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# BEAMA GUIDE TO VERIFICATION OF TEMPERATURE RISE AND SHORT-CIRCUIT WITHSTAND OTHER THAN BY TEST

## Low Voltage Switchgear and Controlgear Assemblies in Accordance with BS EN 61439 series

FIRST EDITION – MARCH 2018

BEAMA is the long established and respected trade association for the electrotechnical sector. The association has a strong track record in the development and implementation of standards to promote safety and product performance for the benefit of manufacturers and their customers.

This Guide provides clear and simple guidance on the verification of Temperature rise limits and Short-circuit withstand strength other than by test.

This Guide has been produced by BEAMA's Building Electrical Systems Portfolio which comprises of major UK manufacturing companies operating under the guidance and authority of BEAMA, supported by specialist central services for guidance on European Single Market, Quality Assurance, Legal and Health & Safety matters.

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**Acknowledgements**
*BEAMA would like to thank IEC and BSI for allowing references to their standards.*

# COMPANIES INVOLVED IN THE PREPARATION OF THIS GUIDE


**Eaton Electric Limited**
270 Bath Road, Slough,
Berkshire SL1 4DX
**Tel: +44 (0) 8700 545 333**
**Email: ukcommorders@eaton.com**
**www.eaton.com/uk**

**Elsteel UK Ltd**
Off Davy Way
Llay Industrial Estate, Llay,
Wrexham LL12 0PG
**Tel: +44 (0) 1978 855909**
**Fax: +44 (0) 1978 855824**
**Email: sales@elsteel.co.uk**
**www.elsteel.co.uk**

**Hager Ltd**
Hortonwood 50, Telford,
Shropshire TF1 7FT
**Tel: +44 (0)1952 675 689**
**Email: Technical@hager.co.uk**
**www.hager.co.uk**

**Legrand Electric Ltd**
Great King Street North,
Birmingham B19 2LF
**Tel: +44 (0) 370 608 9020**
**Fax: +44 (0) 345 600 6760**
**Email: powersales.uk@legrand.co.uk**
**www.legrand.co.uk**

**Schneider Electric Ltd**
Stafford Park 5, Telford,
Shropshire TF3 3BL
**Tel: +44 (0) 1952 290029**
**Fax: +44 (0) 1952 292238**
**www.schneider-electric.co.uk**

**Siemens Ltd**
Sharston Road, Wythenshawe
Manchester M22 4RA
**Tel: +44 (0) 161 945 3956**
**Fax: +44 (0) 8456 053114**
**www.siemens.co.uk**

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| BS EN 61439 Series | TITLE<br>Low-voltage switchgear and controlgear assemblies | Applicable to: |
|---|---|---|
| PD IEC TR 61439-0: 2013* | Guidance to specifying assemblies | Users and specifiers |
| BS EN 61439-1: 2011 | General rules | Reference document for low voltage assemblies |
| BS EN 61439-2: 2011 | Power switchgear and controlgear (PSC) assemblies | Switchboards, Panel boards and Motor Control Centres |
| BS EN 61439-3: 2012 | Distribution boards intended to be operated by ordinary person (DBO) | Consumer units and Distribution boards |
| BS EN 61439-4: 2013 | Particular requirements for assemblies for construction sites (ACS) | Assemblies for temporary supplies |
| BS EN 61439-5: 2015 | Assemblies for power distribution in public networks | Feeder pillars, fuse cabinets and fuse boards |
| BS EN 61439-6: 2012 | Busbar trunking systems (busways) | Busbar trunking |
| IEC TS 61439-7:2014 | Assemblies for specific applications such as marinas, camping sites , market squares, electric vehicles charging stations | Assemblies in public locations |

* Informative IEC document that is not a standard.

## List of standards relevant to the subject matter of this guide

- IEC TR 60890, *A method of temperature-rise verification of low-voltage switchgear and controlgear assemblies by calculation*
- IEC 60909-0, *Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents*
- BS EN 60865-1, *Short-circuit currents – Calculation of effects – Part 1: Definitions and calculation methods*
- PD IEC/TR 60865-2, *Short-circuit currents – Calculation of effects – Part 2: Examples of calculation*
- BS EN 60947 Series, *Low-voltage switchgear and controlgear*
- BS 7671, *Requirements for Electrical Installations. IET Wiring Regulations*
- BS 6423, *Code of practice for maintenance of low-voltage switchgear and controlgear*

# INTRODUCTION

This publication is intended to provide guidance on the design verification of an Assembly for temperature-rise limits (by assessment and comparison) and short-circuit withstand strength (by comparison).

