Transformers

General
A transformer is an important link in the energy supply and allows electrical energy to be transferred from a system with given properties (primary) to a system with the required properties (secondary) using the principle of electromagnetic induction.

Our production range comprises
• Single-phase dry transformers from 0.5 VA – 400 kVA
• Three-phase dry transformers from 25 VA – 630 kVA
• Single-phase and three-phase chokes from 80 VA – 400 kVA

Depending on the transformation ratio, higher throughput power levels can arise in transformers with autotransformer windings. (See explanations on types of winding.)

As transformers are hugely important for keeping people safe and ensuring that electrical systems can be operated safely, the very highest level of quality is required. We use high-quality materials and ensure meticulous workmanship, which means that our products guarantee excellent reliability and a nearly unlimited service life. The transformer cores consist exclusively of high-alloy, low-loss dynamo sheets, whose physical properties comply with the DIN 46400 standard. All of the insulation materials used inside the windings meet the criteria of insulation class B as a minimum when it comes to heat resistance. Furthermore, thanks to their strength and insulation properties, they are able to withstand the high-voltage tests stipulated by VDE regulations.

Continuous checks during production and a final inspection of all devices guarantee a consistently high standard of quality.
Transformers

Definitions

**Power transformers**
Transformers in which the primary winding is separated from the secondary winding by basic insulation at the very least (EN 61558-2-1).

**Control transformers**
Transformers with electrically isolated windings for supplying the electrical and electronic control and signal circuits. Control transformers are fitted with taps (preferably ± 5%) at the input side. These transformers are structured in accordance with VDE 0570 Part 2 – 2 (EN 61558-2-2). The short-time power of a control transformer is the output power at \( \cos \phi = 0.5 \) at which the output voltage may drop by a maximum of 5% compared to the nominal value.

**Isolating transformers**
These are transformers with electrically isolated windings (reinforced insulation) designed to fulfil the requirements of the “protective separation” safety measure for connecting an individual energy consumer (EN 61558-2-4).

**Safety isolating transformers**
These are transformers in which the primary and secondary windings are electrically isolated by double or reinforced insulation. The transformers are intended to supply a distribution circuit, a device or other appliances with safety extra-low voltage up to 50 VAC (open-circuit voltage) and/or 120 V smooth DC voltage. The sum of all of the secondary voltages must not exceed these values (EN 61558-2-6).

**Autotransformers**
These are transformers with a joint primary and secondary winding. The low-voltage winding is part of the high-voltage winding. With this set-up, the overall size, the weight, the costs and the transfer loss are lower than in the case of transformers with separate windings (EN 61558-2-13).

**Chokes**
These are a type of electrical equipment designed to create inductive resistance for the alternating current using the principle of electromagnetic self-inductance (EN 61558-2-20).
Transformers

Ordering information

The following information is required in order to ensure orders and enquiries can be dealt with quickly

**Type of transformer with type designation**
Fundamental difference between single-phase and three-phase transformers. Depending on the application, there may be an additional difference between the main groups such as control transformers (SETN/SETL, FST/SETB model series) or safety isolating transformers (FEST model series).

**Nominal power in VA or kVA**
Where several secondary windings are being used, the power for each winding must be specified separately. The nominal power is determined from the sum of the individual power ratings. Taps on the secondary winding can only be loaded with the current calculated from the secondary power and the highest secondary voltage. Deviating currents must also be specified.

**Nominal frequency or frequency range**
Normally 50/60 Hz.

**Nominal primary voltage**
Nominal voltage or nominal voltage range (V). In the case of three-phase transformers, the phase-to-phase voltage of the 3 phase conductors in relation to one another.

**Nominal secondary load voltage**
Or nominal secondary load voltage range (V). In the case of three-phase transformers, the phase-to-phase voltage of the 3 phase conductors in relation to one another.

**Type of winding**
Separate or autotransformer winding.

**Operating mode**
The operating mode DB does not need to be specified. For other types of load with specific duty cycles, specifying the cycle is essential.

**Vector group**
Required interconnection between the primary and secondary winding (only for three-phase transformers).

**Degree of protection**
Protection against contact, foreign bodies and water.

**Specific operating conditions**
Increased ambient temperatures, use in tropical areas (insulation for tropics), etc.

**Specific electrical conditions**
Particularly low losses, specific drops in voltage for certain loads, degree of protection II, resistance to short circuits, etc.

