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Sustainable Industrial Policy – Building on the Ecodesign Directive – Energy-Using Product Group Analysis/1

LOT 2: Distribution and power transformers
Draft task reports
Task 3: User Behaviour

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Important note:
This report contains the updated draft results of research by the authors and is not to be perceived as the opinion of the European Commission.
This is an updated draft document intended for stakeholder communication.

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0 INTRODUCTION

VITO and BIOIS are performing the preparatory study for the new upcoming eco-design directive for Energy Using Products (EuP) related to power and distribution transformers, on behalf of the European Commission (more info http://ec.europa.eu/enterprise/eco_design/index_en.htm).

The Ecodesign Directive (2005/32/EC) provides coherent EU-wide rules for eco-design. The Directive does not introduce directly binding requirements, but defines conditions and criteria for setting requirements regarding environmentally relevant product characteristics and allows them to be improved quickly and efficiently. Products that comply with these requirements may have the CE mark attached, those that not comply could ultimately be prohibited from being traded within the EC. It contributes to the sustainable development by increasing energy efficiency and the level of protection of the environment, taking into account the whole life cycle cost.

The MEEuP methodology (Methodology for the Eco-design of Energy Using Products) allows the evaluation of whether and to which extent various energy-using products fulfil the criteria established by the Ecodesign Directive for which implementing measures might be considered. The MEEuP model translates product specific information, covering all stages of the life of the product, into environmental impact.

The preparatory phase of this study is to collect data for input in the MEEuP model.

1 DEFINITION

See draft document on the project website www.ecotransformer.org .

2 ECONOMIC AND MARKET ANALYSIS

See draft document on the project website www.ecotransformer.org .

3 USER BEHAVIOUR

Scope:

This chapter explores the consumer behaviour and local infrastructure aspects for transformers and their influence on the energy and environmental performance of these devices.

Product-design may influence the consumer behaviour to some extent which consequently will influence the environmental impacts and the energy efficiency associated with the product during its use phase. Consumer behaviour has a significant direct effect on the use of transformers equipment during all phases of their life-cycle.

Analysing the consumer behaviour and real life situation in comparison with the standard test conditions will provide a more accurate picture of the real energy use.

This section aims to identify the user parameters and also the barriers to possible eco-design measures, due to social, cultural or infra-structural factors.

Please note that this section is currently only related to 'Distribution and power transformers' and not related to smaller industrial transformers. The information on smaller transformers is not yet available, this will be completed during the progress of the study.

Summary:

The most important information contained in this chapter is about the transformer load profiles because they have a significant influence on the real life efficiency of the transformer. The characteristic parameters are the Load Factor (α) and the Load Form Factor (Kf) that were defined for different user profiles. Apart from that also the End-of-Life behaviour is important, it has been reported that about 99% of the transformers are recycled. This high amount of recycling can be explained by the high residual value of the transformer scrap materials (steel, copper, aluminium, oil).

To be completed in the progress of the study

3.1 User Information

Objectives:

The objective of section 3.1 is to investigate the influence of providing product information to the end-users and on the influence it can have on the environmental performance of the equipment, and on eco-practices in sustainable product use; and whether it could be useful to consider labelling or provision of other eco-information (e.g. ecological profile of the product). Barriers to the provision of such information and eco-design measures, due to social, cultural, and infrastructural factors will also be investigated.

3.1.1 Definition of type of users

These products are procured in a B2B market with technical and economic skilled end users.
In general, there are two types of users of transformers within the scope of this study:

1. *Utilities* that operate the electrical distribution or transmission grid, also called Transmission System Operators (*TSO*) or Distribution System Operators (*DSO*) (see also chapter 1).
2. *Owners* of *large industrial plants* or *large sites in the tertiary sector* (e.g. office building, hospital, shopping mall, ..)
3. *Owners of small industrial transformers.* Stakeholders are invited to provide more precise information.

3.1.2 Method of providing product information

These products are procured in a business to business market with technical and economic skilled end users. Lacks of user information can often be deducted to a lack in standards. A missing standard is frequently caused by a disagreement amongst manufacturers on test methods.

In chapter 1 no such missing standard is identified, hence maybe we should not define this as a barrier? Stakeholders please comment.

Is this also the case for the smaller industrial transformers?
Stakeholders please comment.

3.1.3 Influence and impact of product information

3.1.3.1 Lack of awareness on environmental impact of transformer and network losses

End-users possibly do not assess their purchase nor evaluate the available technology options and related energy (and cost) saving potentials for their specific situation. In many cases the new equipment is purchased when the old equipment fails and there is no time to analyse in detail the purchase decision. Purchase decisions for transformers are often not made on life cycle cost or payback considerations. Utility distribution and transmission companies follow an elaborated procurement process (call for tender), and normally select the product providing best value for money i.e. a transformer that meets specifications at the lowest cost. The green public procurement and eco-responsible purchase in private sector are important initiatives to be analysed.

Many utilities do not publish their inventories and network losses at the detail level of transformers losses (ERGEG[1] (2008), (SEEDT (2008)), however network losses are most simply accounted in the distribution cost. Making this detailed information public to the end user or network client might increase awareness.
Stakeholders please comment.

3.1.3.2 Lack of user acceptance for higher cost and long pay back periods

Efficient transformers are often more expensive (see task 2). Purchasers search for the lowest priced equipment that meets the facility's needs and do not necessarily accept or take into account long payback period.