**This guide only considers temperature rise verification for Assemblies with a maximum rated voltage of 1 000V a.c. or 1 500V d.c. and a frequency of up to 60Hz. All other verification requirements of the Standard must be carried out in order to fully verify an Assembly.**

*NOTE: Throughout this guide references to BS EN 61439-1 is related to Edition 2: 2011 of the standard.*

*NOTE: BS EN 61439-1 is identical to IEC 61439-1 and EN 61439-1*

# USEFUL DEFINITION

### An Assembly

A combination of one or more low-voltage switching devices together with associated control, measuring, signalling, protective, regulating equipment, with all the internal electrical and mechanical interconnections and structural parts.

In low voltage assemblies to the BS EN 61439 series, the mechanical and electrical components (enclosures, busbars, functional units, etc.), are those defined by the original manufacturer, and which can be assembled in accordance with the original manufacturer's instructions, so as to conform to the original design and verification certification.

This guide is for the organization that will carry out the design and associated verification of an assembly in accordance with the relevant assembly standard for complete conformity.

# 1 USING THE BS EN 61439 SERIES

BS EN 61439-1 is the general rules for the series of standards and is referred to by the relevant part(s) in accordance with the type of assembly type e.g. BS EN 61439-2 Power switchgear and controlgear assemblies. BS EN 61439-1 is the general rules and not a product standard.

# 2 BENEFITS

Low-voltage Assemblies, by the nature of their application, may be installed for many years before they are called on to operate close to the limit of their intended capability, for example, under planned expansion or changing load conditions. As a result, any marginal performance may not be immediately evident.

When an Assembly is verified and operated in accordance with the manufacturer's instructions, concerns of this nature are eliminated. The design is proven through a comprehensive design verification process which includes tests or other equivalent verification means. Where methods other than test are used, margins are included to ensure the specified performance is achieved. This is an essential assurance for user confidence.

It is not always practical or economical to verify temperature rise and short-circuit withstand strength performance by test. Accordingly, there are options with restrictions and safety factors to verify the Assembly.

# 3 TEMPERATURE RISE VERIFICATION BY ASSESSMENT (CALCULATION)

It is the responsibility of the manufacturer undertaking the development of a design to demonstrate compliance with the standard. The manufacturer shall determine the appropriate verification option available from the standard.

Two options for verification by calculation are considered in this guide:

- Single compartment Assembly with a rated current not exceeding 630 A
- Single or multi-compartment Assembly with rated current not exceeding 1600 A.

*NOTE: A multi-section Assembly not exceeding 1600A can be verified section by section using different verification methods.*

Assemblies with a rated current above 1600 A must be verified by testing or derived from a reference (tested) design.

## 3.1 TEMPERATURE-RISE LIMITS

It is the manufacturer's responsibility to select the appropriate method for temperature rise verification.

All the temperature rise limits given in the standard assume that the Assembly will be located in an environment where the daily average and peak ambient temperatures do not exceed 35 °C and 40 °C, respectively. The standard also assumes that all outgoing circuits within an assembly will not be loaded to their rated current at the same time.

Note that in this guide and in BS EN 61439 series the following notation is used:

- °C which indicates actual temperature in degrees Celsius,
- K which indicates temperature rise in Kelvin. (1 K rise = 1 °C rise)

Temperature rise limits within the assembly are the manufacturers' responsibility, they are essentially determined on the basis of operating temperature not exceeding the long-term capability of the materials used within the assembly. At interfaces between the assembly and the 'wider world', for example, cable terminals and operating handles, the Standard defines temperature rise limits.

Within boundaries defined in the Standard, temperature rise verification can be undertaken by test, calculation or design rules. It is permissible to use one or a combination of the verification methods set out in the Standard to verify temperature rise performance of an assembly. This allows the manufacturer to choose the most appropriate method for the assembly, or part of an assembly, taking into consideration volumes, the construction, design flexibility, current rating and size of the assembly. Indeed, in typical applications involving some adaptation of a standard design it is highly likely more than one method will be used to cover various elements of the assembly design. This guide considers verification by assessment using calculations.

## 3.2 CALCULATION

Two methods (3.2.1 & 3.2.2) of verifying temperature rise performance by calculation are included within the Standard. Both determine the approximate air temperature rise inside the enclosure, which is caused by the power losses of all circuits, and compares this temperature with the limits for the installed equipment. The methods differ only in the way the relationship between the delivered power loss and the air temperature rise inside the enclosure is ascertained.