**Specific intended uses**
For checking motors, for operating heaters, as starting transformers, etc.
Transformers

Nominal power (rated power S)

The nominal power ratings specified in the catalogue are the power ratings that can be drawn at the output side in VA or kVA.

They apply to
- Separate winding with a ratio
- Nominal primary voltage
- Continuous operation (DB)
- Nominal frequency 50/60 Hz
- Ambient temperature 40°C

Calculating the nominal power
- In single-phase transformers, it is calculated as a product of the nominal secondary voltage and the nominal secondary current:

\[ S \text{ [VA]} = U \text{ [V]} \times I \text{ [A]} \]

- In three-phase transformers, it is calculated as a product of the nominal secondary voltage, the nominal secondary current and the interlinking factor \( \sqrt{3} \):

\[ S \text{ [VA]} = U \text{ [V]} \times I \text{ [A]} \times \sqrt{3} \]

- Where several secondary windings are being used, the nominal power is equal to the sum of all of the individual power ratings:

\[ S \text{ [VA]} = S_1 \text{ [VA]} + S_2 \text{ [VA]} + \ldots + S_n \text{ [VA]} \]

Taps at the secondary windings can only be loaded with the current calculated from the secondary power and highest secondary voltage. If constant output power is required over the entire voltage range or if several primary voltages need to be used, the overall size required can increase.

In this context, please observe the nominal primary voltage and nominal secondary voltage sections.
Transformers

Nominal frequency (rated frequency f)

All of the transformers explained here are suitable for use in supply networks with frequencies of 50/60 Hz. The losses, drops in voltage and efficiency levels that are specified relate to a nominal frequency of 50 Hz.

In cases where transformers are designed for different frequencies, the nominal power changes as shown in the following table:

<table>
<thead>
<tr>
<th>Frequency in Hz</th>
<th>16 2/3</th>
<th>40</th>
<th>42</th>
<th>50</th>
<th>60</th>
<th>75</th>
<th>100</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power in [%]</td>
<td></td>
<td>35</td>
<td>80</td>
<td>84</td>
<td>100</td>
<td>110</td>
<td>115</td>
<td>130</td>
<td>135</td>
</tr>
<tr>
<td>of the type power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When using a standard transformer with the frequency value 50/60 Hz in a 60 Hz supply network, the nominal power specified must not be exceeded. Differing frequencies must be taken into consideration as early as the dimensioning stage.

Nominal primary voltage

The nominal primary voltage is the mains voltage for which the transformer is designated. In the case of multiple-phase power supplies (e.g. three-phase power supplies), the voltage specified is the phase-to-phase voltage. The primary voltage is the input voltage to which the transformer is connected.

Transformers can be equipped with taps on the primary winding so that they can be used on various supply networks. However, this often means choosing the next-largest size or type as larger wire cross-sections are required in the lower voltage range than in the higher voltage range.

\[
S_t = S + S \times \frac{(U_2 - U_1)}{2U_2}
\]

Where:
- \( S_t \) = type power
- \( S \) = nominal power
- \( U_1 \) = low voltage
- \( U_2 \) = high voltage

The exception is 2 primary voltages, which are at a ratio of 1:2 to one another. The device can be used for both voltages without the need for additional winding space if two identical winding parts (e.g. 2 x 115 V) are connected either in series or in parallel.

As a variation of this principle, it is possible to combine various primary windings and therefore cover a wide primary voltage range by spending a justifiable amount on winding space. (See our USTB/USTN/USTLB model series.)
Transformers

Nominal secondary voltage

The voltage designated as the nominal secondary voltage or the secondary load voltage occurs under load with the nominal power at the nominal frequency and power factor \( \cos \varphi = 1 \) after the output terminals of the transformer have reached the operating temperature. At the voltage drop, it is always lower than the secondary open-circuit voltage which arises in an unloaded state. You can find the voltage drop that is specific for the individual types, according to the conditions referred to above, in the tables on the relevant page of the catalogue, where it is expressed as a percentage value. To obtain a range of secondary voltages, secondary windings can be supplied with taps. However, these taps can only be loaded with the current calculated from the secondary power and highest secondary voltage. If constant power is required over the entire voltage range, the overall size required can increase. The following formula allows you to roughly calculate the type power required:

\[
S_t = S + S \times \frac{(U_2 - U_1)}{2U_2}
\]