Industry will not be able to replace their transformers if the pay-back time is >20 years. This is only feasible for utility transformers because they calculate the pay back on a very long period.
For smaller industrial transformers this might be even more the case, when transformers do not have significant annual operational hours.

Industry might also benefit from information on the residual value of the transformer after the depreciation time period (e.g. 10, 15, 20 years) due to the copper and steel scrap material price. A solution might be to provide information on the value of scrap material in relation to the product price.
Stakeholders please comment.

3.1.3.3 Lack of information on energy efficiency of existing transformers in service

Furthermore, operators will often not substitute transformers before they fail. Although they may be aware of the losses, or maybe oversized older, less energy-efficient transformers, it is not foreseen realistic to change them. In many cases the losses of existing transformers are not exactly known, as they are not included on the transformer nameplate (picture will be add).
In order to avoid this situation in the future it could be recommended to include the load and no-load losses on the name plate, alternatively the classes as defined in EN 50464-1 for oil filled transformers.

Options are:

A. No information on transformer name plate;
B. Add the load and no-load losses on the name plate;
C. Add a load and no-load losses class indicator on the name plate (e.g. EN 50464-1);
D. Add a separate energy efficiency label similar to household appliances.

Stakeholders please comment.

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[1] ERGEG (2008): ERGEG Position Paper for public consultation, Treatment of Losses by Network Operators, Ref: E08-ENM-04-03

3.1.3.4 Possible barrier by lack on information on dimensional an physical constraints

More efficient transformers tend to be bigger in size and heavier in weight. This could be of concern for retrofit applications, mining applications, telephone pole capacities, and other installations where transformers have to comply with dimensional or physical constraints. As approximately 80% of transformers sold are for replacement installations (DOE, September 2007[2]), this issue of pre-existing space limit will cause problems.

There might be a need to timely inform the user on this increased need for installation space.

Stakeholders please comment.

3.1.3.5 Any other need or method product information

Stakeholders please comment.

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[2] Department of Energy (DOE), Technical support document: energy efficiency program for commercial and industrial equipment: electrical distribution, September 2007

3.2 User behaviour in the use phase

The end-user behaviour has a significant impact on the transformer’s overall environmental performance. This paragraph describes the most important functional performance parameters of transformers which influence the energy efficiency and transformer application.
Furthermore best practices and maintenance practices to reduce failures and improve the overall performance of a transformer are discussed.

3.2.1 Real life efficiency

3.2.1.1 Transformer load profile

a) General introduction

The key input for estimating the distribution of the transformer energy use in real life is the transformer load profile.

A load profile is a graph of the variation in the electrical load versus time. In an electricity distribution network, the load profile of electricity usage is important to the efficiency and reliability of the power transmission.

The sizing and modelling of transformers depends on the load profile. Transformers need to be sized to cope with expected peak loads, rather than average loads. A transformer typically has a cyclic rating allowing for the variation in the load profile. This cyclic rating allows the transformer to be overloaded at peak times as long as there is a sufficient cooling down period at the lower point in the load profile.

For example, distribution transformers serving primarily residential loads regularly carry average loads that are only 15 percent to 20 percent of the transformer's rated capacity but also must be designed to support peak morning and evening loads. Because of the wide gap between peak and non-peak loads, and the relatively limited amount of time that the transformer is peak-loaded, average transformer load tends to be fairly low. In this case, total losses may be mainly attributed to core losses.

Larger distribution transformers, used more often in transforming power for commercial or industrial customers, tend to be loaded at higher average levels over the course of the year. Transformers that serve businesses operating from 9:00 am to 5:00 pm, for example, typically experience a consistent and relatively higher load throughout the day.

The factory specification of transformers thus depends on the characteristics of the load profile that the transformer is expected to be subjected to. The main characteristics are the average *load form factor (see § d) and the load factor* (see § e), which can all be calculated based on a given load profile.

b) Impact of load profile on transformer efficiency

As shown in Figure 3-1, the load will affect the efficiency and also adversely affect the total life costs of the transformer. If the load is below 15 % then the overall energy-efficiency is also low. The maximum efficiency is obtained at 60% load.

As the load profile varies according to customer type (typical examples include residential, commercial and industrial), this also means that there will be some variation in the energy efficiency between domestic, industrial and commercial applications because these have different load profiles. The load of industrial transformers is higher than that of utility transformers, so their energy efficiency will usually be higher.

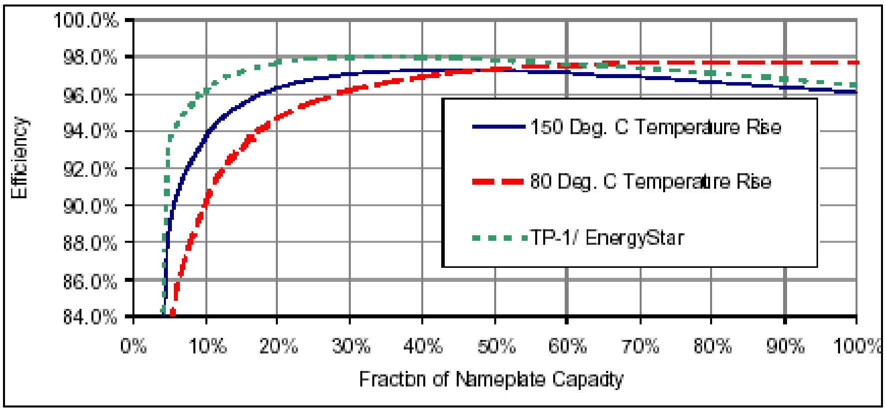

Figure 3-1: Efficiency versus load for three 75 kVA transformer models (NEEP, 1999[3])

c) Impact of load profile on transformer energy losses

The energy used by distribution transformers is characterised by two types of losses (see chapter 1). The first type are no-load losses (Po), which arise primarily from the switching of the magnetic field in the transformer core material. No-load losses are roughly constant and exist whenever the transformer is connected. The second type of losses are load losses (Pk), which are also known as resistance or I^2R losses. Load losses vary with the load on the transformer and at any point in time are proportional to the load squared, Figure 3-2.