*It should be noted that rated diversity factor is not considered when verifying temperature rise by calculation. In the calculation, the most onerous power loss combination as deemed by the assembly designer/manufacturer of circuits operating at their rated current ($I_{nA}$) shall be used to distribute the rated current ($I_{nc}$) of the assembly.*

It should be noted, that the thermal equivalent current calculation in annex E of BS EN 61439-1 for predictably varying / intermittent loads, is not an assembly current rating. The formula enables the electrical installation design engineer to calculate an equivalent r.m.s current representing the thermal effect of the real intermittent current of the load and to then specify the required assembly current rating.

### 3.2.1 Verification of temperature rise of a single compartment assembly with a rated current not exceeding 630 A

The power loss method of temperature rise verification set out in sub clause 10.10.4.2.1 of BS EN 61439-1 is a quick and conservative approach. Essentially, the total power loss from the components and conductors within the enclosure is compared with the enclosures ability to dissipate power without the air temperature exceeding the maximum operating temperature of any device. The scope of this approach is very limited and in order that there are no difficulties with hot spots, all components must be de-rated to 80% of their free air current rating.

To use this approach, the following information is required:

1. Rated current of each circuit ($I_{nc}$) within the assembly.
2. Rated current of each device (power and control) ($I_n$) in free air.
3. Power dissipation of each device when operating at the rated current of the circuit in which it is to be installed. If the power loss of the device at the rated circuit is unknown, then it can be calculated using the following equation given that the power loss is directly proportional to the square of the current ($I^2$).

$$P(I_{nc})=P(I_n).\left(\frac{I_{nc}}{I_n}\right)^2$$

Where

$P(I_{nc})$ = Power loss at the rated current of the circuit.

$P(I_n)$ = Power loss of the device at its rated current.

$I_{nc}$ = Rated current of the circuit in the assembly.

$I_n$ = Rated current of the device in free air.

*NOTE: The above equation does not take account of the power loss associated with fixed current consuming devices for example the coils of contactors, lamps etc. The power loss of fixed current devices needs to be added to the above calculation to obtain the total Watts loss.*

4. Maximum permissible surrounding air temperatures for each device at various operating currents.
5. Enclosure parameters.

   Power dissipation capability of the enclosure for a known internal air temperature rise or a range of air temperature rises at the top of the enclosure. (The enclosure manufacture may provide ranges of air temperature rise corresponding to different power dissipations. Alternatively, if the power dissipation for the enclosure is not known it can be established by test in accordance with sub clause 10.10.4.2.2 of BS EN 61439-1).
6. External ambient temperature shall not exceed +40 °C and its average over a period of 24 hours shall not exceed +35 °C.

Having obtained the basic data, the most simplistic temperature rise verification can be performed if:

i. all devices are suitable for use in a surrounding air temperature of 55 °C, and;

ii. the power dissipation capability of the enclosure for an air temperature rise, not exceeding 20 K, at the top of the enclosure is known

In this case the temperature rise performance is verified by the following analysis:

→ Confirm that the internal conductors have a minimum cross section for 125 % of the rated current of the associated circuit, in accordance with Annexes H and N of BS EN 61439-1 for an assumed internal air temperature at the top of the assembly of 55 °C. For cables the appropriate rating for a conductor with a temperature of 70 °C can be read directly from Table H.1. Likewise, for copper bars the rating can be taken directly from Table N.1 for an assumed conductor operating temperature of 70 °C. If the higher temperature option of a conductor temperature of 90 °C is considered appropriate, then the operating currents given in Table N.1 are increased by the factor $k_4$ (1.62 for an assumed air temperature inside the enclosure of 55 °C).

- Confirm that all insulating materials including busbar supports are capable of operating at their anticipated maximum temperatures.
- Calculate the power dissipation of all the main circuit conductors within the enclosure (including incoming and outgoing cables) when operating at the rated current of the applicable circuit within the assembly. For each circuit this is achieved by adjusting the power loss per metre of conductor given in Annex H or N of BS EN 61439-1, as applicable, to suit the rated current of the circuit in which the conductor is used and then multiplying the result by the length of conductor in metres to give the power loss of the conductor within the assembly.
- Determine the power loss capability of the enclosure, $P_{enc}$, for an air temperature rise at the top of the enclosure not exceeding 20 K.
- Sum the power loss from all devices and conductors in the incoming circuit plus as many outgoing circuits as are necessary to distribute all the incoming current, all operating at their rated current, plus the dissipation of any normally energised control circuit devices to give the total power to be dissipated within the enclosure – $P_{max}$.

**The assembly is verified if the total power dissipation, $P_{max}$ is less than or equal to $P_{enc}$.**

If the foregoing assumptions are not feasible or the analysis does not lead to an acceptable result a more in depth analysis as follows may be beneficial.

