6 Choice and use of MV equipment and MV/LV transformer

6.1 Choice of MV equipment

The electrical equipment must withstand both electrical and environmental constraints to which it will be submitted during its life time without any mechanical and dielectric degradation reducing its level of performances.

6.1.1 Standards and specifications

Depending on the devices, components and products included in the MV switchgear, different standards have to be considered for compliance, such as:
- IEC 62271-1, 62271-100, 62271-102, 62271-103, 62271-105, 62271-200.

Local regulations may also require compliance with national standards:
- ANSI/IEEE for USA
- EN for European Union
- GOST for Russia
- GB/DL for China.

6.1.2 Types of MV equipment

Substations shall be designed and built according to local standards and practices. The following types of equipment may be used:
- Compartmented modular units supporting all types of single line diagram and layout
- Compact solution based on ring-main unit solution when the supply is provided by a ring.

A ring main unit includes two load break switches for the connection of the substation to the ring and a transformer protection unit. Some compact RMU designs are particularly suitable when harsh environmental conditions apply.

6.1.3 Modular metal-enclosed switchgear (Fig. B36)

The IEC 62271-200 standard specifies requirements for "AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV".
Different categories of prefabricated metal enclosed switchgear are defined with respect to the consequences on network service continuity in case of maintenance on the switchgear.
For classification in categories, various aspects have to be taken into account:
- Definition of functional unit: "a switchgear component contained in a metallic enclosure and incorporating all the main and auxiliary circuit equipment required to perform a single function" - usually a modular unit
- Definition of compartment: "a switchgear component contained in a closed metallic enclosure. The manufacturer defines the content (e.g. busbar, cable connections, etc.)
- Accessibility to individual compartments (see 3.4.1):
  - Controlled by interlocking
  - In accordance with procedures; for compartments which can be opened during normal operation
  - Using tools; for compartments which should not be opened during normal operation
  - Not accessible for compartments which must not be opened
- Loss of Service Continuity (LSC) (see 3.4.3) defining the extent to which other compartments can remain energised when one compartment is open. Four LSC categories are defined:
  - LSC1, LSC2, LSC2 A, LSC2 B
- Definition of partition "a switchgear component contained in a metallic enclosure and separating one compartment from another" They are two types of partition :
  - PM: metallic partitions
  - PI: insulating partitions.

Metal-enclosed switchgear can be based on all modern switchgear technologies, such as:
- AIS (**A**ir **I**nsulated **S**witchgear)
- SIS (**S**olid **I**nsulated **S**witchgear)
- GIS (**G**as **I**nsulated **S**witchgear)
- 2SIS (**S**hielded **S**olid **I**nsulated **S**witchgear).

Fig. B36: SF6 modular unit

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6.1.4 Choice of MV switchgear panel for a transformer circuit

Three types of MV switchgear panel can be used:
- Load-break switch associated to MV fuses without coordination between the fuses and the breaking capability of the load break switch
- Load-break switch/MV fuses combination with coordination between the fuses and the breaking capability of the load break switch
- Circuit breaker

As explained in paragraph 3.3, a circuit breaker with a dedicated protection relay ensures a better protection of the transformer than the MV fuses coordinated or not with a load break switch.

Note: The fuses used in the load-break/switch fuses combination have striker-pins which ensure tripping of the 3-pole switch as soon as at least one fuse blows.

6.2 Instructions for use of MV equipment

The purpose of this chapter is to provide general guidelines on how to avoid or greatly reduce MV equipment degradation on sites exposed to humidity and pollution.

6.2.1 Normal service conditions for indoor MV equipment

All MV equipment are intented to be used in the normal services conditions as defined in IEC 62271-1 standard "Common specifications for high-voltage switchgear and controlgear".

For instance, regarding humidity, the standard mentions:
- The average value of the relative humidity, measured over a period of 24 h does not exceed 90 %;
- The average value of the water vapour pressure, over a period of 24 h does not exceed 2.2 kPa;
- The average value of the relative humidity, over a period of one month does not exceed 90 %;
- The average value of water vapour pressure, over a period of one month does not exceed 1.8 kPa.

As indicated in the standard, condensation may occasionally occur even under normal conditions. Either switchgear designed for such conditions shall be used and/or special measures concerning the substation premises can be implemented to prevent condensation, such as suitable ventilation and heating of the station.

Fig. B37: SM6 Modular Unit

6.2.2 Use under severe conditions

Under certain severe conditions concerning humidity and pollution, largely beyond the normal conditions of use mentioned above, electrical equipment can be subject to damage by rapid corrosion of metal parts and surface degradation of insulating parts. Examples of suitable measures of protection against condensation and pollution are listed bellow.