\( S_t \) = type power  \( S \) = nominal power  \( U_1 \) = low voltage  \( U_2 \) = high voltage

Types of winding

Separate winding

There is no electrically conductive connection between the primary and secondary winding. The energy is transferred with the help of a closed magnetic circuit, which links the windings with each other magnetically. The secondary winding is non-earthed; i.e. there is no contact voltage relative to the earth potential.

In the case of transformers with separate windings, the type power ratings and the nominal power ratings specified in the catalogue are identical.

Autotransformer winding

The primary and secondary winding are linked to one another via an electrically conductive connection. The low-voltage winding is part of the high-voltage winding of the transformer. Some of the throughput power is transferred inductively and some via the current line. The smaller the difference between the high and low voltage, the smaller the proportion of power transferred inductively – therefore, the overall size required is smaller too.

The overall size or type power of an autotransformer is always smaller than the nominal power (throughput power) and can be calculated using the following formula:

\[
S_t = S \times (1 - \frac{U_1}{U_2})
\]

\( S_t \) = type power  \( S \) = nominal power  \( U_1 \) = low voltage  \( U_2 \) = high voltage

Autotransformers cannot be used as safety transformers. The output has voltage potential to earth.
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Operating modes

**Continuous operation (DB)**
The operating time is, as a minimum, long enough to reach the operating temperature.

**Intermittent duty (AB), short-term duty (KB)**
The operating time specified as permissible is short enough to ensure that the operating temperature is not reached. The interruption that follows, during which the transformer is separated from the power supply on the input side, is too short to allow the device to cool down to the ambient temperature.

The nominal power values in the catalogue relate to the operating mode DB. If you know the actual load period (AB), you can therefore use a transformer with a lower type power in many cases.

**Procedure for determining the required type power**
a) Determine the duty cycle as a percentage value using the following formula:

\[
\text{Duty cycle (%)} = 100 \times \frac{\text{load period in minutes}}{\text{cycle duration in minutes}}
\]

The cycle duration (operating time + interval) must not exceed 10 minutes.

b) Determine the required type power as a % of the nominal power using the following table:

<table>
<thead>
<tr>
<th>Duty cycle (%)</th>
<th>1.5</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>40</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N_T) (%)</td>
<td>12</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>45</td>
<td>60</td>
<td>70</td>
</tr>
</tbody>
</table>

In this case, however, it is important to note that the voltage drop increases at the ratio of the nominal power to the type power.

**Voltage drop as a % of the secondary nominal voltage \((S/S_T)\)\times \text{specific voltage drop}.**

This is particularly important if the transformer is to be operated with a relatively low base load in continuous operation, combined with short-term load spikes. In general, the maximum permissible voltage difference that occurs between the smallest and largest output load is the main criterion when choosing the type size.
Transformers

Operating modes

Permissible overload
A transformer can be loaded with a higher power rating than the nominal power in accordance with the table below without exceeding the permissible overtemperature if the previous continuous load was smaller than the nominal power of the transformer.

<table>
<thead>
<tr>
<th>Previous cont. load as a % of nom. power</th>
<th>Permissible overload duration for an overload as a % of the nom. power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>75</td>
<td>55</td>
</tr>
<tr>
<td>90</td>
<td>45</td>
</tr>
</tbody>
</table>

Vector groups

In the case of three-phase transformers, the vector group identifies the circuit of the windings and their phase positions relative to one another.

The name of the vector group is formed using upper-case letters for the high-voltage windings, lower-case letters for the low-voltage windings, and a figure for the phase position. The figure indicates the lag of the low voltage compared to the high voltage as a multiple of 30°.