- For the devices being considered determine, from the manufacturers' data, the lowest of the maximum permissible surrounding air temperature ($T_{LM}$).
- Establish the maximum permitted air temperature rise ($K_M$) at the top of the enclosure. This is the lesser of
  - **i.** $K_{M1}$, where $K_{M1} = T_{LM}$ minus 35 °C (35 °C = daily average ambient), or,
  - **ii.** the highest air temperature rise within the enclosure, below KM1, for which the power dissipation of the enclosure is known.
- Confirm that the internal conductors have a minimum cross section for 125 % of the rated current of the associated circuit, in accordance with Annexes H and N of BS EN 61439-1 for an assumed internal air temperature at the top of the assembly of (35 + $K_M$) °C. This is undertaken as follows:

  Current ratings for cables with a permissible conductor temperature of 70 °C are taken from Table H.1, and adjusted by the factor in Table H.2. For example, if the air temperature at the top of the assembly is 60 °C the conductor rating is calculated as follows: -

  From Table H.1, a 16 mm$^2$ cable has a maximum operating current of 67A with conductor temperature of 70 °C in an air temperature of 55 °C. Using the factors in Table H.2 (noting that Table H.1 and Table H.2 use a reference temperature of 55 °C and 30 °C, respectively) this is reduced to 54,9 A (67 x 0.50/0.61 A) in a 60 °C air temperature.

  Likewise, for copper bars the rating can be taken directly from Table N.1 and adjusted by the factor $k_4$ given in Table N.2. On this occasion, Tables N.1 and N.2 both use the same reference temperature of 55 °C. Hence the values given in Table N.1 are simply multiplied by the factor given in Table N.2 to determine ratings for the different conditions.
- Confirm that all insulating materials including busbar supports are capable of operating at their anticipated maximum temperatures.
- Calculate the power dissipation of all the main circuit conductors within the enclosure (including incoming and outgoing cables) when operating at the rated current of the applicable circuit within the assembly. For each circuit this is achieved by adjusting the power loss per metre of conductor given in Annex H or N of BS EN 61439-1, as applicable, to suit the rated current of the circuit in which the conductor is used and then multiplying the result by the length of conductor in metres to give the power loss of the conductor within the assembly.
- Determine the power loss capability of the enclosure, $P_{enc}$, for an air temperature rise at the top of the enclosure not exceeding $K_M$.
- Sum the power loss from all devices and conductors in the incoming circuit plus as many outgoing circuits as are necessary to distribute all the incoming current, all operating at their rated current, plus

the dissipation of any normally energised control circuit devices to give the total power to be dissipated within the enclosure – $P_{max}$.

The assembly is verified if the total power dissipation, $P_{max}$ is less than or equal to $P_{enc}$

Should the foregoing simple method conclude the assembly's temperature rise performance is not verified then the more detailed approach given in sub-clause 10.10.4.3 of BS EN 61439-1 should be considered. This takes into account the position of components within the enclosure and the air temperatures at different heights within the enclosure, thereby providing a more accurate representation of temperature rise performance within the assembly.

## Process for Temperature rise verification by calculation

10.10.4.2 Single compartment assembly with rated current not exceeding 630 A

**1.** Required rated current of each circuit ($I_{nc}$) / every device **within the assembly** provided by the electrical installation designer from drawings / specifications or as specified by the assembly manufacturer.

$$I_{nc} \text{ required} \geq I_b$$

**2.** Rated current of each device (power and control) ($I_n$) in free air
To reduce the iterative process in 3, In can be selected on the basis of $I_{nc}$ x 1.25.

**3.** Each device de-rated by 20 % (10.10.4 of BS EN 61439-1) i.e. not to exceed 80 % of its rated conventional free air thermal / rated current.

$$I_n \times 0.8 = \text{Rated current within the assembly } (I_{nc})$$

$$I_{nc} \geq I_{nc} \text{ required} \geq I_b$$

**4.** Power dissipation of each device when operating at the rated current of the circuit in which it is to be installed. If the power loss of the device at the rated circuit is unknown, then it can be calculated using the following equation given that the power loss is directly proportional to the square of the current ($I^2$).

$$P(I_{nc}) = P(I_n).\left(\frac{I_{nc}}{I_n}\right)^2$$

**5.** Power loss of each fixed current consuming device, for example; the coils of contactors, lamps etc.

**6.** Internal conductors have a minimum cross section for 125 % of the rated current of the associated circuit, in accordance with Annexes H and N of BS EN 61439-1 for an assumed internal air temperature at the top of the assembly of 55 °C. For a conductor with a temperature of 70 °C from Table H.1. For copper bars Table N.1 for an assumed conductor operating temperature of 70 °C. If the higher temperature option of a conductor temperature of 90 °C is considered appropriate, then the operating currents given in Table N.1 are increased by the factor $k_4$ (1.62 for an assumed air temperature inside the enclosure of 55 °C).