Remedial measures for condensation problems
- Carefully design or adapt substation ventilation.
- Avoid temperature variations.
- Eliminate sources of humidity in the substation environment.
- Install an **H**eating, **V**entilation, **A**ir **C**onditioning unit (HVAC)
- Make sure cabling is in accordance with applicable rules.

Remedial measures for pollution problems
- Equip substation ventilation openings with chevron-type baffles to reduce entry of dust and pollution especially when the transformer is installed in the same room with switchgears or controlgears.
- Install the transformer in a different room to use more efficient ventilation grids if any,
- Keep substation ventilation to the minimum required for evacuation of transformer heat to reduce entry of pollution and dust
- Use MV cubicles with a sufficiently high degree of protection (IP)
- Use air conditioning systems or air forced cooling with filters installed in air inlet to restrict entry of pollution and dust.
- Regularly clean all traces of pollution from metal and insulating parts.
- Instead of using AIS equipment (**Fig. B37**), use equipment that is insensitive to the environment such as GIS or 2SIS type (see **Fig. B38**).

Fig. B38: PREMSET. Shielded Solid Insulated MV equipment

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6.3 Choice of MV/LV transformer

The transformers shall comply with IEC 60076. A transformer is characterized by its electrical parameters, but also by its technology and its conditions of use.

6.3.1 Characteristic parameters of a transformer

■ Rated power: the apparent-power in kVA on which the values of the design parameters and the construction of the transformer are based. Manufacturing tests and guarantee refer to this rated power
■ Frequency: for power distribution systems discussed in this guide, the frequency is either 50 Hz or 60 Hz
■ Rated primary voltage: the service voltage of the electrical network on which the transformer in connected
■ Rated secondary voltage: the voltage measured between the secondary terminals when the transformer is off load and energized at its rated primary voltage
■ Transformer ratio: RMS value of the rated primary voltage divided by the RMS value of the rated secondary voltage
■ Rated insulation levels: are defined by the values of the overvoltage power frequency withstand test, and high voltage lightning impulse tests.
For the voltage levels considered in this guide, the encountered switching over voltages are generally lower than the expected lightning over voltages, so no over voltage switching tests are required for these voltages
■ Off-load tap-Changer switch: allows to adjust the rated primary voltage and consequently the transformer ratio within the range ± 2.5 % and ± 5 %.
The transformer must be de-energized before the operation of the switch
■ Winding configurations: Star, Delta and Zigzag high and low voltage windings connections are defined by an alphanumeric code red from the left to the right. The first letter refers to the high voltage winding, the second letter to low voltage winding :
□ Capital letters are used for the high voltage windings
- D = delta connection
- Y = star connection
- Z = zigzag connection
- N = neutral point brought out to a dedicated terminal
□ Lower-case letters are used for the low voltage winding
- d = delta
- y = star
- z = interconnected-star (or zigzag)
- n = neutral point brought out to a dedicated terminal
□ A number between 0 and 11 indicates the phase shifting between the primary and the secondary voltages.
□ A common winding configuration used for distribution transformers is Dyn 11:
- High voltage primary windings connected in Delta
- Low voltage secondary windings connected in Star
- Low voltage neutral point brought out to a dedicated terminal.
- Phase shifting between the primary and the secondary voltage: 30°.

6.3.2 Technology and utilization of the transformers

There are two basic types of distribution transformer:
■ Dry type (cast resin encapsulated) transformer
■ Liquid filled (oil-immersed) transformer.

According IEC 60076, the standard conditions of utilization of the transformers for outdoor and indoor installation are the following:
■ Altitude ⩽ 1000 m
■ Maximum ambient temperature: 40 °C
■ Monthly average temperature: 30 °C during the hottest month
■ Annual average temperature: 20 °C.

Dry type transformers (see **Fig. B39**)
The dry type transformers shall comply with IEC 60076-11:
Each individual winding of these transformers is casted in resin according a vacuum dedicated process.
The high voltage winding, the low voltage winding and the frame are separate by air.

The encapsulation of a winding uses three components:
■ Epoxy-resin based on biphenol A with a viscosity that ensures complete impregnation of the windings
■ Anhydride hardener modified to introduce a degree of resilience in the moulding, essential to avoid the development of cracks during the temperature cycles occurring in normal operation
■ Pulverulent additive composed of trihydrated alumina Al (OH)3 and silica which enhances its mechanical and thermal properties, as well as giving exceptional intrinsic qualities to the insulation in the presence of heat.