Example: Dyn5

- High-voltage winding in delta
- Low-voltage winding in star with brought-out neutral conductor
- Low-voltage lag compared to high-voltage lag
  \[5 \times 30° = 150°\]

If no particular vector group is specified, three-phase transformers are configured as a double-star circuit with brought-out neutral conductor on the secondary side. The vector groups are Yyn0 for transformers with separate windings and YNa0 for autotransformer windings. The neutral point can be loaded with around 10% of the phase-to-phase current without requiring any special measures.

Other preferred vector groups are

- Delta-star circuit with brought-out neutral conductor on the secondary side: Dyn5
- Star-delta circuit: Yd5
- Star-zigzag circuit with brought-out neutral conductor on the secondary side: Yzn5
- Zigzag-autotransformer circuit with brought-out neutral conductor: ZNa

In the case of transformers with the vector groups Dzn0, Dyn5, Dyn11, Yzn5, Yzn11 and Zna, the neutral point can be loaded with 100% without requiring any special measures.
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Degrees of protection

The IP degree of protection indicates the level of protection for electrical equipment against contact, foreign bodies and water. The most common degrees of protection are IP 00, IP 20, IP 23, IP 44 and IP 54. If just one key figure is required for the degree of protection, the other figure is replaced by an X.

The individual degrees of protection are defined as follows according to DIN 40 050

<table>
<thead>
<tr>
<th>1st figure</th>
<th>Degree of protection against contact and foreign bodies</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No special protection</td>
</tr>
<tr>
<td>1</td>
<td>Live parts are protected against contact with the backs of hands (solid foreign bodies with Ø ≥ 50 mm)</td>
</tr>
<tr>
<td>2</td>
<td>Live parts are protected against contact with fingers (solid foreign bodies with Ø ≥ 12.5 mm)</td>
</tr>
<tr>
<td>3</td>
<td>Live parts are protected against contact with tools (solid foreign bodies with Ø ≥ 2.5 mm)</td>
</tr>
<tr>
<td>4</td>
<td>Live parts are protected against contact with wires (solid foreign bodies with Ø ≥ 1 mm)</td>
</tr>
<tr>
<td>5</td>
<td>Live parts are fully protected against contact (protection against dust deposits on the inside)</td>
</tr>
<tr>
<td>6</td>
<td>Live parts are fully protected against contact (protection against dust penetration)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2nd figure</th>
<th>Degree of protection against water</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No special protection</td>
</tr>
<tr>
<td>1</td>
<td>Protection against water drops falling vertically (no damaging effect)</td>
</tr>
<tr>
<td>2</td>
<td>As for 1; additional protection when the machine is tilted up to 15° from the normal position</td>
</tr>
<tr>
<td>3</td>
<td>Protection against spray. Water that falls at any angle up to 60° from the vertical shall have no damaging effect.</td>
</tr>
<tr>
<td>4</td>
<td>Protection against splashes. Water that splashes in any direction shall have no damaging effect.</td>
</tr>
<tr>
<td>5</td>
<td>Protection against water jets. Water jets aimed at the housing from any direction shall have no damaging effect.</td>
</tr>
<tr>
<td>6</td>
<td>Protection against flooding. In the event of temporary flooding, damaging quantities of water shall not enter the equipment.</td>
</tr>
<tr>
<td>7</td>
<td>Protection during immersion. Damaging quantities of water shall not enter if the equipment is immersed in water under specified pressure and time conditions.</td>
</tr>
<tr>
<td>8</td>
<td>Protection during submersion. Damaging quantities of water shall not enter if the equipment is immersed in water and the conditions are harsher than in the case of key figure 7.</td>
</tr>
</tbody>
</table>
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Specific operating conditions

Ambient temperature
If an unimpeded flow of cool air is guaranteed, the heating of the transformers that occurs under normal operating conditions does not exceed the overtemperatures permissible according to VDE 0570 at a maximum ambient temperature of 40°C.