Considering both load and no-load losses, the transformer energy loss can be calculated by the following formula:

$$Etr(t) = Po + Pk \times [Load(t)/(S \times PF)]^2 \qquad \text{(formula 3.1)}$$

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[3] Northeast Energy Efficiency Partnership (NEEP), Metered Load factors for Low-Voltage, dry-type transformers in commercial, industrial and public buildings, July 1999)

Where,

Etr(t) = the energy used by the distribution transformer at time t [W],
Po = no-load losses at rated load (see chapter 1),
Pk = the load losses at rated load (see chapter 1),
Load(t) = the load served by the transformer at time t,
S = the rated power of the transformer (see chapter 1)
PF = the power factor of the load served by the transformer (see chapter 1).

A pronounced peak in the load profile adds to losses, compared to a flat load. Experience with load profiles shows that load losses in a transformer will be about 10% lower if the profile is flat rather than peaked.

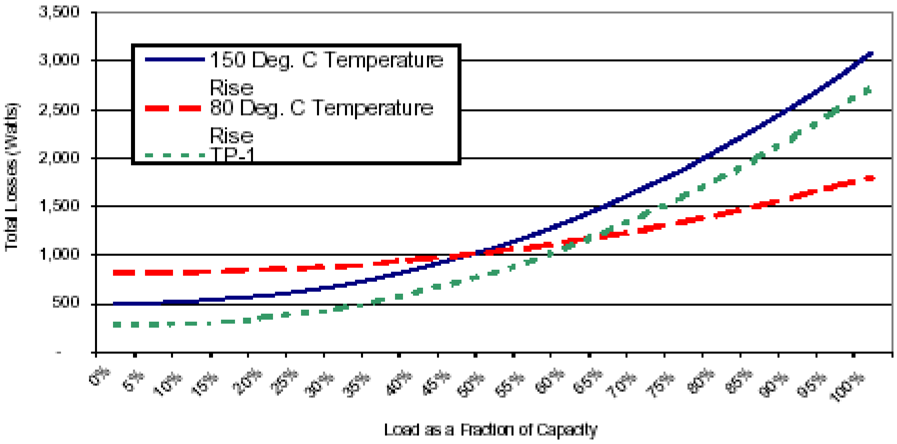

Figure 3-2: Load losses versus load for three 75 kVA transformer models (NEEP, 1999[3])

In order to easily calculate the annual energy loss of the transformer from data files it is more convenient to switch to time independent parameters and use the so-called RMS load (Prms) or root-mean-square value of the load. The RMS load values can be easily computed from data files, e.g. the Synthetic Load Profiles. In this case the annual energy loss (Etr(y)) formula is:

$$Etr(y)\,[kWh] = (Po[W] + Pk[W] \times (\alpha \times Kf/PF)^2) \times 8760/1000 \qquad \text{(formula 3.2)}$$

Where,

Etr(y) = the energy used by the distribution transformer per year [kWh],
Po = no-load losses at rated load (see chapter 1),
Pk = the load losses at rated load (see chapter 1),
α = The load factor (Pavg/S) (see chapter 1),
Kf = Load form factor (=Prms/Pavg) (see chapter 1),
PF = the power factor of the load served by the transformer (see chapter 1).

d) Load form factor (Kf)

Load form factor for distribution and industry transformers:

In the free electricity market the knowledge of the load profile of a customer is used by DSO to calculate the rates for electricity retailers because electricity rates vary with time.
Metering energy consumption in function of time is too complex when no automatic meter reading is available, hence distribution companies use so-called Synthetic Load Profiles. Load profiles are commonly used in electrical distribution grids because they can be determined by direct metering. However on smaller distribution transformers (< 100 kVA) this is not routinely done. Therefore, for these transformers, suppliers implement a method that gives a sufficiently accurate picture of hourly consumption of groups of customers without appropriate meters. These costumer groups –e.g. industrial, non-industrial– are allocated to standardised load profiles or synthetic load profiles. These synthetic load profiles (SLP) are based on historical data and take into account the most important variables which determine the consumption, e.g. year calendar (weekdays, weekends, holidays) and seasonal factors (temperature, sunrise).

For example Germany and Belgium use these synthetic load profiles in order to take small customers' load behaviour into consideration:

- Synergrid, the Belgian federation for electricity and gas distributors, determines these synthetic load profiles for the residential consumers and the non-residential with < 56 kVA and with 56-100 kVA. An example of the Belgian synthetic load profile for the non-residential sector > 56-100 kVA for January 2009 is given in Figure 3-3.

