Totally Integrated Power

Technical Series Edition 5

Load Impact in the Feed-in Circuit on Life Cycle Energy Costs

Answers for infrastructure.

Contents

Totally Integrated Power

Comparable to a lifeline, electric power supply forms the basis for the reliable and efficient operation of all electrically powered building facilities. Therefore, electric power distribution in buildings requires integrated solutions.
Our response: Totally Integrated Power

Introduction

Electric power systems in buildings are planned on the basis of current technical standards and guidelines. This means that cables and wires must be dimensioned with regard to protection against overload and short circuit, as well as personal protection and voltage drop.

Switching and protective devices are sized accordingly. Objectives, such as full selectivity, are either desired by customers or required in the relevant standards.

The SIMARIS design software tool supports users in the creation and dimensioning of an electric power system for a building.

Within the scope of this technical article, we will define the terms listed below as follows:

Life cycle costs:
Total cost across the entire equipment service life

Life cycle energy costs:
Cost share for electrical energy (consumption and investment) as part of the life cycle costs

Depending on the power usage, e.g. in an office building or a factory etc., the instantaneous values of consumed base and peak load vary under normal operating conditions (see Fig. 3 and Fig. 4).

Power Loss Calculation

Power loss in the three-phase system can be precisely established for transformers, busbar trunking systems and cables/wires based on the following formulae.

- Transformer

$$P_v = P_0 + \left(\frac{S_{Last}}{S_{rT}}\right)^2 \times P_k$$

or

$$P_v = P_0 + \left(\frac{I_{Last}}{I_{rT}}\right)^2 \times P_k$$

P_v	Power loss
P_0	No-load losses
P_k	Short-circuit losses • Oil-immersed transformers ($P_{k75°C}$) • GEAFOL transformers ($P_{k120°C}$)
S_{load} or I_{load}	Apparent power or apparent current from the load curve (due to connected equipment)
S_{rT} or I_{rT}	Rated apparent power or rated apparent current

- Busbar trunking system or cables

$$P_v = 3 \times I_{Last}{}^2 \times R$$

P_v	Power loss
I_{load}	Operating current (apparent current) from the load curve (due to connected equipment)
R	Resistance at conductor temperature and transmission distance

The load ratio (ratio of connected load and rated apparent transformer load) is calculated in the power loss formula of the transformer as a square factor, so that the resulting load losses (also called transmission losses) become increasingly significant as the load ratio rises.

When the rated apparent power is kept constant, transformers can also be constructed to have lower no-load losses. No-load losses do not only depend on the power to be transmitted, but are generated as soon as the transformer is supplied with voltage from one side (fixed value).

In analogy to the square dependency of the load losses on the transformer load ratio, the apparent current is also included in the loss calculation of a busbar trunking system or a cable system with a square factor.

In addition, the conductor temperature must be factored in, since it affects the conductor resistance and thus the losses. Since the conductor temperature also depends on the load among other factors, a fixed temperature value is defined to simplify calculations (e.g. 55°C).

Determining the Active Energy based on the Load Curve

Depending on the building type and usage, a certain consumption pattern may be assumed, as shown in Fig. 3 and Fig. 4, for example. Owing to the different power values at different times, different losses will occur. Therefore, it is not possible to assume fixed values for apparent power and apparent current, when the active energy is calculated. Fig. 2 depicts power transmission via the feed-in circuit as a load curve. Accordingly, the transmitted power is divided in the downstream network dependent on the connected load as follows.

At the load transfer point (metering panel in the medium-voltage switchgear) of the distribution system operator's network to the customer network, the active energy is recorded as 15-minute mean value. The value of 145,260 kWh represents the measured active energy between 0:15 a.m. and 0:30 a.m. (see Fig. 1 as example).

The individual active energy values taken from Fig. 1 can be converted into apparent power and apparent current values. Basically, it is necessary to always document voltage values and the active power factor cos φ in addition to the active energy, since these values may vary depending on whether loads are connected into or disconnected from the circuit. This means that higher-grade measuring instruments featuring this functionality must be built in.

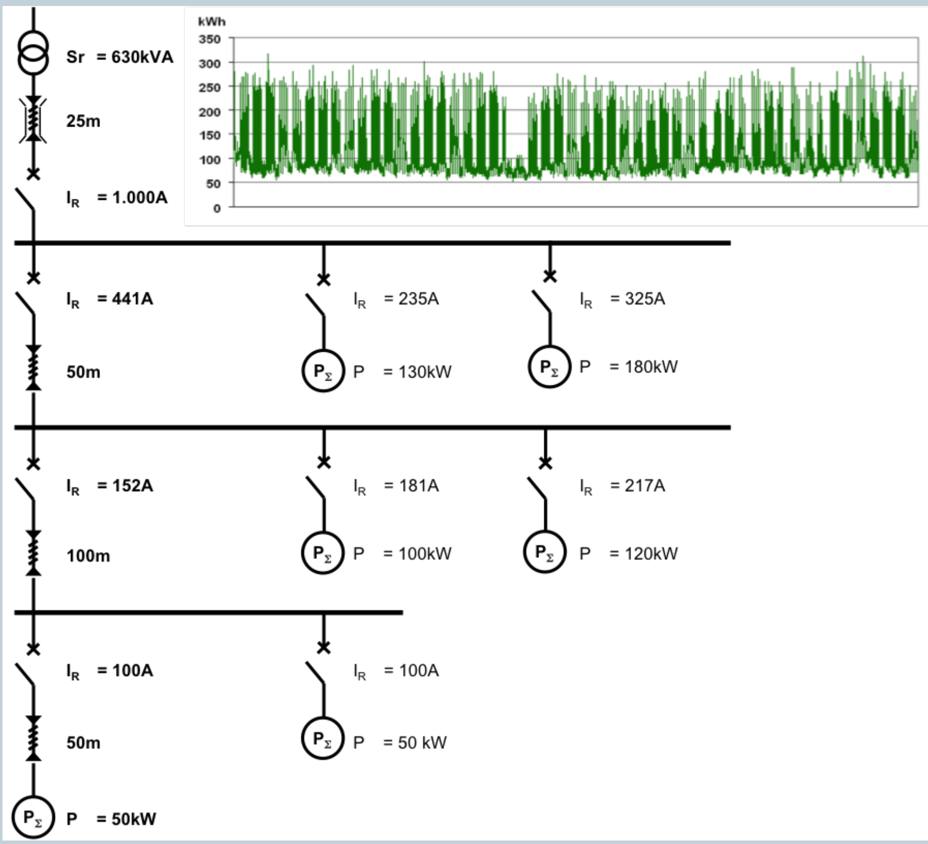
To simplify the calculation, you may assume a constant voltage and a constant active power factor cos φ to determine the respective apparent power and apparent current value.