Fig. B39: Dry type transformer

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■ This three-component system of encapsulation gives Class F insulation ($\Delta\theta$ = 100 K) with excellent fire-resisting qualities and immediate self-extinction. The moulding of the windings contain no halogen compounds (chlorine, bromine, etc.) and no other compounds capable of producing corrosive or toxic pollutants, thereby guaranteeing a high degree of safety to personnel in emergency situations, notably in the event of a fire.
These transformers are classified as nonflammable. Transformers exposed to fire risk with low flammability and self extinguishing in a given time.
They are also exceptionally well adapted for hostile industrial atmospheres and comply with the following class of environment:
■ Class E3: up to 95 % of humidity and/or high level of pollution
■ Class C3: utilization, transport and storage down to -50 °C.

Liquid-filled transformers

The most common insulating liquid used in these transformers is mineral oil, which also acts as a cooling medium.
Mineral oils are specified in IEC 60296, they must not contain PCB (**P**oly**C**hlorinated **B**iphenyl).
Mineral oil can be replaced by an alternative insulating liquid such as high density hydrocarbons, esters, silicones, halogen liquids.
The oil being flammable, dedicated safety measures against fire are mandatory in many countries, especially for indoor substations.

The dielectric liquids are classified in several categories according to their fire performance. This latter is assessed according to two criteria (see **Fig. B40**):
■ The flash-point temperature
■ The minimum calorific power.

Fig. B41: Hermetically-sealed totally-filled oil transformer

Code	Dielectric fluid	Flash-point (°C)	Minimum calorific power (MJ/kg)
O1	Mineral oil	< 300	-
K1	High-density hydrocarbons	> 300	48
K2	Esters	> 300	34 - 37
K3	Silicones	> 300	27 - 28
L3	Insulating halogen liquids	-	12

Fig. B40: Categories of dielectric fluids

There are two types of liquid filled transformers: Hermetically-sealed totally-filled transformers and Air-breathing transformer.
■ Hermetically-sealed totally-filled transformers up to 10 MVA (see **Fig. B41**)
For this type of transformers the expansion of the insulating liquid is compensated by the elastic deformation of the oil-cooling radiators attached to the tank.
The protection against internal faults is ensured by means of a DGPT device: Detection of Gas, Internal Over Pressure and Oil Over Temperature.
The "total-fill" technique has many advantages:
□ Water cannot enter the tank
□ Oxidation of the dielectric liquid with atmospheric oxygen is entirely precluded
□ No need for an air-drying device, and so no consequent maintenance (inspection and changing of saturated desiccant)
□ No need for dielectric-strength test of the liquid for at least 10 years
■ Air-breathing transformer (see **Fig. B42**)
This type of transformer is equipped with an expansion tank or conservator mounted above the main tank. The expansion of the insulating liquid is compensated inside the conservator by the raising of the oil level.

A conservator is required for transformers rated above10 MVA which is presently the upper limit for "totally filled type transformers".
In the conservator the top of the oil is in contact with the air which must remain dry to avoid any oxidation. This is achieved by admitting the outside air in the conservator through a desiccating device containing silica-gel crystals.
The protection of breathing transformers against internal faults is ensured by means of a buchholz mounted on the pipe linking the main tank to the conservator.
The buchholz ensures the detection of gas emission and internal over pressure.
The over temperature of the oil is commonly detected by an additional thermostat.

Fig. B42: Air-breathing oil transformer

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6.3.3 Choice of technology

As discussed above, the choice of transformer is between liquid-filled or dry type. For ratings up to 10 MVA, totally filled units are available as an alternative to conservator type transformers.
The choice depends on a number of considerations, including:
- Local regulations and recommendations. In some countries dry-type transformers are mandatory for specific buildings such as hospitals, commercial premises etc.
- Risk of fire
- Prices and technical considerations, taking account the relative advantages of each technology.

6.3.4 Determination of the optimal power

The over sizing of a transformer results in:
- Excessive investment
- Un necessarily high no-load losses
- Lower on-load losses.

Under sizing a transformer causes:
- A reduced efficiency when fully loaded. The highest efficiency is attained in the range 50 % - 70 % of the full load,
- On long-term overload, serious consequences for the transformer, owing to the premature ageing of the windings insulation, and in extreme cases, resulting in failure of insulation and loss of the transformer.