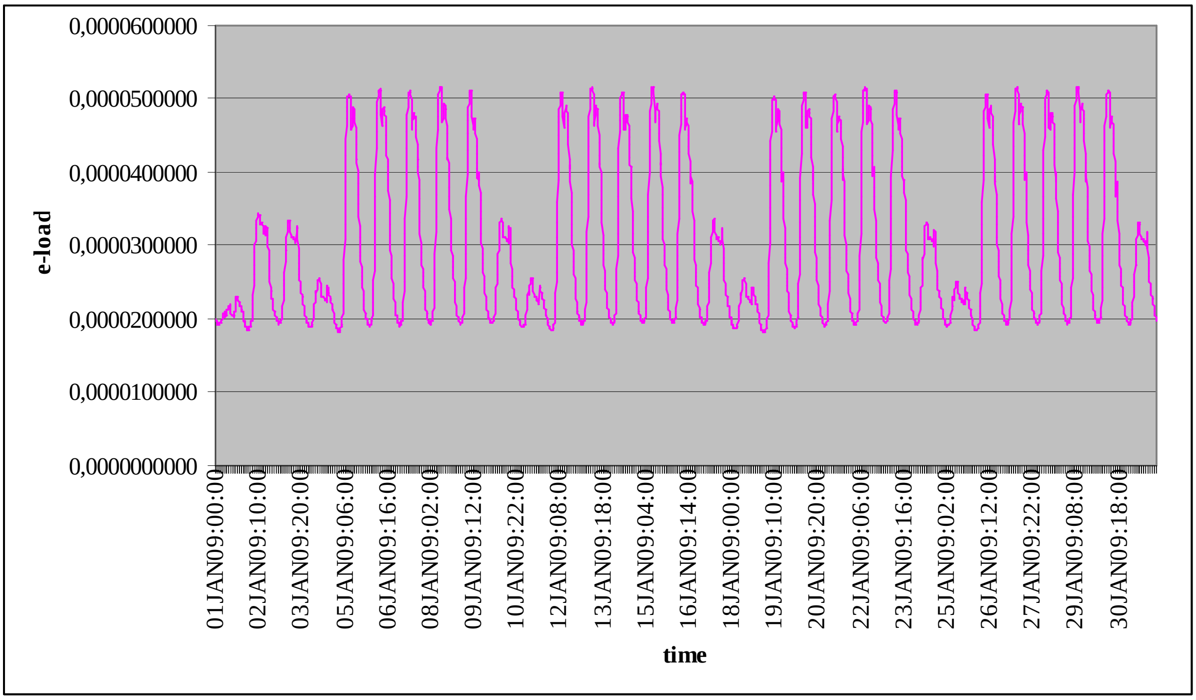

Figure 3-3: Synthetic load profile for the non-residential sector > 56-100 kVA for the month January 2009, electricity load (MW) versus day of the month (date: hour)(www.synergrid.com)

- In German electricity organisation, VDEW, also determines synthetic load profiles for households, industry and agriculture. An example of the SLP for the industry is given in *Figure 3-4*.

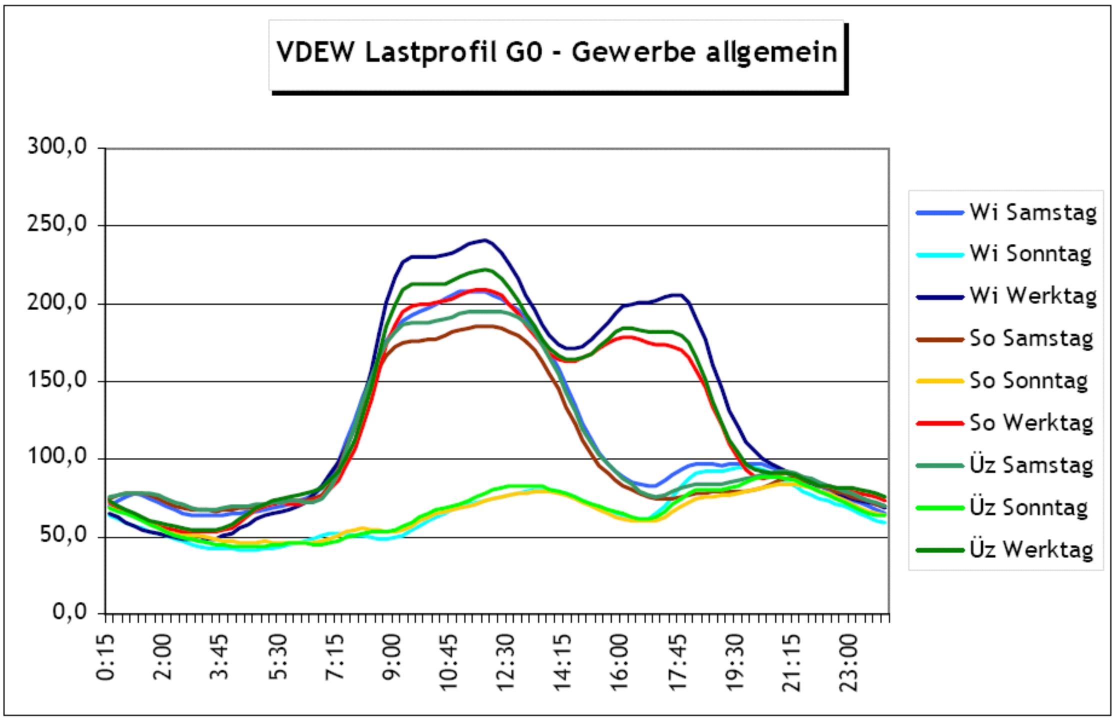

Figure 3-4: Synthetic load profile for the industry for one specific day (Kalab[4]*), consumption (W) versus time of the day (h)*