The optimization of the life cycle energy costs depends on the equipment used (transformers/busbars/cables) at a given load. The following example examines such a cost analysis based on real conditions.

Time stamp	Active energy [kWh]
1.1.10 0:15	146.501
1.1.10 00:30	145.260
1.1.10 00:45	146.453
1.1.10 01:00	146.835
1.1.10 01:15	146.357
1.1.10 01:30	147.455
1.1.10 01:45	147.073
1.1.10 02:00	146.644

Fig. 1: Energy metered in 15-minute cycles

Fig. 2: Example of a building network with the load at the feed-in point



Determination of the Life Cycle Energy Costs Exemplified for Some Operational Configurations

First of all, please note that it is not possible to make any generalized determinations. On the contrary, it is absolutely crucial to precisely know the operational configuration and operating conditions in order to make any statements on life cycle energy costs as early as in the planning stage. Starting from the configuration depicted in Fig. 2, our example distinguishes between two variants of feed-in circuits: stand-alone operation and parallel operation. In addition, a fictitious industrial power supply and power supply to a fictitious office environment are considered as different load scenarios with the corresponding load curves. Some alternatives of transformers and busbar trunking systems are analysed for these four cases and compared to one another.

Scenarios under consideration

Two different yearly load curves (load curve over one year) are used to perform a life cycle energy cost analysis.

Scenario 1:
Scenario 1 (see Fig. 3) describes the load curve of an industrial plant with a high base load and small load peak variations.

The following characteristic parameters can be derived from the one-year load curve.

- One-year peak load value: 1,000 kVA
- Mean load value: 847 kVA
- Base load: 634 kVA
- One-year energy: 6,673,867 kWh/a
- Usage period 7,415 h
- Loss hours: 6,318 h
- One-year active power peak: 900 kW

Scenario 2:
Scenario 2 (see Fig. 4) depicts the load curve for an office building with great day and night variations at a relatively low base load.

Characteristic parameters of the one-year load curve:

- One-year peak load value: 1,000 kVA
- Mean load value: 321 kVA
- Base load: 88 kVA
- One-year energy: 2,534,522 kWh/a
- Usage period 2,816 h
- Loss hours: 1,262 h
- One-year active power peak: 900 kW

The usage period indicates, how many hours per year the one-year peak load value must actually be transmitted in order to obtain the one-year energy value shown in the real load curve.

$$\textit{Usage period}\,[h] = \frac{\textit{One - year energy}\ [kWh]}{\textit{One - year active power peak}\ [kW]}$$

If the load losses were determined for transformers based on the 15-minute values of the load curve, the loss hours can be determined on the basis of the following formula:

$$\textit{Loss hours}\ [h] = \frac{\textit{Sum of annual load losses}\ [kWh]}{\textit{Load losses}\ [kW] \times \left(\dfrac{\textit{One - year active power peak}\,[kW]}{\textit{Rated apparent power}\,[kW]}\right)^2}$$

Hence, the number of loss hours depends on the load curve. If this transformer is replaced by another transformer with a greater apparent power rating, its load losses can be calculated using the previously determined loss hours.