In the VDE 0570 transformer regulation, the temperature values for normal use and continuous load are divided into individual classes of insulation, which are listed in the table below:

<table>
<thead>
<tr>
<th>Insulation system class</th>
<th>Temperature in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
</tr>
<tr>
<td>E</td>
<td>115</td>
</tr>
<tr>
<td>B</td>
<td>120</td>
</tr>
<tr>
<td>F</td>
<td>140</td>
</tr>
<tr>
<td>H</td>
<td>165</td>
</tr>
</tbody>
</table>

The transformers listed in the catalogue are built with class B insulation. At higher ambient temperatures, the nominal power reduces in accordance with the following table:

<table>
<thead>
<tr>
<th>Ambient temperature [°C]</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal power as a % of the type power</td>
<td>95</td>
<td>85</td>
<td>80</td>
<td>75</td>
<td>70</td>
<td>60</td>
</tr>
</tbody>
</table>

Insulation
The insulation structure means that the transformers can be used in dry or damp areas as the transformers are impregnated with a finishing substance under a vacuum. This largely eliminates any moisture.

To create resistance to tropical conditions, this impregnation process is repeated using a protective lacquer as a finishing treatment, which contains a special substance that protects against mould and fungi.
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Specific electrical conditions

Resistance to short circuits
Under certain conditions, transformers must be able to withstand the overloads that occur in normal use as well as short circuits.

In the VDE regulations, transformers are divided into categories according to the type of resistance to short circuits they demonstrate. These categories are explained below:

• Absolutely short circuit-proof
  Transformers without a protective device. In the event of an overload or a short circuit, the temperature does not exceed the defined limit temperatures. The transformers can be operated again after the overload or short circuit has been eliminated. This resistance to short circuits is attained thanks to a voltage drop in the device.
  **Note:** Due to physical restrictions, these transformers can only be used for systems with low nominal power ratings. The open-circuit voltage factor may assume a value of up to 2.5.

• Limited short circuit resistance
  Transformers with a built-in protective device which opens the circuit or limits the current in the input or output circuit if the transformer is overloaded or short-circuits.
  **Note:** Examples of protective devices are fuses, overload releases, temperature fuses, automatically or non-automatically resetting temperature limiters, PTC thermistors, and circuit breakers that are triggered automatically and mechanically.

• Not short circuit-proof
  Transformers without a protective device. The operator must protect the transformers against overloads by using suitable protective devices in the supply or discharge line. In these circumstances, they comply with the provisions concerning transformers with limited short circuit resistance.

Unless there is a technical reason which states otherwise, the protective device for transformers with limited short circuit resistance must be installed in the input circuit.

When protecting the input circuit with fuses, it is important to note that switch-on current spikes – which equate to a multiple of the primary nominal current – occur in the majority of transformers. We therefore advise only using time-delay fuses.
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Protection class

The protection class shows which type of protective measures against impermissible touch voltages the devices are prepared for incorporated into.

Protection **class I** includes transformers and chokes in which all the exposed metal parts that could have voltage applied to them in the event of an operational insulation fault are linked together permanently and with good electrical conductivity. They are also linked to an appliance for connecting a protective conductor. As a protective conductor is connected, they fall under the “protective earthing” category of protection.

Protection **class II** includes transformers in which all the exposed, conductive parts of components that could have voltage applied to them in the event of an operational insulation fault are separated by additional insulation (protective insulation such as a plastic housing). They do not have an appliance for connecting a protective conductor.

With the exception of the RK, RKG, RKS and RKR model series, we prepare all the transformers explained here for protection class I.
Transformers

Accident prevention regulations

**BGV A2 (VBG4)**

issued by the German professional association for precision mechanics and electrical engineering

**What is the BGV A2 (VBG4)?**

This is an accident prevention regulation for electrical systems and equipment. It addresses the operators of these systems and aims to prevent accidents. Alongside the provisions for work and operation on or in the proximity of live parts, it also looks at the subject of occasional handling in detail.

**Occasional handling occurs when**

- Changing screw locking devices and indicator lamps
- Operating protective devices on switches and releases
- Releasing relays (resetting the overcurrent release)
- Adjusting releases

**The BGV A2 (VBG4) requirements**

The live parts of electrical systems and equipment must be protected against direct contact using insulation, their positioning and arrangement, or permanently attached appliances, in accordance with their voltage, frequency, application and operating location.

**Live parts may be touched**

a) with the fingers
b) with the back of the hand

**BGV A2 (VBG4) recognises**

a) devices that protect against contact with the fingers
b) devices that protect against contact with the back of the hand

Transformers from Gebrüder Frei GmbH & Co are always fitted with connecting terminals that prevent contact with the fingers.