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[4] Kalab Otto, Standardisierte Lastprofiele

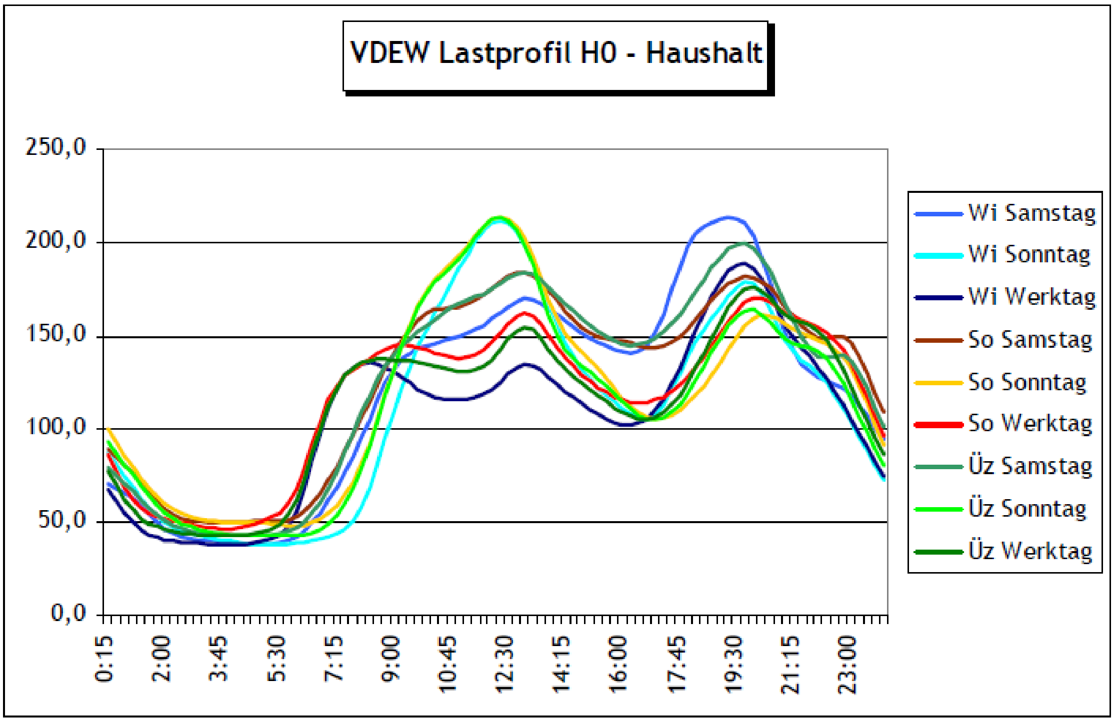

Figure 3-5 *Synthetic load profile(%) for households for one specific day (Kalab[5]), consumption versus time of the day*

More input from stakeholders is welcome.

Load form factor for DER transformers (DER[6]):

For distributed energy systems based on wind energy or solar energy no such synthetic load profiles are used, they can be deducted from metered data in literature. A load form factor of 1.60 is assumed for wind energy. This means that the energy produced by wind varies strongly over time.

More input from stakeholders is welcome.

To be completed.

Load form factor for power transformers:

An average profile of distribution and industry could be used.
More input from stakeholders is welcome.

To be completed.

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[5] Kalab Otto, Standardisierte Lastprofiele
[6] Distributed Energy Resource

Load form factor for small and other types of transformers:

The same profile as the industry profile could be taken?
More input from stakeholders is welcome.

To be completed.

Conclusion on load form factors:

For industry it proposed to use the VDEW G0 profile and for distribution VDEW H0 is used (see Table 3.1). As can be seen those values do not vary significantly and as a consequence they do not have a strong impact on the result.

Table 3.1 Load form factors (Kf) to be used in this study

Application	**Kf (= Prms/Pavg)**	**Profile used**
Distribution	1.073	VDEW G0
Industry	1.096	VDEW H0
Power	1.08	Assumption
DER (wind)	1.60	Experimental data (Vito)
Small transformers	1.096	VDEW H0

e) Load Factor (α)

Load factors (α) for distribution and industry transformers

Based on the information given in Task 2 and the definition of the load factor given above, the load factors for the transformers considered in this study can be calculated, see below:

Table 3.2: Calculation of the load factors for utility and industrial distribution transformers based on the annual electricity demand per sector and the maximum capacity

	Annual demand TWh	***Installed MVA***	***Hours per year***	***Average load factor (α)***
Distribution	1553	893 913	8 760	0.15
Industry	1136	461 096	8 760	0.28

To verify the calculated load factors, literature regarding the average load factor on the transformer (commercial, industrial, residential) are examined:

- In 1999, the Northeast Energy Efficiency Partnership (NEEP)[3] contracted the Cadmus Group to measure transformer loading and harmonic levels in a variety of commercial and industrial installations. In the 89 buildings that were analysed (comprised of a collection of universities, health care facilities, manufacturing facilities, office buildings and retail facilities) the average RMS loading factor was found to be 15.9% (varying between 14.1% to 17.6%).