7. Power loss of each internal conductor at the rated current multiplying the result by the length of conductor in metres to give the power loss of the conductor within the assembly.

8. Power loss of each external conductor at the rated current multiplying the result by the length of conductor in metres to give the power loss of the conductor within the assembly.

*NOTE: Typically power loss of internal & external conductors can be conservatively estimated as 50 % of all device watts.*

9. Total power loss of every device, internal and external conductor to be dissipated within the enclosure ($P_{max}$).

10. Power loss capability of the enclosure ($P_{enc}$)

    Power dissipation capability of the enclosure for a known internal air temperature rise or a range of air temperature rises at the top of the enclosure. (The enclosure manufacture may provide ranges of air temperature rise corresponding to different power dissipations. Alternatively, if the power dissipation for the enclosure is not known it can be established by test in accordance with sub clause 10.10.4.2.2 of BS EN 61439-1).

    The Heat transfer coefficient (k) W/m2 °C from the enclosure manufacturer may be utilised.

11. External ambient temperature 35 °C.

12. Rated diversity factor fixed at 1. The effective power losses of all circuits including interconnecting conductors shall be calculated based on rated current of the circuits (10.10.4.2 in 61439-1).

13. Calculated air temperature at top of enclosure.

14. Each device current rating at the calculated air temperature at the top of enclosure.

    The assembly is verified if the air temperature determined from the calculated power loss does not exceed the permissible operating air temperature as declared by the device manufacturer. (10.10.4.2.3 in 61439-1)

15. The assembly total power dissipation $P_{max}$ is less than or equal to Power dissipation capability of the enclosure $P_{enc}$.

    The related air temperature determined from the calculated power loss does not exceed the permissible operating air temperature as declared by the device manufacturer (10.10.4.2.3 in 61439-1)

16. Confirmation that all insulating materials including busbar supports are suitable for the capable of operating at their anticipated maximum temperatures within the assembly.

### 3.2.2 Verification of temperature rise of an assembly with a rated current not exceeding 1600A

Temperature rise verification is by calculation in accordance with IEC TR 60890 with additional safety margins. The scope of this approach is limited to 1600 A, components are de-rated to 80 % of their free air rating or less and any horizontal partitions must have, as a minimum, a 50 % open area for convection.

Initially internal conductor cross sections have to be determined on the basis of an assumed internal air temperature within the assembly and the Tables set out in Annexes H and N of the standard. (See 3.2.1 above for application of the factors given in Tables H.2 and N.2.) Once the approximate air temperatures within the assembly have been established, components may have to be changed and/or internal conductor cross sections adjusted to suit the actual air temperatures, and further iterations of the calculation carried out until all components and conductors are operating within their intended parameters.

The actual local temperatures of the current-carrying parts cannot be calculated by these methods, therefore some limits and safety margins are necessary, as illustrated in the following example: -

#### 3.2.2.1 Examples of de-rating for verification of temperature rise by calculation

*A specification requires a three-phase 200 A assembly with a 200 A MCCB as the main incoming unit.*

## Device de-rating

Device de-rating by 20 % (10.10.4 of BS EN 61439-1) i.e. not to exceed 80 % of its rated conventional free air thermal / rated current

*Consideration 1)*

An adjustable MCCB with a maximum current setting of 250 A and various intermediate settings is set to 0.8. Alternatively, a 250 A MCCB with a fixed overcurrent setting of 200 A can be used.

- ➜ De-rating by 20 % = 0.8 x 250 = a maximum 200 A rating in the assembly
- ➜ The MCCB power loss at 200 A is used for the calculation of air temperature within the enclosure. If its 200 A current rating is suitable for the calculated air temperature, it complies as it's a 250 A device de-rated by 20 %. If the current rating for the calculated air temperature is higher than 200 A, a higher rated MCCB is required e.g. next frame size possibly 400 A (proceed to consideration 2) below).

*Consideration 2)*

An adjustable MCCB with a maximum current setting of 400 A and various intermediate settings which includes 0.5 is selected. Alternatively, a 400 A MCCB with a fixed overcurrent setting of 200 A can be used.