Definition of optimal power
In order to select an optimal power rating for a transformer, the following factors must be taken into account:
- List the consumers and define the factor of utilization ku and the diversity factor ks for each load as describe in chapter A
- Determine the load cycle of the installation, noting the duration of loads and overloads
- Take into account all possible future extensions of the installation.
- Arrange for power-factor correction, if justified, in order to:
  - Reduce billing penalties in tariffs based, in part, on maximum kVA demand
  - Reduce the value of the required apparent power: P(kVA) = P (kW)/cos ϕ
- Select the transformer, among the range of standard transformer ratings available.

To avoid over heating and consequently premature ageing of the transformer, it is important to ensure that cooling arrangements of the transformer are adequate.

6.4 Ventilation in MV Substations

Substation ventilation is generally required to dissipate the heat produced by transformers and other equipement, and to allow drying after particularly wet or humid periods.
However, a number of studies have shown that excessive ventilation can drastically increase condensation.

6.4.1 Remark concerning HV/LV outdoor prefabricated substation

- Any installation of any transformer in a same room or in a same enclosure with HV and LV switchgears will impact the lifespan of the products
- Any air change generated by the transformer heating reduces the impact of irradiance. This air flow change is a natural convection
- Any separation of the transformer by a partition wall with the HV and LV switchgears compartment improve the service condition of the switchgears for moderate climates.
- For outdoor installations, any switchgear should be preferably installed in a thermal insulated enclosure protecting it from outdoor service condition (dust, humidity, solar radiation etc.) especially for very hot and cold climates.

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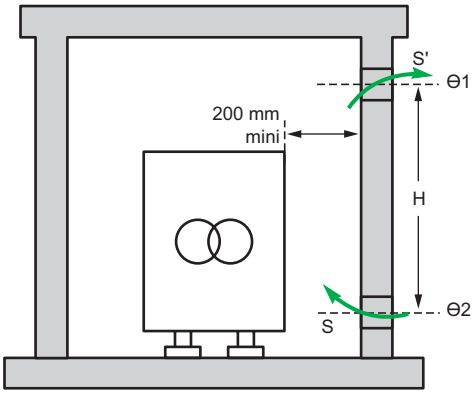
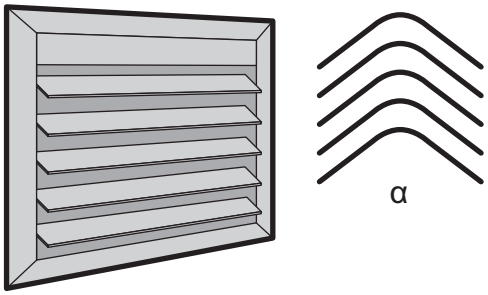


Fig. B43: Natural ventilation



IP23 Chevrons blade
(ξ = 33 if α = 60°, and ξ = 12 if α = 90°)

Other openings:
Additional vermin proof wiremesh with 1 mm² openings using a wire thickness 0.6 mm, whole covering ventilation grid
ξ become ξ + 5

Grid only with 38 mm x 10 mm openings: ξ = 9

Fig. B44: Coefficient of pressure losses defined by air flow tests

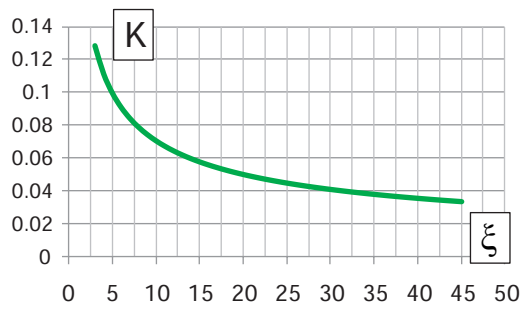


Fig. B45: Impact of the ventilation grids

6.4.2 General requirements

Ventilation should be kept to the minimum level required.
Furthermore, ventilation should never generate sudden temperature variations that can cause the dew point to be reached.

For this reason, natural ventilation should be used whenever possible. If forced ventilation is necessary, the fans should operate continuously to avoid temperature fluctuations. When forced ventilation is not enough to assure the indoor service condition of the switchgear or when the installation surrounding is a hazardous area, HVAC unit will be necessary to separate completely the indoor service conditions to the outdoor service conditions.

Natural ventilation, (see **Fig. B43**), being the most used for MV installations, a guideline for sizing the air entry and exit openings of HV/LV substations is presented hereafter.

