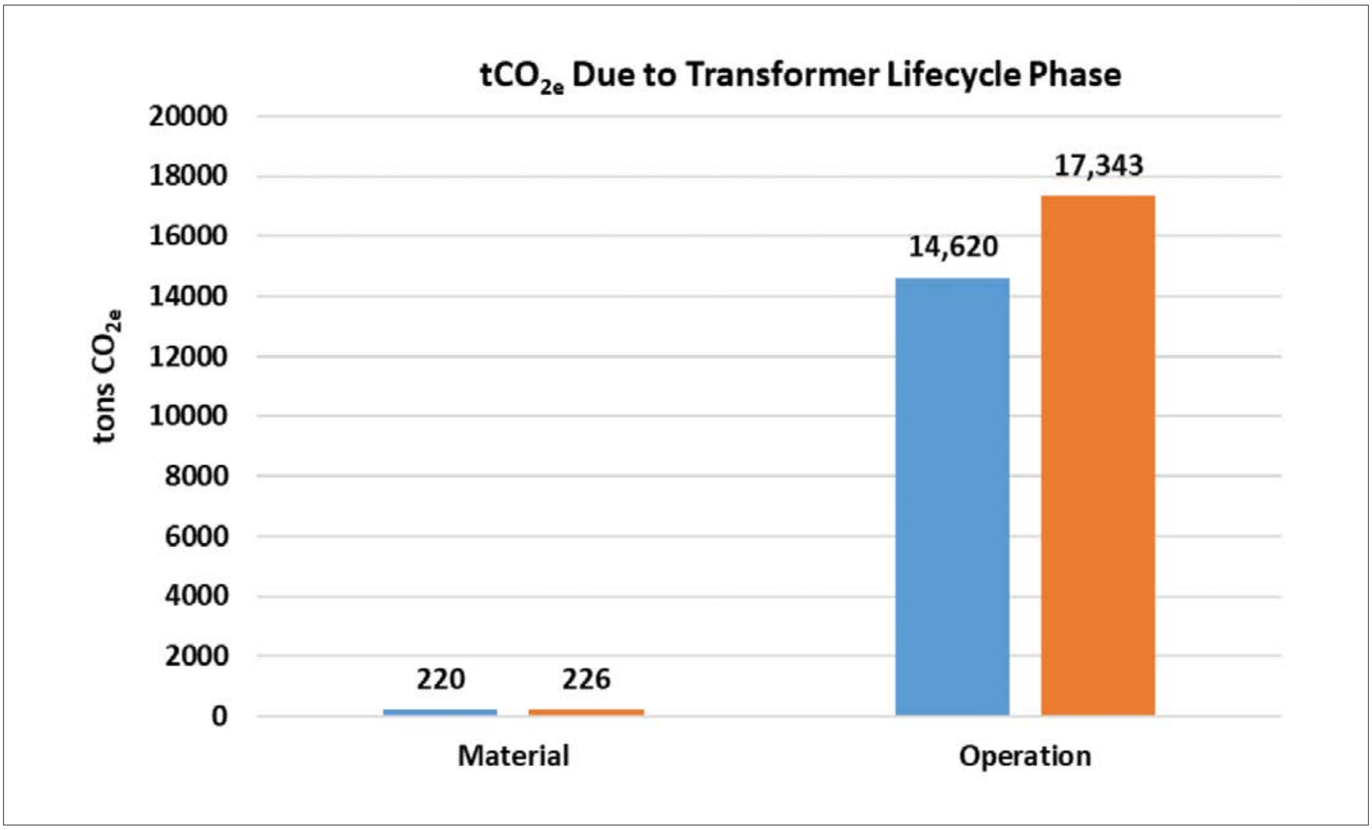

Figure 2. Comparison of material and operational carbon footprint: Design 1 vs Design 2

that almost 20% of the carbon footprint is increased during a considered lifetime of 35 years.

Newer technologies such as condition-based impedance changing devices, that exhibit a small increase in impedance at nominal load and a fast increase in impedance under the fault conditions must be investigated to determine the impact on carbon footprint during the lifetime of the device.

The environmental performance of a 62.5 MVA 154/33.6 kV transformer at X= 12% against X = 20% impedance shows that almost 20% of the carbon footprint is increased during a lifetime of 35 years

Reference

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