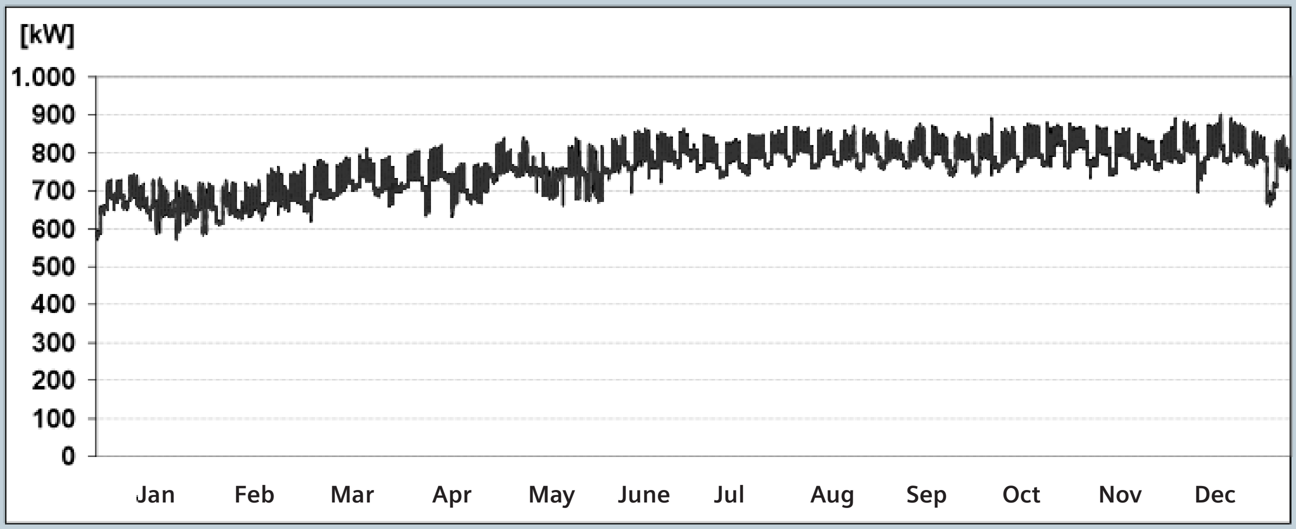


Fig. 3: Load curve for Scenario 1

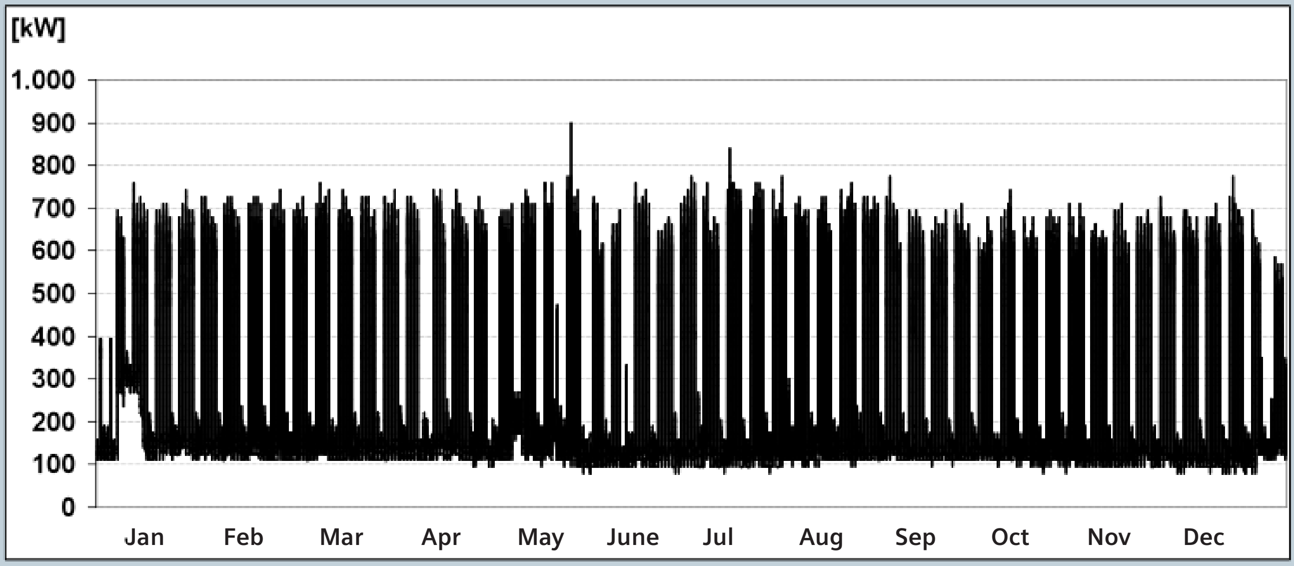


Fig. 4: Load curve for Scenario 2

Description of the variants under consideration and their associated alternatives

Starting from the feed-in configuration in Fig. 5, two variants will be discussed in the following. In the one variant, the equipment will only be power-supplied from one of the two transformers (stand-alone operation – one transformer for the entire load, the second transformer acts as stand-by) and in the other variant, it will be power-supplied from both transformers simultaneously (parallel operation).

In both variants, the transformers are assumed to be of identical construction. Due to their versatile application options, GEAFOL transformers will be used.

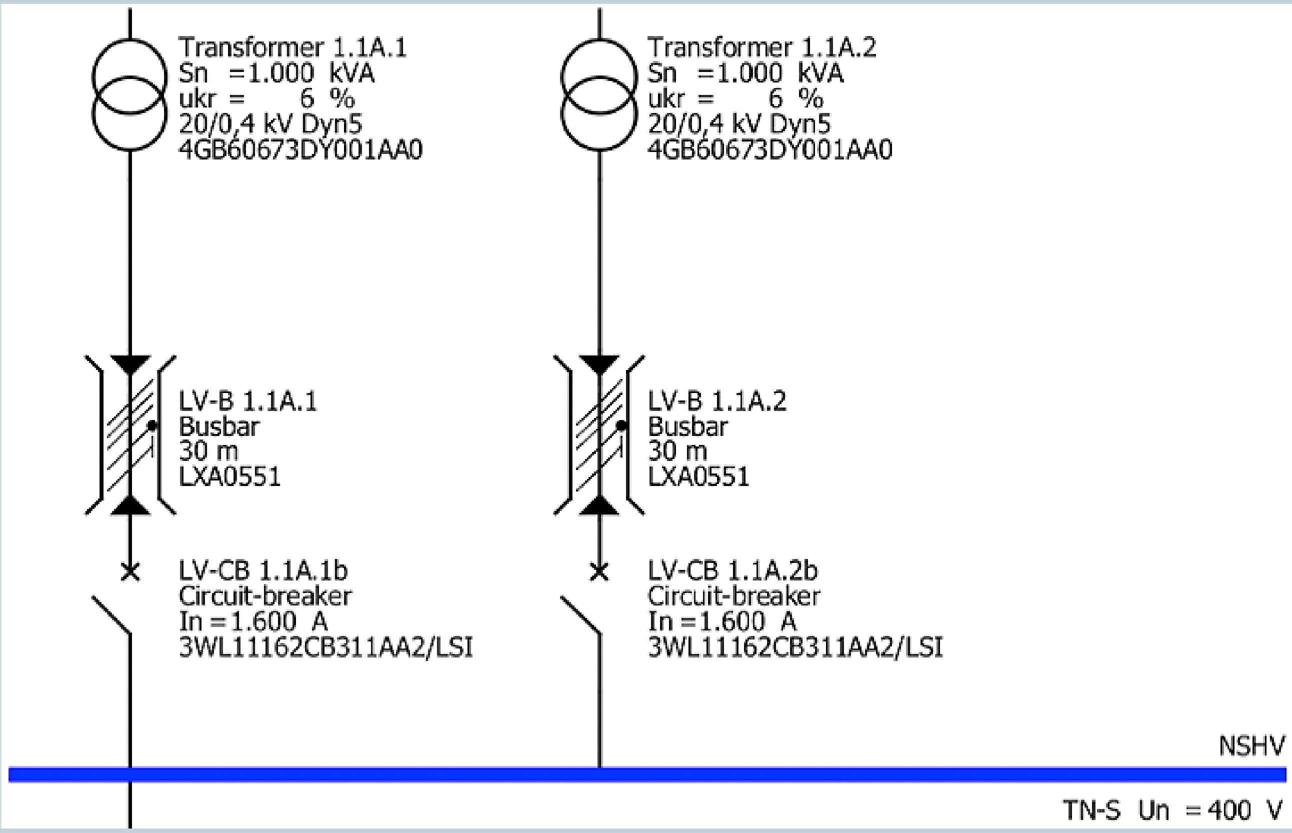
At first, the transformers will be dimensioned according to the load connected. To obtain alternative solutions, the transformers are analysed with different nominal apparent power values and/or reduced no-load losses in both variants. Please note that in case one feed-in system fails, the other transformer is capable of supplying the maximum load required. If necessary, it must be cooled with built-on fans. GEAFOL transformers can be overloaded up to 40% of their normal rating. The costs of investment for the fans have been taken into account for these transformers.