- A study from the Leonardo energy organisation[7] states a load factor of 15-20% for transformers used to serve residential customers. Commercial customers use typically 30-50% of the transformer capacity. Other sources report for utility transformers average loading levels of about 25-30% are reported (TR Blackburn, October 2007[8]).

- Industrial transformers have higher average loads than utility transformers and so the energy savings are potentially higher. On the negative side, they do not always have the same quality of maintenance procedures such as those used by utilities. Also, in the industry,overloading is more likely to occur with the attendant reduction of efficiency that the higher load losses cause.

- An overview of the RMS load factors (= α x Kf) for distribution transformers in different sectors is given in the table below. These load factors are based on a questionnaire from 290 users in Japan (Japan Electrical Manufacturers Association). In order to obtain the load factor (α) the RMS load factor needs to be divided by the form factor (Kf), which is about 1.1.

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[7] Leonardo Energy Transformers, ‘Potential for global energy savings from high efficiency distribution transformers’, February 2005

[8] Leonardo Energy Transformers, ‘Potential for global energy savings from high efficiency distribution transformers’, February 2005

Table 3.3: Overview of the RMS load factors (α x Kf) in different sectors (Leonardo energy, February 2005[7])

Sector	**Daytime**	**Night time**	**Day average**
Industry			
Electric	0.50	0.36	0.43
Food	0.47	0.32	0.41
Metal	0.42	0.31	0.37
Chemical	0.48	0.26	0.38
Machinery	0.40	0.15	0.30
Fabrication	0.56	0.58	0.57
Pulp	0.35	0.35	0.35
Transport	0.25	0.00	0.18
Other	0.50	0.27	0.40
Services			
Offices	0.25	0.06	0.18
Stores	0.61	0.05	0.43
Public sector			
Hospitals	0.30	0.09	0.22
Libraries	0.23	0.05	0.17
Rail road	0.20	0.14	0.17
Government	0.40	0.10	0.29
Other	0.37	0.34	0.36

Load factors for DER transformers

KEMA T&D Consulting [9] reports a load factor of 0.30 for wind turbine transformers, based on 750 kW wind turbine with a production 2550 MWh per year (38.8% load) and a transformer of 1000 kVA.

Load factors for power transformers

For power transformers, no robust data on the load factors was found in available literature. Based on the information given in Task 2 and the information given by the sector organisation T&D Europe, the load factor for the power transformers is set at 0.20.

Load factors for small and other transformers

More input from stakeholders is welcome.

To be completed.

Conclusion on load factors:

The calculated load factors seem to be on the lower side of the ranges found in the literature or indicated by the sector organisations. Based on the available literature and information, an

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[9] KEMA T&D Consulting, Cost savings by low-loss distribution transformers: the influence of fluctuating loads and energy price on the economic optimum, September 2003

average estimation for the considered transformers in this study is made to use in further evaluations, Table 3.4.

Table 3.4 Load factors (α) to be used in this study

Application	**α**
distribution	0.19
industry	0.40
power	0.20
DER (wind)	0.30
small industry	0.40

Stakeholders please comment.

3.2.1.2 Power factor

The power factor is the real power used by the load divided by the apparent power required by the load conditions, and is a number between 0 and 1. The real power is the time average of the instantaneous product of the voltage and current. The apparent power is the product of the root mean square (RMS) voltage and the RMS current.

In an electric power system, for the same amount of useful power transferred, a load with a low power factor draws more current than a load with a high power factor. For example, if the load power factor were as low as 0.7, the apparent power would be 1.4 times the real power used by the load. Line current in the circuit would also be 1.4 times the current required at 1.0 power factor, so the losses in the circuit would be doubled (since they are proportional to the square of the current).
A high power factor is thus generally desirable in a transmission system to reduce transmission losses, and improve voltage regulation at the load. Typically domestic loads have power factors around 1, while industrial load will have lower power factors.

Synergrid[10] assumes a power factor of 0.95.

3.2.1.3 Availability factor

The availability factor (AF) indicates the proportion of time that a transformer is predicted to be energised. This is estimated to be 1, although for wind turbines this might be lower due to the non-constant wind availability.

However for the smaller industrial transformers it is unlikely that they are under continuous operation. They could be linked to the typical annual operational hours in industry or the service sector (2250 h/y), nevertheless a big spread is possible. Some industry equipment might also be operated partially (e.g. welding, industrial batch processes, seasonal processes, ..). Stakeholders are welcome to provide more information.

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[10] Synergrid, Raming van de verliezen in de distributienetten, August 2003

The proposed Availability Factors for this study are in

Table 3.5 Proposed Availability Factors for this study

Application	**AF (typ.)**	**AF (min.)**	**AF (max.)**
distribution	1	1	1
industry	1	1	1
power	1	1	1
DER (wind)	1	0.5	1
small industry	0.25	0.12	1

3.2.1.4 Impact of harmonics

Almost all industries have non-linear loads. Non-linear loads generate high levels of higher frequency components in the load current (harmonics). Typical non-linear loads include:

- computers
- UPS systems
- variable speed drives
- inverters e.g. to allow the connection of photovoltaic and wind generators to the distribution grid system.