6.4.3 Calculation methods

The proposed method is suitable for transformers installed in prefabricated enclosures or in dedicated rooms inside buildings. **Fig. B44** using the same ventilation grids for air inlet and air outlet.
A number of calculation methods are available to estimate the required size of substation ventilation openings, either for the design of new substations or the adaptation of existing substations for which condensation problems have occurred.
The basic method is based on transformer dissipation by natural convection.
The required ventilation opening surface areas S and S' can be estimated using the following formulas, knowing or not the air flow resistance coefficient of the ventilation grids ξ (see **Fig. B44**):

1- Heat dissipation: Qnac=P-Qcw-Qaf

2- Opening surface areas : S and S'

■ **2.1** The air flow resistance coefficient of the ventilation grid is unknown

$$S = 1.8 \cdot 10^{-1} \cdot \frac{Qnac}{\sqrt{H}}$$ if air flow resistance is unknown

S '= 1.1 * S S and S' are efficient net area

■ **2.2** Openings with chevrons blade

$$S = \frac{Qnac}{K \cdot \sqrt{H \cdot (\theta 2 - \theta 1)^3}}$$ with $$K = 0.222 \cdot \sqrt{\frac{1}{\xi}}$$ (see **Fig. B45**)

S' = 1.1 * S S and S' are the gross area

The formula 2.2 is near the formula 2.1 if $\Delta\theta = (\theta 2 - \theta 1)$ = 15 K, and if ξ = 5, then K= f (ξ) = 0.1. This is equivalent to free opening, without ventilation grid.
When K = 0.1 the formula 2.2 is equivalent to the formula given in IEC 60076-16 standard for transformers dedicated to wind turbine applications.

Qnac is the dissipation by natural air circulation [kW].

P is the sum of the power dissipated [kW] by:
- The transformer dissipation: no load losses+Load losses
- The LV switchgear dissipation
- The MV switchgear dissipation.

Qcw is the heat dissipation by conduction through the walls and ceiling [kW] (assumption Qcw = 0 in the example). The losses by conduction through the walls, the ceiling and the slab can be expected from 200 W for a thermal insulated housing up to 4 kW for a 10 m² prefabricated substations using concrete material.

Qaf is the heat dissipation by forced air circulation [kW]
(assumption Qaf = 0 in the example)

$\theta 1$ and $\theta 2$ are the respectively air temperatures of inlet and outlet [°C]

ξ is the resistance coefficient of the pressure losses depending on the design of the ventilation grid.(see **Fig. B44**)

S is the lower (air entry) ventilation opening area [m²] as expressed by formulas 2.1 and 2.2.

S' is the upper (air exit) ventilation opening area [m²] as expressed by formulas 2.1 and 2.2.

H = the height between ventilation opening mid-points [m].

($\theta 2 - \theta 1$) is the air temperature rise which reflects the double of the transformer overheating (Loading guide IEC 60076-7) for oil immersed transformer and (Loading guide IEC 60076-11) for dry type transformer.

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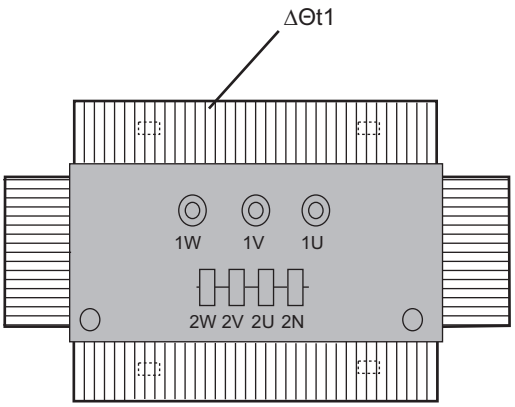
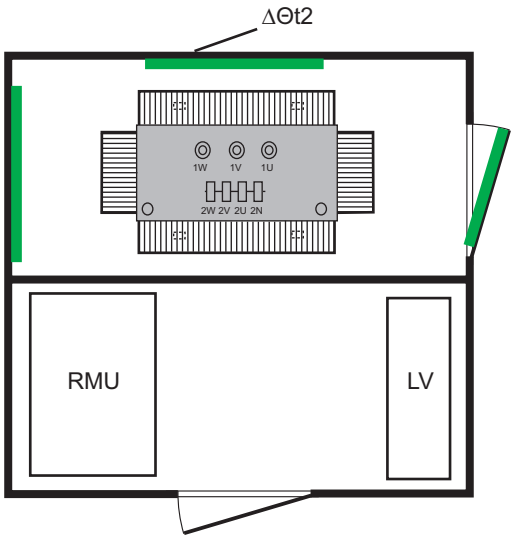


$\Delta\theta t1$ = tt1 - ta1 where tt1 is the temperature 1 of the transformer at rated power (IEC 60076-2:2011 and IEC 60076 - 11:2004) and ta1 is the ambient temperature 1 outside any enclore or dedicated room.