Busbar trunking systems are the only method of connection used between the transformer and the low-voltage main distribution board. SIVACON 8PS busbars, type series LX in aluminium conductor design, are selected on the basis of the nominal transformer current. Suitably larger busbar trunking system versions are considered for the analysis of alternatives.

Transformers and busbar trunking systems are analysed independently to maintain the utmost variability in the choice of variants and alternatives. The interest rate for any additional costs of investment is not taken into account.

The values for the no-load losses P_0 and the short-circuit losses $P_{k120°C}$ given in the tables below always apply to one transformer. A length of 30 m and a conductor temperature of 55°C is assumed for the busbar trunking system.

Fig. 5: An example for parallel operation



Variant 1: Stand-alone operation
In the first variant, only one transformer of the two parallel feed-in transformers is loaded. After a month, the load is changed over to the second transformer. Owing to the higher number of operating cycles, the change-over is performed by the low-voltage circuit-breaker in the feed-in circuit. Thus, alternating operation takes place. The no-load losses of the transformer not connected at the secondary side are considered in the calculation.

This variant is called stand-alone operation.

	Stand-alone operation					
	Design	Alternative				
Rated apparent power [kVA]	2 x 1,000 normal	2 x 1,000 reduced	2 x 1,250 normal	2 x 1,250 reduced	2 x 1,600 reduced	2 x 800 reduced
Cooling	-	-	-	-	-	vented
u_{kr}	6%	6%	6%	6%	6%	6%
P_0 [kW]	2.3	1.8	2.7	2.1	2.4	1.5
$P_{k120°C}$ [kW]	9.4	9.4	12	12	12.8	8.3
Δ investment	reference	+2,040 €	+4,140 €	+6,820 €	+20,180 €	+2,560 €
Busbar system	2 x LXA05 ...	2 x LXA06 ...	2 x LXA06 ...	2 x LXA07 ...	2 x LXA07 ...	2 x LXA06 ...
Rated current [A]	1,600	2,000	2,000	2,500	2,500	2,000
Δ investment	reference	+14,898 €	+14,898 €	+23,226 €	+23,226 €	+14,898 €

Variant 2: Parallel operation
In the second variant, each of the two transformers is loaded for the purpose of parallel feed-in. The load is split into two 50% shares. In case one feed-in line fails, the remaining transformer is capable of supplying the full load. If necessary, it must be cooled. This variant is called parallel operation. Additional ventilation will increase the cost of investment for the 800 kVA transformers.

	Parallel operation					
	Design	Alternative				
Rated apparent power [kVA]	2 x 1,000 normal	2 x 1,000 reduced	2 x 1,250 normal	2 x 1,250 reduced	2 x 800 normal	2 x 800 reduced
Cooling	-	-	-	-	vented, if necessary	vented, if necessary
u_{kr}	6%	6%	6%	6%	6%	6%
P_0 [kW]	2.3	1.8	2.7	2.1	1.95	1.5
$P_{k120°C}$ [kW]	9.4	9.4	12	12	8.3	8.3
Δ investment	reference	+2,040 €	+4,140 €	+6,820 €	+1,740 €	+2,560 €
Busbar system	2 x LXA05 ...	2 x LXA06 ...	2 x LXA06 ...	2 x LXA07 ...	2 x LXA06 ...	2 x LXA06 ...
Rated current [A]	1,600	2,000	2,000	2,500	2,500	2,000
Δ investment	reference	+14,898 €	+14,898 €	+23,226 €	+14,898 €	+14,898 €

Each variant is calculated for the two scenarios described above to see which life cycle energy costs will accrue, and whether they can be reduced by optimization measures (comparison of alternatives).
Operation under fault conditions (failure of one transformer) is not considered.

To allow for the transmission of the 1.4-fold of the nominal current of one single remaining 800 kVA transformer, an LXA06 type busbar trunking system is rated for 2,000 A.

Loss analyses

All loss costs are based on a kilowatt-per-hour rate of 0.15 €/kWh. The four cases presented for analysis illustrate the respective differences of the alternative solutions.

	Scenario 1: Stand-alone operation					
	Design	Alternative variants				
Rated apparent power [kVA]	2 x 1,000 normal	2 x 1,000 reduced	2 x 1,250 normal	2 x 1,250 reduced	2 x 1,600 reduced	2 x 800 reduced
Relative loss	reference	-9 %	-4 %	-14 %	-26 %	+9 %
Cost of loss	reference	-€1,314	-€579	-€2,156	-€3,907	+€1,280
Busbar system	LXA05	LXA06	LXA06	LXA07	LXA07	LXA06
Relative loss	reference	-25 %	-25 %	-36.1 %	-36.1 %	-25 %
Cost of loss	reference	-1,823 €/a	-1,823 €/a	-2,633 €/a	-2,633 €/a	-1,823 €/a

	Scenario 1: Parallel operation					
	Design	Alternative variants				
Rated apparent power [kVA]	2 x 1,000 normal	2 x 1,000 reduced	2 x 1,250 normal	2 x 1,250 reduced	2 x 800 normal	2 x 800 reduced
Relative loss	reference	-12.5 %	+2.2 %	-12.8 %	+7.3 %	-3.9 %
Cost of loss	reference	-1,314 €/a	+236 €/a	-1,341 €/a	+771 €/a	-411 €/a
Busbar system	2 x LXA05	2 x LXA06	2 x LXA06	2 x LXA07	2 x LXA06	2 x LXA06
Relative loss	reference	-25 %	-25 %	-36.1 %	-25 %	-25 %
Cost of loss	reference	-912 €/a	-912 €/a	-1,317 €/a	-912 €/a	-912 €/a

	Scenario 2: Stand-alone operation					
	Design	Alternative variants				
Rated apparent power [kVA]	2 x 1,000 normal	2 x 1,000 reduced	2 x 1,250 normal	2 x 1,250 reduced	2 x 1,600 reduced	2 x 800 reduced
Relative loss	reference	-16.8 %	+9.3 %	-10.9 %	-7.3 %	-18.2 %
Cost of loss	reference	-1,314 €/a	+726 €/a	-851 €/a	-570 €/a	-1,427 €/a
Busbar system	LXA05	LXA06	LXA06	LXA07	LXA07	LXA06
Relative loss	reference	-25 %	-25 %	-36.1 %	-36.1 %	-25 %
Cost of loss	reference	-364 €/a	-364 €/a	-526 €/a	-526 €/a	-364 €/a