- ➜ De-rating by 20 % = 0.8 x 400 = a maximum 320 A rating in the assembly
- ➜ MCCB set to 0.5 x 400 = 200 A. Its power loss at 200 A is used for the calculation of air temperature within the enclosure. If its 200 A current rating is suitable for the calculated air temperature, no further de-rating is required, as it's a 400 A device de-rated by more than 20 %

*In the above examples the rated current of the MCCB in the Assembly is less than the rated current marked on the device. This rated current of the circuit must be identified in the manufacturers documentation supplied with the Assembly in accordance with BS EN 61439-1 Clause 6.2.*

## Increased conductor cross-sectional area

All conductors shall have a minimum cross-sectional area based on 125 % of the required current rating of the associated circuit.

Example:

The required current rating of the main busbar circuit is 200 A, the minimum cross-sectional area is based on a current of; 1.25 x 200 A = 250 A.

The cross-section of bars shall be as tested or as given in Annex N of BS EN 61439-1 therefore:

a) In the case of a conductor temperature of 70 °C and an internal air temperature of 55 °C*; from Annex N of BS EN 61439-1, there are several options as used in this example

- a radius edged copper bar; 40 mm x 5 mm (199 mm$^2$) having an operating current of 313 A.
- a radius edged copper bar; 20 mm x 10 mm (199 mm$^2$) having an operating current of 278 A

OR

b) In the case of a conductor temperature of 90 °C and an internal air temperature of 55 °C*; then the current ratings in Table N.1 are multiplied by 1.62. Under these circumstances the following conductor is acceptable;

- radius edged copper bar, 20 mm x 5 mm (99 mm$^2$) having an operating current of 288 A.

* For other internal temperatures reference, should be made to Table N.2 of BS EN 61439-1.

## Process for Temperature rise verification by calculation

10.10.4.3 Single or multiple compartment assembly with rated current not exceeding 1600 A using IEC TR 60890

**1.** Required rated current of each circuit ($I_{nc}$) / every device within the assembly provided by the electrical installation designer from drawings / specifications or as specified by the assembly manufacturer.

$$I_{nc} \text{ required } \geq I_b$$

**2.** Rated current of each device (power and control) ($I_n$) in free air
To reduce the iterative process in 3, $I_n$ can be selected on the basis of $I_{nc}$ x 1.25

**3.** Each device de-rated by 20 % (10.10.4 of BS EN 61439-1) i.e. not to exceed 80 % of its rated conventional free air thermal / rated current

$$I_n \times 0.8 = \text{Rated current within the assembly } (I_{nc})$$

$$I_{nc} \geq I_{nc} \text{ required } \geq I_b$$

**4.** Power dissipation of each device when operating at the rated current of the circuit in which it is to be installed. If the power loss of the device at the rated circuit is unknown then it can be calculated using the following equation given that the power loss is directly proportional to the square of the current ($I^2$).

$$P(I_{nc}) = P(I_n).\left(\frac{I_{nc}}{I_n}\right)^2$$

**5.** Power loss of each fixed current consuming device, for example; the coils of contactors, lamps etc.

**6.** Internal conductors have a minimum cross section for 125 % of the rated current of the associated circuit, in accordance with Annexes H and N of BS EN 61439-1 for an assumed internal air temperature at the top of the assembly of 55 °C. For a conductor with a temperature of 70 °C from Table H.1. For copper bars Table N.1 for an assumed conductor operating temperature of 70 °C. If the higher temperature option of a conductor temperature of 90 °C is considered appropriate, then the operating currents given in Table N.1 are increased by the factor $k_4$ (1.62 for an assumed air temperature inside the enclosure of 55 °C).

7. Power loss of each internal conductor at the rated current multiplying the result by the length of conductor in metres to give the power loss of the conductor within the assembly.

8. Power loss of each external conductor at the rated current multiplying the result by the length of conductor in metres to give the power loss of the conductor within the assembly.

NOTE: *Typically power loss of internal & external conductors can be conservatively estimated as 50% of all device watts.*

9. Total power loss of every device, internal and external conductor to be dissipated within the enclosure ($P_{max}$).

10. External ambient temperature 35 °C.

11. Rated diversity factor fixed at 1. The effective power losses of all circuits including interconnecting conductors shall be calculated based on rated current of the circuits (10.10.4.3 in 61439-1)

12. There are no more than three horizontal partitions in the assembly or a section of an Assembly.

13. For enclosures with compartments and natural ventilation the cross section of the ventilating openings in each horizontal partition is at least 50 % of the horizontal cross section of the compartment.

14. The temperature rise within the assembly is then determined from the total power loss using the method of IEC TR 60890.