$\Delta\theta t2$ = tt2 - ta2 where tt2 is the temperature 2 of the transformer at rated power (IEC 60076-2:2011 and IEC 60076 - 11:2004) and ta2 is the ambient temperature 2 inside the enclosure or the room where the transformer is installed.

$\Delta\theta t2 - \Delta\theta t1$ is the overheating of the transformer due the use inside housing.

***Fig. B46**: Transformer overheating*

The transformer overheating is an extra temperature rise due to the installation of the transformer in a prefabricated enclosure or in a dedicated room inside a building. (see **Fig. B46, B47.1, B47.2**)
It is the extra temperature rise measured at the top of the oil (see **Fig. B47.1**) for liquid filled transformers or the extra average temperature rise of the winding (see **Fig. B47.2**) for dry type transformer.

The normal service condition of the power transformers are the following:
- ■ Ambient temperatures
- □ 40 °C Maximum temperature at any time
- □ 30 °C Monthly average temperature during the hottest month
- □ 20 °C Yearly average temperature
- ■ Maximum temperatures and temperatures rises for oil filled transformer
- □ Maximum temperature measured on the top of the oil: 100 °C
- □ Maximum temperature of the winding: 105 °C
- □ Maximum oil and winding temperature rise: 30-35 K, 40-45 K, 50-55 K, 60-65 K
- ■ Maximum temperatures and temperatures rises for dry type transformer
- □ Maximum temperature of the winding: 155 °C corresponding to class F of insulation
- □ Maximum average temperature rise of the winding: 100 °C.

Example of transformer overheating (see **Fig. B46**)**:**
Assuming $\Delta\theta t1$ = tt1 - ta1 = 60 K for oil temperature rise of a liquid filled transformer installed outside any enclosure it will become $\Delta\theta t2$ = tt2 - ta2 = 70 K when installed inside an enclosure generating an over heating $\Delta\theta t2 - \Delta\theta t1$ of 10 K.
The air temperature rise inside the enclosure will reach the double of the transformer overheating: 10 K x 2 = 20 K.

When these transformer overheatings are assessed by a type test according to IEC 62271-202 (HV/LV prefabricated substations) this overheating is the rated enclosure class. The overheating, combined with the average temperature, gives the limit load factor to maintain the expected transformer lifespan according to the IEC transformer loading guides (see **Fig. B47.1** and **Fig. B47.2**).

For masonry substation the overheating of the transformer is expected unknown, as the calculation shall define the ventilation areas S and S'. So only the ambient temperature and load factor can be known. The following examples explain how assess the overheating of transformer then the temperature rise of air ($\theta 2 - \theta 1$) to use the formula 2.2.

Process to use graphes (see **Fig. B47)**:
a) select the average ambient temperature in a given period of time for the substation site on the vertical axis;
b) select the load factor of the transformer
c) the intersection gives an expected overheating of the transformer corresponding to the maximum top oil temperature rise limit for liquilled filled transformers (see **Fig. B47.1**) or the average winding temperature rise for dry type transformers (see **Fig. B47.2**).

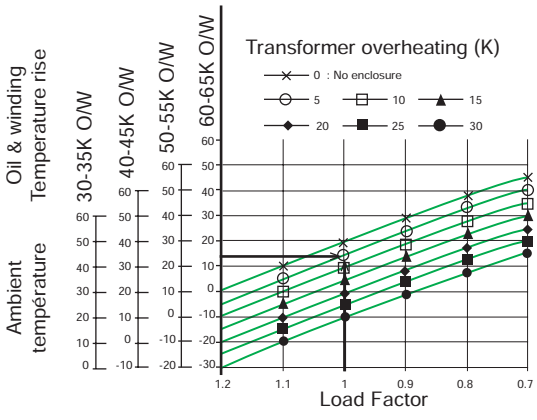


***Fig. B47.1**: Liquid filled transformer load factor*

***Fig. B47**: Load factor limits*

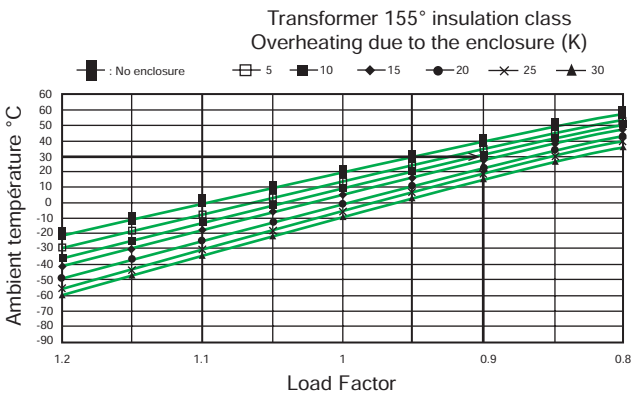


***Fig. B47.2**: Dry type transformer load factor (155 °C insulation class)*

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Examples:

■ Moderate climate 10 °C as yearly average using a 60-65 K respectively for oil and winding temperature rise of the transformer, can be used at full load. Expected overheating is 10 K then air temperature rise ($\theta 2 - \theta 1$) is expected at 20 K.
■ Hot Climate 30 °C as summer average using 50-55 K respectively for oil and winding temperature rise transformer can be used with a load factor at 0.9. Expected overheating is 10 K then air temperature rise ($\theta 2 - \theta 1$) is expected at 20 K.
■ Cold Climate -20 °C as winter average using 60-55 K respectively for oil and winding temperature rise transformer can be used with a load factor at 1.2. Expected overheating is 20 K then air temperature rise ($\theta 2 - \theta 1$) is expected at 40 K.
■ Hot Climate 30 °C as summer average using a dry type transformer at 155 °C insulation thermal class can be used with a load factor at 0.9. Expected overheating is 10 K then air temperature rise ($\theta 2 - \theta 1$) is expected at 20 K.

For prefabricated substation, the overheating is known due the temperature rise class of the enclosure defined by type test. Any use with a defined enclosure class, limited by the maximum losses, will adapt the transformer load factor to the ambient temperature to assure the transformer lifespan.

The calculation methods use formulas reflecting specific cases of a general formula based on Bernouilli equation and stack effect due the transformer heating, assuring the natural convection inside the transformer compartment as required by the IEC 62271-202 standard.
Indeed, the real air flow is strongly dependant:

■ On the openings shape and solutions adopted to ensure the cubicle protection index (IP): metal grid, stamped holes, chevron louvers etc. (see **Fig. B44**)
■ On transformer temperature rise and overheating in °K (class) due to the use in an envelope as mentioned in **Fig. B47**.
■ On internal components size and the whole layout as follow:
□ transformer and/or retention oil box position
□ distance from the transformer to the openings
□ transformer in a separate room using partition wall
■ On some physical and environmental parameters as follow:
□ outside ambient temperature $\theta 1$ used in equation 2.2
□ altitude
□ solar radiation.

The understanding and the optimization of the attached physical phenomena are subject to precise flow studies, based on the fluid dynamics laws, and realized with specific analytic software. These could be separated in two categories as follow:
■ Software used for thermal dynamic studies of the building especially used for energy management for building efficiency.
■ Software used for air flow study especially when a component embeds it's own air cooling system (Inverter, Grid Frequency Converter, Data centres etc.)

Example for HV/LV substation:

Oil immersed transformer 1250 kVA
Ao (950 W No load losses) Bk (11000 W Load losses)
Transformer dissipation = 11950 W
LV switchgear dissipation = 750 W
MV switchgear dissipation = 300 W
H the height between ventilation opening mid-points is 1.5 m.
ξ is 12 for chevrons louvers if α = 90° then K = 0.064
($\theta 2 - \theta 1$) air temperature rise taken at 20 K for expected transformer overheating at 10 K.

Calculation:

Dissipated Power P = 11.950 + 750 + 300 = 13.000 KW

- Formula 2.1:

$$S = 1.8 \cdot 10^{-1} \cdot \frac{Qnac}{\sqrt{H}}$$

S = 1.91 m² and S' 1.1 x 1.91 = 2.1 m² (Net area)

- Formula 2.2: Chevrons Blade

$$S = \frac{Qnac}{K \cdot \sqrt{H \cdot (\theta 2 - \theta 1)^3}}$$

S = 1.85 m² and S' 1.1 x S = 2.04 m² (Gross area)

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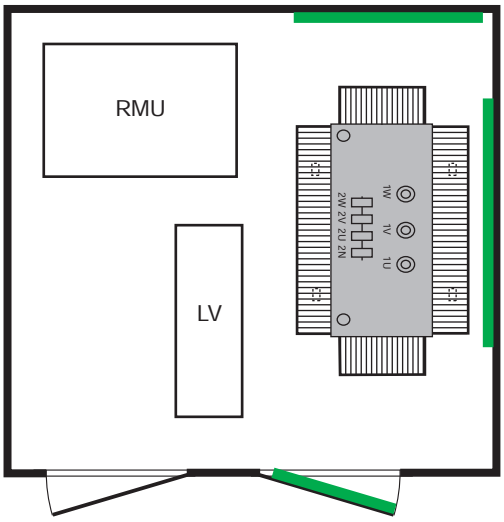