	Scenario 2: Parallel operation					
	Design	Alternative variants				
Rated apparent power [kVA]	2 x 1,000 normal	2 x 1,000 reduced	2 x 1,250 normal	2 x 1,250 reduced	2 x 800 normal	2 x 800 reduced
Relative loss	reference	-18.9 %	+12.8 %	-9.9 %	-8.4 %	-25.4 %
Cost of loss	reference	-1,314 €/a	+888 €/a	-688 €/a	-582 €/a	-1,765 €/a
Busbar system	2 x LXA05	2 x LXA06	2 x LXA06	2 x LXA07	2 x LXA06	2 x LXA06
Relative loss	reference	-25 %	-25 %	-36.1 %	-25 %	-25 %
Cost of loss	reference	-182 €/a	-182 €/a	-263 €/a	-182 €/a	-182 €/a

Life cycle energy cost analyses

To illustrate the different shares of life cycle energy costs accrued in different scenarios, variants and alternatives, a colour coding (see Fig. 6) is introduced. The analysis period for the consideration of life cycle energy costs is limited to five years. A depreciation of investment costs and interest rates for the loan amount is not factored in.

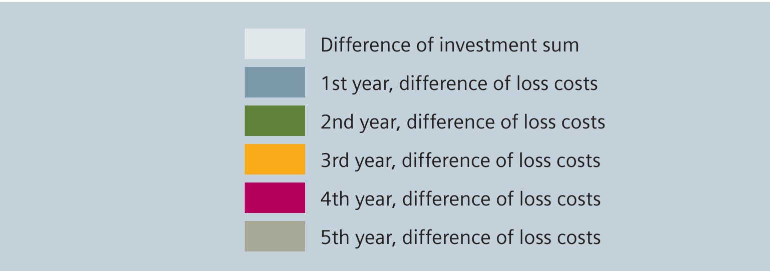


Fig. 6: Colour coding of shares in life cycle costs

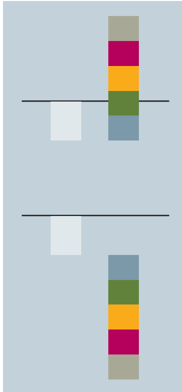
Since it is only the differences that are to be shown, the life cycle energy costs established for the system over a 5-year planning cycle are taken as zero point for each of the cases considered in Figures 7, 8, 9, and 10. Distinct from this, the additional or reduced costs for alternatives in the different scenarios and variants are depicted.

Attention:
The absolute costs of loss are different for the design variant in the four cases. For this reason, a meaningful comparison of the four cases always requires a consideration of the absolute costs and the investment options. To interpret the graphics properly, you must note that each zero line is based on a different total cost value of the components in the design system and their operation over five years.

Starting from the zero point, the additional costs of investment are entered first, and then the annual differences in loss costs between the design system and its alternative are shown for a period of five years. Thus it becomes easily obvious, whether, and within how many years, an additional investment pays off as a result of loss costs saved.

Explanations on the analyses

The following cases appear in the analyses:



Additional costs of investment (down), but lower loss costs (up)

Additional costs of investment (down) and higher loss costs (up)

The differences of the loss costs are not considered from the zero-€ line (zero point) but always start from the difference value of investments to be made. The starting point - here the zero-€ line - refers to the costs of investment and loss for the design system in the considered case.

Note: An individual assessment should be performed for each plant and kind of usage.

i) Assessment of stand-alone operation and Scenario 1

In Fig. 7, the differences in the life cycle energy costs are indicated for the following transformer alternatives:

- Two GEAFOL transformers (1,000 kVA) with reduced losses
- Two GEAFOL transformers (1,250 kVA) with normal losses
- Two GEAFOL transformers (1,250 kVA) with reduced losses
- Two GEAFOL transformers (1,600 kVA) with reduced losses
- Two 800 kVA GEAFOL transformers with additional ventilation and reduced losses

As to the busbar trunking systems, Fig. 7 compares the two systems LXA06 and LXA07 to the scheduled basic type LXA05. The loss-optimized transformer variants featuring a higher rated apparent power often account for significant cost advantages regarding loss costs due to their reduced no-load losses. In the light of the magnitude of saving effects between alternatives T1, T3 and T4 for variant 1 – Scenario 1 shown in Fig. 7, a precise cost finding including depreciation, maintenance and usage period should be performed for concrete projects. The like applies to the two alternative busbar systems under consideration.

Alternative 1-1 T5 proves to be unfavourable in case of continuous high capacity utilization under overload conditions, since the losses are higher as compared to the design variant and the fans consume additional energy.