The extensive use of these electronic units causes increasing problems for distribution transformers:

- Higher frequency components in the load current (harmonics) cause extra losses because harmonics do not fully penetrate the conductor. They travel on the outer edge of the conductor. This is called skin effect. When skin effect occurs, the effective cross sectional area of the conductor decreases; increasing the resistance and the I^2R losses, which in turn heats up the conductors and anything connected to them (KEMA, May 2002)[11].
- The harmonics in the load current will also increase losses in the transformers by generating eddy currents in the windings, which cause increased heating in the windings. These eddy currents in the windings represent 5% of the load loss. These losses are proportional to the square of the frequency. If the load current contained 20% fifth harmonic, the eddy current loss due to the harmonic current component would be 5 x 5 x 0.2 x 0.2 multiplied by the eddy current loss at the fundamental frequency. Consequently, the load losses in a transformers supplying non-linear loads can easily be twice the rated losses.

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[11] KEMA, Energy saving in industrial distribution transformers, May 2002

- The harmonics on the voltage will lead to increased core loss (no-load losses) due to higher frequency magnetic field components generated in the cores (SEEDT, 2008[12]).

To deal with these harmonics a few options are possible (LPQI, March 2009[13]) :

- For existing transformers: de-rating of the transformer so that the total loss on harmonic load does not exceed the fundamental design loss. To estimate how much a transformer should be de-rated, the de-rating factor (known as factor K method, used in Europe)) may be calculated according to formula in HD 538.3.S1:

$$K = \left[1 + \frac{e}{1+e} \left(\frac{Ih}{I} \right)^2 \sum_{n=2}^{n=N} \left(n^q \left(\frac{In}{I1} \right)^2 \right) \right]^{0.5}$$

with

e = eddy current loss at the fundamental frequency divided by the loss due to a DC current equal to the RMS value of the sinusoidal current, both at reference temperature.

n = harmonic order

I = RMS value of the sinusoidal current including all harmonics given by

$$I = \left(\sum_{n=1}^{n=N} (In)^2 \right)^{0.5} = I1 \left[\sum_{n=1}^{n=N} \left(\frac{In}{I1} \right)^2 \right]^{0.5}$$

In = magnitude of the n-harmonic

I1 = magnitude of fundamental current

q = exponential constant that is dependent on the type of winding and frequency. Typical values are 1.7 for transformers with round rectangular cross-section conductors in both windings and 1.5 for those with foil low voltage windings

- For new transformers: special design of transformers rated for non-sinusoidal load currents. The increase in eddy current loss is calculated and the transformer will be designed so that it can cope with these extra losses. These transformers are sold as ‘K rated’ transformers. The K-factor is estimated using the following equation:

$$K = \sum_{n=1}^{n=n\max} In^2 n^2$$

A pure linear load, one that draws sinusoidal currents, will have a K factor of 1. A higher K factor indicates that the eddy current loss in the transformer will be K times the value at the fundamental frequency. K rated transformers are thus designed to have very low eddy current loss at fundamental frequency.

- Use energy efficient transformers to minimise losses with non-linear loads.

The latter option is obviously the best approach.

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[12] Strategies for development and diffusion of Energy Efficient Distribution Transformers (SEEDT), Selecting Energy Efficient Distribution Transformers, A Guide for Achieving Least-Cost Solutions, Intelligent Energy for Europe, 2008

[13] Leonardo Power Quality Initiative (LPQI), Harmonics: selection and rating of transformers, March 2009

The impact of these harmonics is expected to increase in the future due to the significant growth of connection of renewable energy generation systems to the distribution grid. To reduce the resulting losses in the transformers, the highest efficiency transformers should be used.

Amount of harmonics in a normal distribution grid.
Stakeholders are invited to provide input.

Conclusion:
It is proposed to not take this effect into account by a lack of data and it will not benefit inefficient transformers in normal use.
Stakeholders please comment.

3.2.1.5 Transformer ambient temperature

The copper and aluminium resistance increases with temperature, hence the load losses can increase or decrease with temperature.
The following formula is applicable for copper:

Pk = Pk x (235° + 75 °)/(235° + tm)

Where,
tm = is the measured temperature at the reference point
75 ° is the reference temperature at the reference point

The following formula is applicable for aluminium:

Pk = Pk x (225° + 75 °)/(225° + tm)

Conclusion:
It is proposed not to take this effect into account because its impact is relative to the chosen reference, hence it will not influence the outcome.
Stakeholders please comment.

3.2.2 Best practice in sustainable product use

The lifetime of a transformer is mainly determined by the lifetime of the insulation of the transformer. The insulation mainly has an organic nature; being composed of mineral oil, impregnated paper, cellulose materials etc. The stability of such materials is very dependent on the operational temperature. The usual rule of thumb is that continuous operation above the rated temperature by only 6°C will halve the lifetime of the insulation (T.R. Blackburn, October 2007[14]).

The end-user behaviour, e.g. regularly overloading of the transformer, has a significant impact on the transformer life time. Therefore, a number of manufacturers give recommendations for smart use of such transformers and "energy-saving tips" to end-users. Such strategies aim at reducing the losses and improving overall performance of transformers which can be achieved through better monitoring and maintenance practices.

3.2.3 Repair and maintenance practice (frequency of repair and failure, spare parts, transportation and other impact parameters):

Transformers require less care and attention than almost any other kind of electrical apparatus. However, transformers not only represent considerable investment but they are essential in maintaining the continuity of electric service. Failure of a transformer can cause a great deal of consequential damage to associated apparatus. Therefore, it is important that transformers be kept in serviceable condition.