Fig. B48: Example of layout for 13 kW of total losses
$\Delta\theta 2 - \Delta\theta 1$ *= Air temperature rise = 20 K corresponding to transformer overheating at 10 K*

Fig. B49: Example of HV/LV prefabricated substation tested with 1250 kVA liquid filled transformer, 19 kW of losses

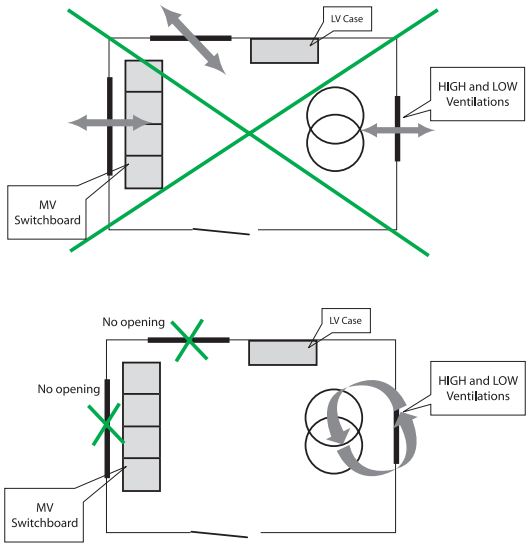

Fig. B50: Ventilation opening locations

Three ventilations with the following dimensions (see **Fig. B48** and **Fig. B49**) 1.2 m x 0.6 m, 1.4 m x 0.6 m, 0.8 m x 0.6 give a gross area S' at 2.04 m².

6.4.4 Ventilation opening locations

To favour evacuation of the heat produced by the transformer via natural convection, ventilation openings should be located at the top and bottom of the wall near the transformer. The heat dissipated by the MV switchboard could be neglected. To avoid condensation problems, the substation ventilation openings should be located as far as possible from the switchboards (see **Fig. B50**).

6.4.5 Type of ventilation openings

To reduce the entry of dust, pollution, mist, etc., the substation ventilation openings should be equipped with chevron-blade baffles when the transformer is installed in a same room with the switchboards, otherwise a use of higher efficiency ventilation grids is allowed, especially advised when total losses are above 15KW. Always make sure the baffles are oriented in the right direction (see **Fig. B44**).

6.4.6 Temperature variations inside cubicles

To reduce temperature variations, always install anti-condensation heaters inside MV cubicles if the average relative humidity can remain high over a long period of time. The heaters must operate continuously, 24 hours a day all year long. Never connect them to a temperature control or regulation system as this could lead to temperature variations and condensation as well as a shorter service life for the heating elements. Make sure the heaters offer an adequate service life.

6.4.7 Temperature variations inside the substation

The following measures can be taken to reduce temperature variations inside the substation:
- Improve the thermal insulation of the substation to reduce the effects of outdoor temperature variations on the temperature inside the substation
- Avoid substation heating if possible. If heating is required, make sure the regulation system and/or thermostat are sufficiently accurate and designed to avoid excessive temperature swings (e.g. no greater than 1 °C). If a sufficiently accurate temperature regulation system is not available, leave the heating on continuously, 24 hours a day all year long
- Eliminate cold air drafts from cable trenches under cubicles or from openings in the substation (under doors, roof joints, etc.).

6.4.8 Substation environment and humidity

Various factors outside the substation can affect the humidity inside.
- Plants: avoid excessive plant growth around the substation, and closing any opening.
- Substation waterproofing: the substation roof must not leak. Avoid flat roofs for which waterproofing are difficult to implement and maintain.
- Humidity from cable trenches: make sure cable trenches are dry under all conditions. A partial solution is to add sand to the bottom of the cable trench.

6.4.9 Pollution protection and cleaning

Excessive pollution favours leakage current, tracking and flashover on insulators. To prevent MV equipment degradation by pollution, it is possible to either protect the equipment against pollution or regularly clean the resulting contamination.

6.4.10 Protection

Indoor MV switchgear can be protected by enclosures providing a sufficiently high degree of protection (IP).

6.4.11 Cleaning

If not fully protected, MV equipment must be cleaned regularly to prevent degradation by contamination from pollution.
Cleaning is a critical process. The use of unsuitable products can irreversibly damage the equipment.
For cleaning procedures, please contact your Schneider Electric correspondent.

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