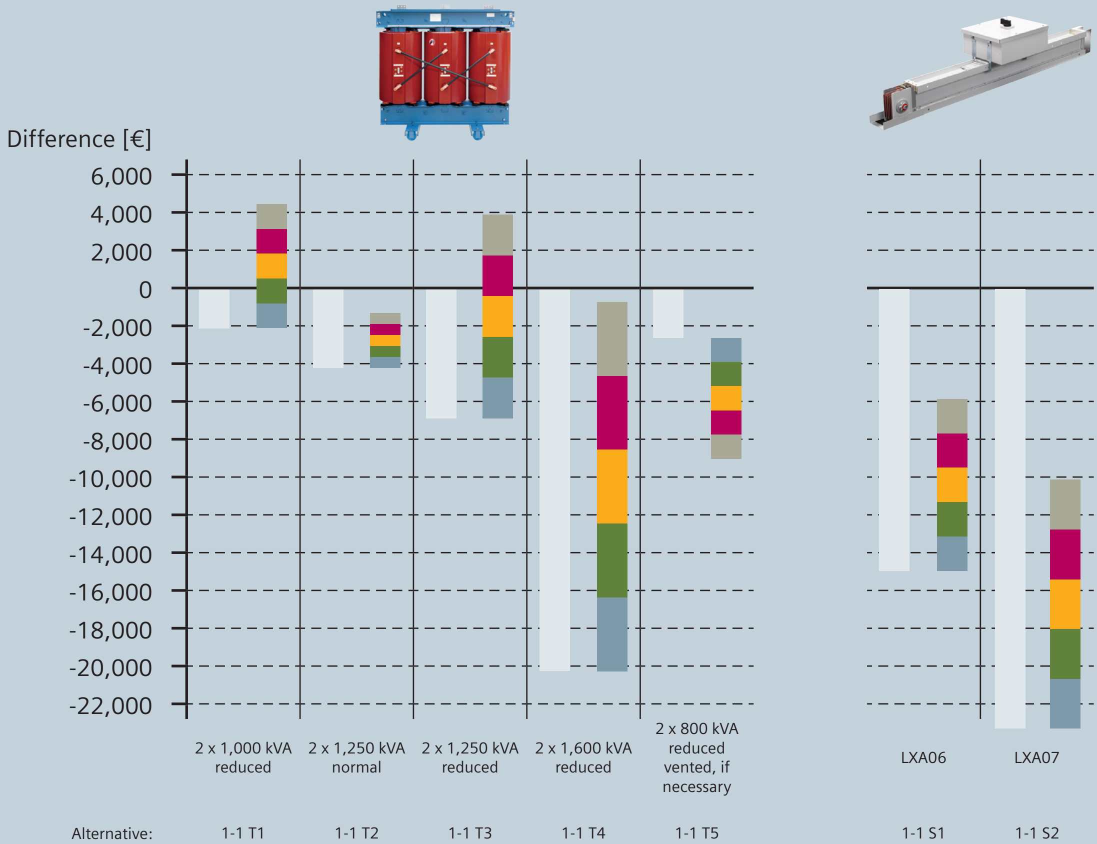


Fig. 7: Comparison of the life cycle energy costs for GEAFOL transformers and LXA busbar trunking systems in stand-alone operation (variant 1) and for Scenario 1 (design system: 2 x GEAFOL 1,000 kVA with normal losses; 2 x LXA05, 30 m in length)

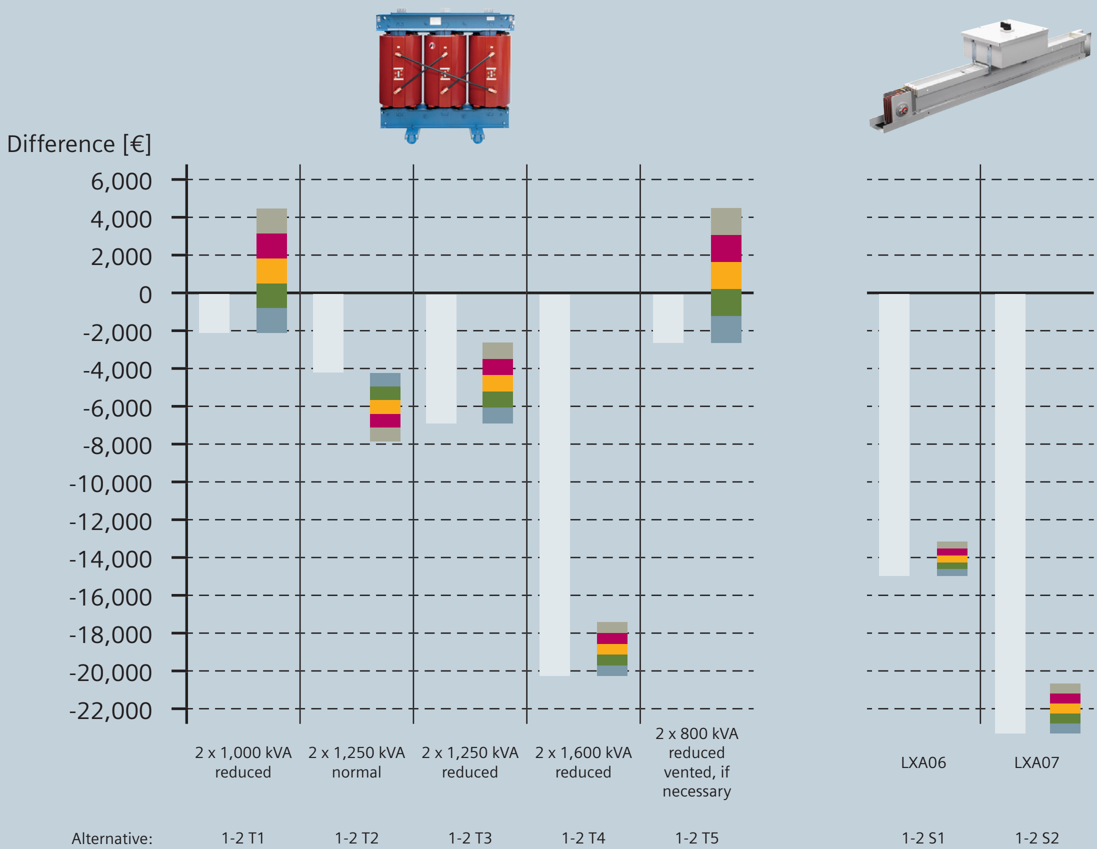


Fig. 8: Comparison of the life cycle energy costs for GEAFOL transformers and LXA busbar trunking systems in stand-alone operation (variant 1) and for Scenario 2 (design system: 2 x GEAFOL 1,000 kVA with normal losses; 2 x LXA05, 30 m in length)

ii) Assessment for stand-alone operation and Scenario 2
The same alternatives as under i) were chosen for stand-alone operation in Scenario 2 (see Fig. 8).

Investment for the individual alternatives does not distinguish between Scenario 1 and 2. When considering the cost of losses regarding busbar trunking alternatives, please note that costs relating to Scenario 2 will fall to about one-fifth of the amount incurring in the design system in Scenario 1, so that major benefits as a result of higher conductor cross sections needn't be expected. We have to bear in mind that none of the two busbar trunking alternatives described can be applied at low cost.

Owing to the lower rate of utilization of the feed-in system as compared to Scenario 1, the larger transformers featuring reduced no-load losses become less cost-effective, whereas Alternative 1-2 T5 can be operated at similar cost benefits as Alternative 1-2 T1. An important criterion for decision-making will be the user's expectation as to the consumption profile. If a rising consumption is expected, Scenario 2 draws near Scenario 1 and the alternative using the smaller, vented transformers becomes less cost-effective.

iii) Assessment of parallel operation and Scenario 1
Owing to the different usage options, the alternative using the two 1,600 kVA GEAFOL transformers is replaced by two 800 kVA GEAFOL transformers with additional ventilation and normal losses (see Fig. 9).