Although transformers are highly reliable and efficient devices, routine inspections performed by the equipment owner can identify potential problems in their early stages. Most transformers are equipped with basic indicating devices that, when routinely monitored and recorded, will indicate a change from normal operation conditions.

Stakeholders are invited to provide input on the frequency of repair and failure, spare parts, transportation and other impact parameters

3.2.4 Economic product life (= actual time to disposal):

Lifetime is a crucial component of the life cycle cost (LCC) calculation. Transformers are durable and have long working lives. For financial purposes, the amortisation period for an investment in a transformer is often set at ten years. After that period, companies are no longer motivated to invest in new, more efficient, transformers since the 10 year-old one bears no cost and cannot be logically compared to the cost of a new investment. The average technical life of a transformer is 30 years or more; more than 10% of the European transformer fleet is 40 years old or more. This 10% of the transformer fleet contributes more than 20% of the total no-load losses and more than 15% of load losses in European distribution companies.

The minimum reasonable transformer lifetime in LCC calculations could be 20 years and arguments mentioned above indicate that applying 30 years lifetime in industry and commerce, and 40 years lifetime in electricity distribution companies can be justified as well (SEEDT, 2008[12]).

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[14] T.R. Blackburn, 'Technical Report - Distribution Transformers: Proposal to Increase MEPS Levels, Prepared for Equipment Energy Efficiency Program', October 2007

3.3 End-of-Life behaviour

Two main end of life options are available, which always entail considerable expenditure by the owner (The Hartford Steam Boiler Inspection and Insurance Company, October 2002[15]).

1. Repair: Repair costs can be high essentially because of design constraints, and the effects of the unknown. The most extensive (and expensive) repair is a complete *rewind* of the transformer coils. However, in the decision to rewind versus replace old transformers, it is important to include the costs of transformer losses. The cost of core and copper losses for a 1950's transformer may be twice that of a new transformer. Customers thus decide to replace the transformer (instead of rewinding it) because the reduction in core losses could economically justify it. Another major repair option is *reblocking and reclamping* the transformer coils. Over time, thermal and mechanical cycling can result in a gradual decrease in the vertical clamping pressure (axial) on the coils. These forces can decay at a different rate for different windings or for different layers of the same winding. At some point, the coil clamping may fall below the level required to hold the coils stable during through-fault events. The transformer is typically reclamped to the original values specified by the manufacturer. However, if there is any possibility of internal insulation damage or conductor "tilting", due to previous faults, the reclamping process should be avoided. Reclamping, in this case, may exacerbate the pre-existing condition, and accelerate a failure. Other options include the *repair or replacement of ancillary equipment*, such as surge arresters, bushings, fans, pumps, radiators, pressure relief devices, oil and winding temperature gauges, liquid level gauges, fault-pressure relays, gas detector relays, load tap changer maintenance /upgrade (contacts), and oil dry out/reclamation.
2. Replacement: Replacement with a new unit provides the benefits of an improved, more energy efficient design but is very expensive. In Europe dismantling and incineration is mostly used, with the recovery/recycling of the metallic components (copper, steel, aluminium). The contained oil will be either incinerated, or treated with a solvent to extract the PCB. This PCB concentrate will be sent to a chemical company for conversion to hydrochloric acid. Decontamination of the transformer oil by chemical methods is however little used because of the prevalence of incineration. Oils are easy to transport in drums, and incinerate easily. New transformers will use a non-PCB dielectric fluid or be designed without a liquid dielectric fluid (dry-type transformers) (UNEP, May 2002[16]).

   Furthermore, delivery times are also decreasing and are beginning to approach repair spans. Some utilities used to replace a transformer when the associated load reached 100% of transformer nameplate capacity. Some utilities also used to replace a transformer when its calendar age reached an arbitrary value of 30 to 35 years. Due to the extraordinary growth in power consumption during the late 1960's and 1970's, many transformers were simply replaced with larger units. But today the continued operation of aging transformers is crucial to the financial performance and economic

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[15] The Hartford Steam Boiler Inspection and Insurance Company, Life Cycle Management of Utility Transformer Assets, paper presented at Breakthrough Asset Management for the Restructured Power Industry October 10–11, 2002 Salt Lake City, Utah

[16] United Nations Environmental Program (UNEP), PCB Transformers and Capacitors: From management to reclassification and disposal, May 2002

> viability of the electric utility. The transformer engineer and/or the asset manager is regularly expected to make timely replacement decisions on aging transformers. Transformer replacement is no longer a unilateral or arbitrary decision process. Substantial technical and financial data specific to the individual transformer, plus demographics, load growth, and overall performance of the transformer population must be taken into consideration. The decision to defer a replacement should no longer be a simple Net Present Value analysis. The decision should also include an increased risk calculation. The probability of failure for an “old” transformer is not constant; it is increasing exponentially each year. Obviously, this requires an in-depth knowledge of the corporate risk tolerance, current investment strategy (and “hurdle rates”), and the prevailing business and regulatory environment.

Approximately 99% are recycled (source: T&D Europe (2009), the other are repaired or sold second hand.
Stakeholders please comment

4 ASSESSMENT OF BASE-CASE

5 TECHNICAL ANALYSIS BAT AND BNA

6 IMPROVEMENT POTENTIAL

7 POLICY AND IMPACT ANALYSIS