- Two 1,000 kVA GEAFOL transformers
  with reduced losses
- Two 1,250 kVA GEAFOL transformers
  with normal losses
- Two 1,250 kVA GEAFOL transformers
  with reduced losses
- Two 800 kVA GEAFOL transformers
  with additional ventilation and normal losses
- Two 800 kVA GEAFOL transformers
  with additional ventilation and reduced losses

Important note: The costs of loss relating to the transformers in the design system are approx. 30% lower that those incurred in stand-alone operation. This means that the cost ratio of losses to investment is also different.

As before, the loss-reduced transformer variants also provide cost benefits in this case when it comes to cost of losses. And the load distribution to two parallel transformers also makes Alternative 2-1 T5 an interesting option, since these transformers will not be overloaded, as it would be the case in stand-alone operation. It becomes obvious, that Alternative 2-1 T1 offers the greatest benefits.

Busbar trunking systems require a detailed project-specific analysis. The higher cost of investment into larger busbar trunking systems may prove advantageous across the system life cycle when power values are increased. The loss costs are halved in case of parallel operation so that any differences will also seem less significant.

iv) Assessment for stand-alone operation and Scenario 2
The same alternatives as under iii) are analysed for parallel operation and Scenario 2, (see Fig. 10).

To a certain extent, the results applying to Case iv) may also be derived from the previous statements made. Here too, the differences in the loss costs relating to the different busbar trunking systems play no important role, so that larger busbar trunking systems should only be considered in case of a future increased power demand. Owing to the lower rate of transformer utilization, the smaller sizes (Alternative 2-2 T5) featuring reduced no-load losses and additional ventilation become an interesting option to boost power output.

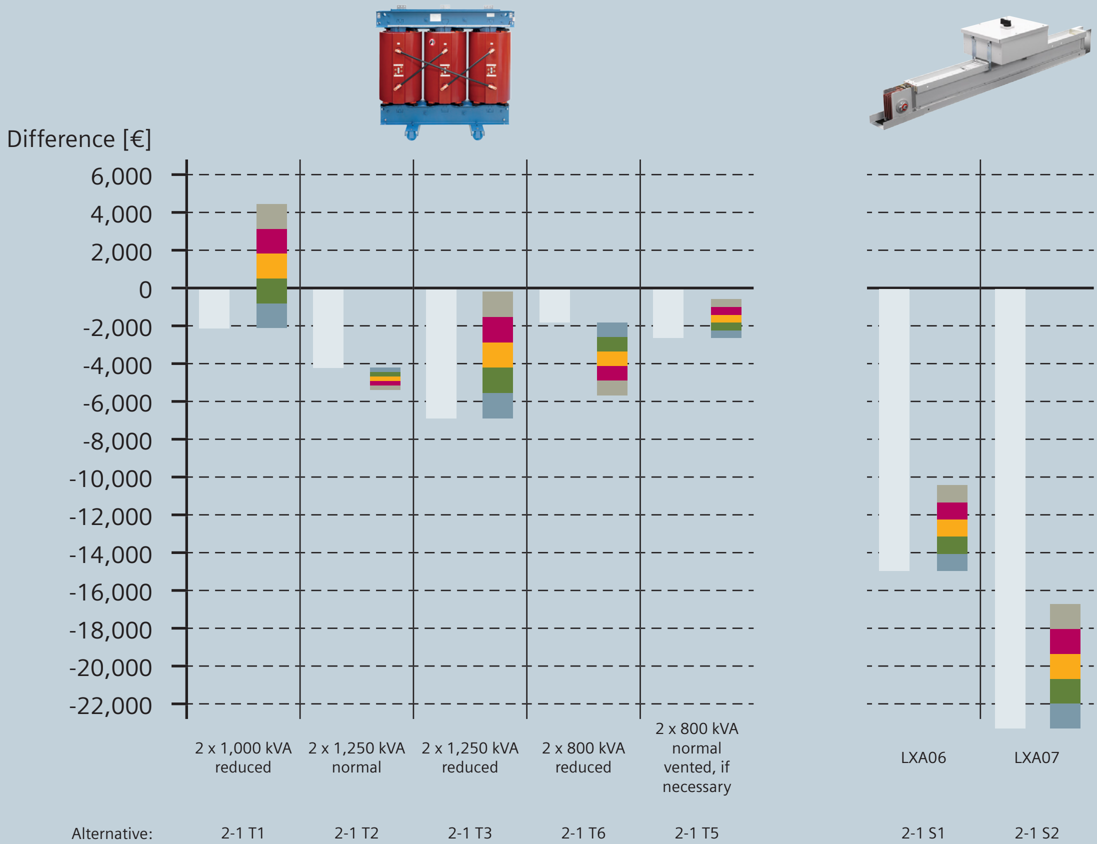


Fig. 9: Comparison of the life cycle energy costs for GEAFOL transformers and LXA busbar trunking systems in parallel operation (variant 2) and for Scenario 1 (design system: 2 x GEAFOL 1,000 kVA with normal losses; 2 x LXA05, 30 m in length)

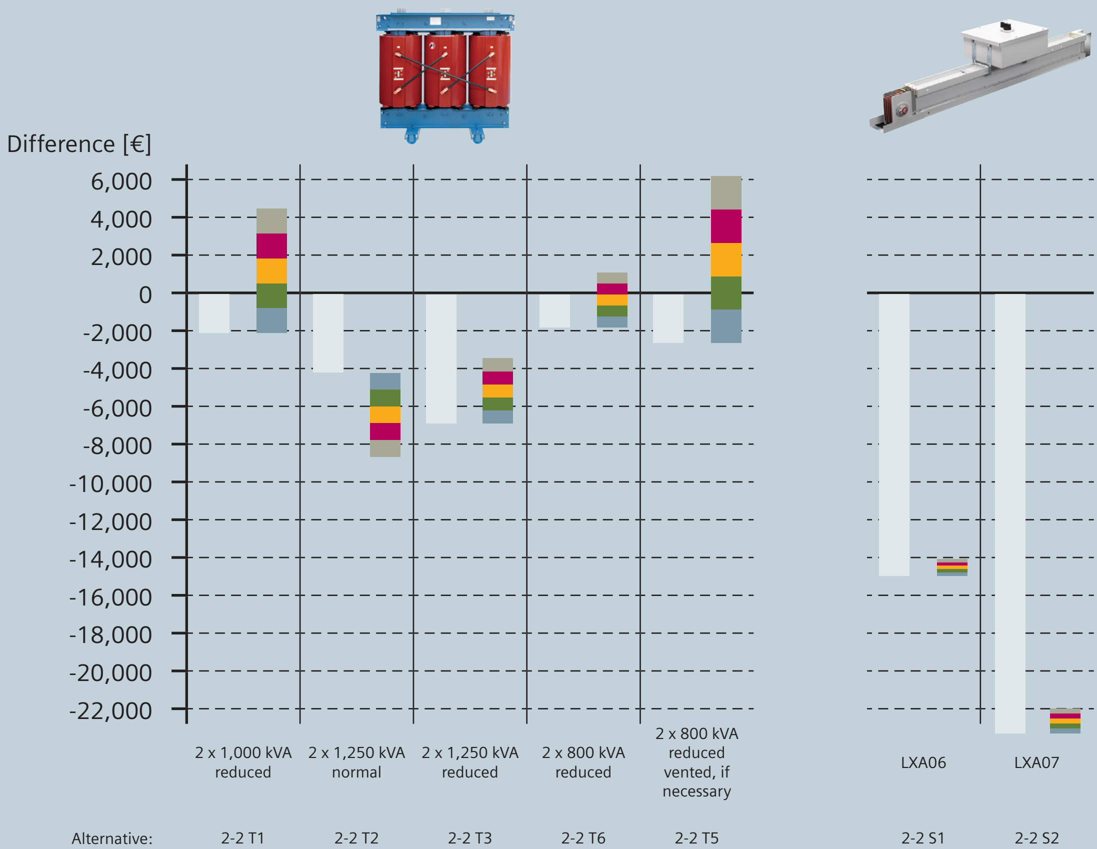
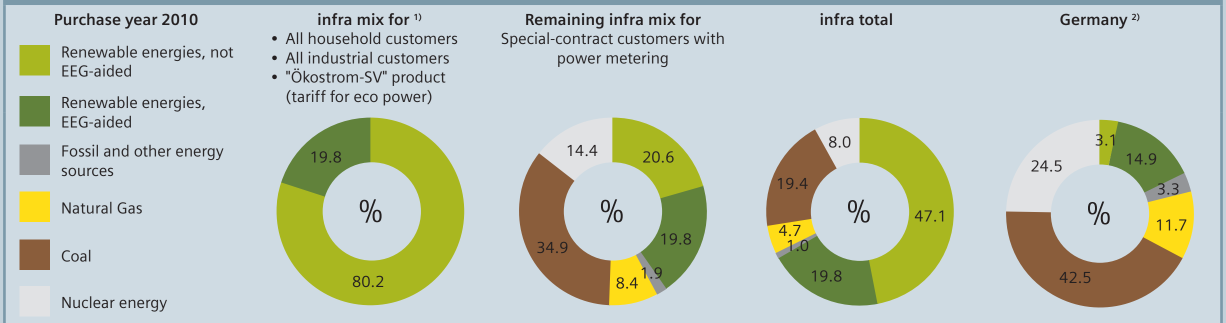


Fig. 10: Comparison of the life cycle energy costs for GEAFOL transformers and LXA busbar trunking systems in parallel operation (variant 2) and for Scenario 2 (design system: 2 x GEAFOL 1,000 kVA with normal losses; 2 x LXA05, 30 m in length)

Power loss evaluation and CO_2 emissions

The power supplier informs on the electricity mix on the invoice. This allows to see, how the electricity is generated and how many CO_2 shares per supplied kWh are emitted, see Fig. 11 for illustration.

Current characterisation of infra fürth GmbH based on § 42 EnWG



The following environmental impact will incur during the production of one kilowatt-hour:

CO_2 emissions:	0 g/kWh	373 g/kWh	207 g/kWh	494 g/kWh
Radioactive waste:	0.0000 g/kWh	0.0004 g/kWh	0.0002 g/kWh	0.0007 g/kWh

1) Those quantities not aided by the EEG consist of 100% hydro power.

2) Source: BDEW (German Association of Energy and Water Industries), as of 6 October 2011

CO_2: carbon dioxide, EnWG: Energiewirtschaftsgesetz (German Energy Act), EEG: Erneuerbare-Energien-Gesetz (German Act for the Preference of Renewable Energies), g: grams, kWh: kilowatt-hour, %: Percentage

Source: infra fürth GmbH, http://www.infra-fuerth.de/de/energie/strom/stromkennzeichnung/, as of 01 November 2011

Fig. 11: Load curve for Scenario 1

The loss energy saved for some of the previously considered alternatives results in a reduction of the CO_2 emissions.

For example, parallel operation in Scenario 1 using 1,250 kVA transformers with reduced no-load losses will reduce the loss energy by approx. 8,937 kWh/a compared to the design basis. Assuming a CO_2 factor of 0.494 kg/kWh, this will result in savings in CO_2 emissions amounting to approx. 4.4 t/a.

Conclusion

To a large extent, the amount of losses produced, and thus the entire life cycle energy costs involved, depend on the usage of the building or property. Whether, and to which extent, an optimization will make sense is determined by the energy purchase data on the one hand, and the predictability of future developments on the other. If the power purchase is very high, so that the transformer is utilized to a high degree, it does well make sense to opt for a transformer with a higher apparent power rating and reduced no-load losses. If, however, there are merely some high load peaks to be covered, it might be useful to allow a smaller transformer to run in its overload range. If changes in the usage profile are foreseeable, power supply design should take account of them. Financing options and system service life will also have an impact on costing.

Thanks to the reduced power loss, it is not only the life cycle energy costs that will be cut, but CO_2 emissions during electricity generation in the power station and in the further course of power transmission and distribution will also be avoided. This may be helpful for enterprises wanting or having to prepare an annual environmental report.

Siemens AG
Infrastructure & Cities Sector
Low and Medium Voltage Division
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