15. Calculated air temperature at the mounting height of each device

    The assembly is verified if the calculated air temperature at the mounting height of any device does not exceed the permissible ambient air temperature as declared by the device manufacturer.

16. Confirmation that all insulating materials including busbar supports are suitable for the operating temperatures within the assembly.

## 3.3 COMPARISON OF RESULTS OF DIFFERENT VERIFICATION METHODS

**For the same 200 A application:**

- **Verification by calculation** determines that a 250 A MCCB is required together with 199 mm$^2$ busbars (selected) or 99 mm$^2$ busbars with the higher busbar operating temperature of 90 °C.
- **Verification by test** determines that a 200 A MCCB and 75 mm$^2$ busbars are required.

All other verification criteria must also be met for complete compliance.

# 4 TEMPERATURE RISE VERIFICATION BY COMPARISON (DERIVATION)

According to design rules as per BS EN 61439-2 Clause 10.10.3, rated currents of variant circuits of assemblies can be verified by derivation from similar tested arrangements by applying design rules, and calculations as required.

## 4.1 IN GENERAL (ASSEMBLIES AND CIRCUITS OF ASSEMBLIES)

- Tested arrangements at 50 Hz are applicable for 60 Hz frequency up to a rating of 800 A
- Tested arrangements at a given frequency are applicable for the same current ratings for frequencies lower than that tested and also at d.c.
- Where test results are not available for 60 Hz, a de-rating factor of 0.95 is applicable ($I_{nA}$ & $I_{nc}$)
- No de-rating required where the maximum temperature-rise at 50 Hz does not exceed 90 % of the permissible value

A fictitious assembly arrangement is created as shown below in figure 1 with reference to the different aspects of a Power Switchgear and Controlgear (PSC) assembly which would be required to be verified by comparison:

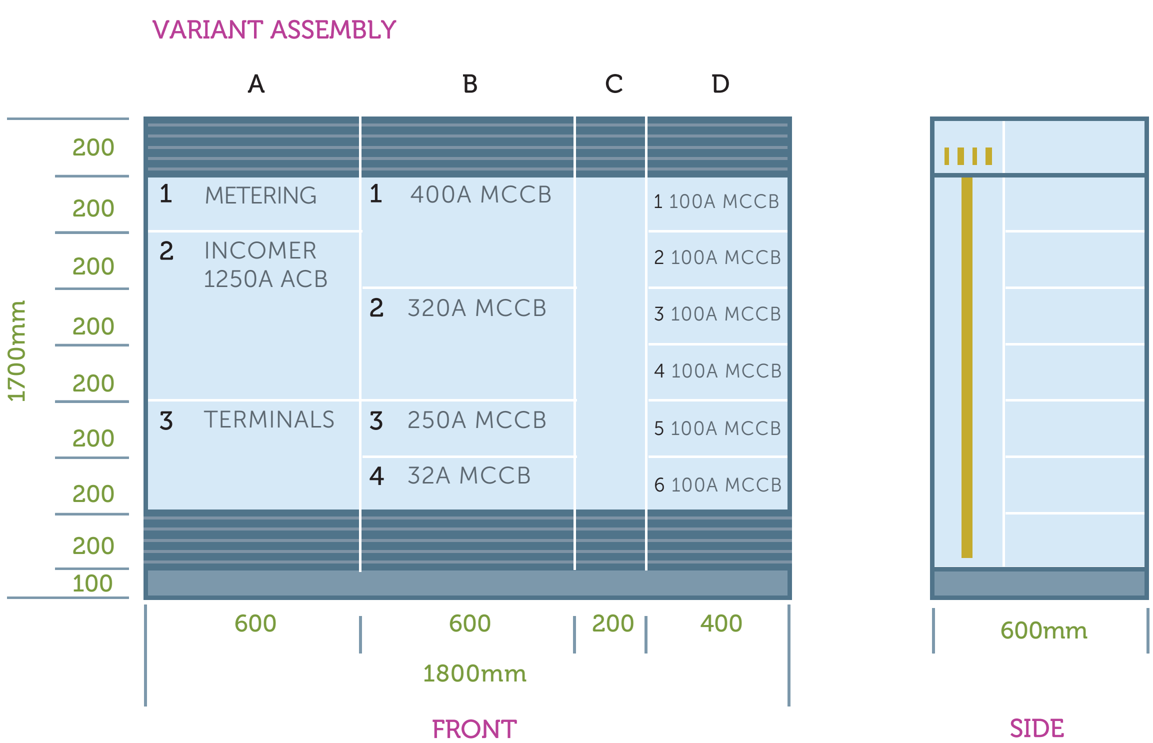



**FIGURE 1** – VARIANT ASSEMBLY

## 4.2 FOR PSC ASSEMBLIES

When verifying an assembly referring to tested arrangements, the following design rules are applicable:

| Design rules (BS EN 61439-2 Sub-clause 10.10.3.2) | Compliant with tested reference design(s) |
|---|---|
| Functional units shall belong to the same group as the functional unit selected for test | Original\Assembly Manufacturer to confirm] |
| The same type of construction as used for the tested reference design | Original\Assembly Manufacturer to confirm] |
| The same or increased overall dimensions as used for tested reference design | Original\Assembly Manufacturer to confirm] |
| The same or increased cooling conditions as used for the test (forced or natural convection, same or larger ventilation openings | Original\Assembly Manufacturer to confirm] |
| Same or reduced internal separation as used for the tested reference design | Original\Assembly Manufacturer to confirm] |
| Same or reduced power losses in the same section as used for the test | Original\Assembly Manufacturer to confirm] |
| Alternative arrangement(s) of functional units within the assembly or section compared to the tested variant is allowed as long as the thermal influences of the adjacent units are not more severe. | Original\Assembly Manufacturer to confirm] |

- The variant assembly may comprise all or part of the tested arrangement designs
- Tested arrangements comprising 3-phase 3-wire networks are considered representative of 3-phase 4-wire networks on the basis the neutral conductor is equal to or greater than the dimension of the tested arrangement, and the physical arrangement is the same.

*Example 1 – Verifying the variant assembly (as a whole)*

Review of design rules:

| Design rules (BS EN 61439-2 Sub-clause 10.10.3.2) | Compliant with tested reference design(s) |
|---|---|
| Functional units shall belong to the same group as the functional unit selected for test | YES – Incomer & feeder circuits |
| The same type of construction as used for the tested reference design | YES – Same enclosure system |
| The same or increased overall dimensions as used for tested reference design | YES – Same dimensions |
| The same or increased cooling conditions as used for the test (forced or natural convection, same or larger ventilation openings | YES – Same IP43 Louvres (Top & Bottom) |
| Same or reduced internal separation as used for the tested reference design | YES – Same Form4b separation |
| Same or reduced power losses in the same section as used for the test | YES – Reduced, refer to calculation |
| Alternative arrangement(s) of functional units within the assembly or section compared to the tested variant is allowed as long as the thermal influences of the adjacent units are not more severe. | YES – Thermal influences of functional units considered no more severe than tested arrangement |

Calculation - *Total power losses in sections, where Pt = Total power losses per section*

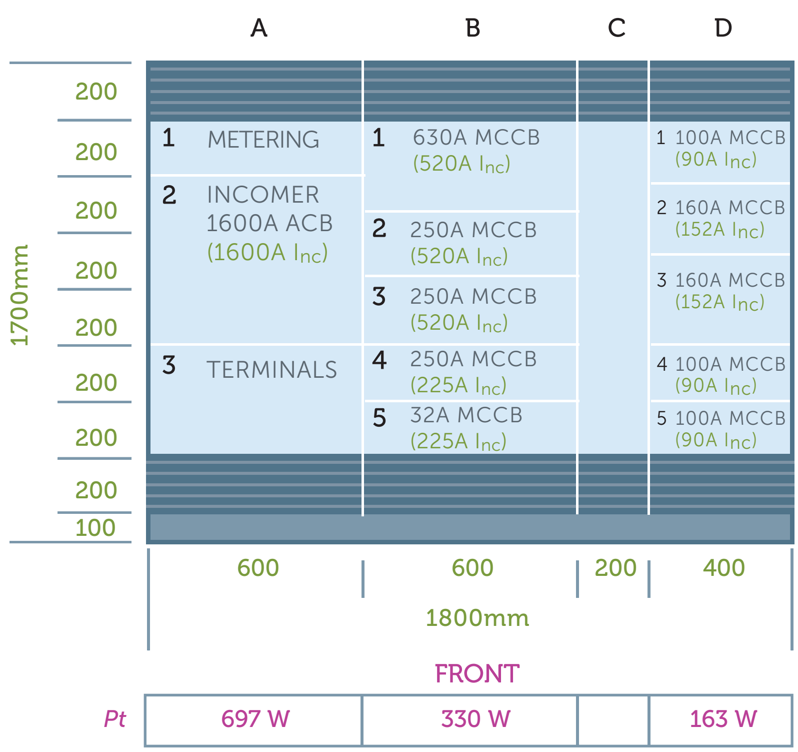



FIGURE 2 – ASSEMBLY WITH VALUES VERIFIED BY TEST

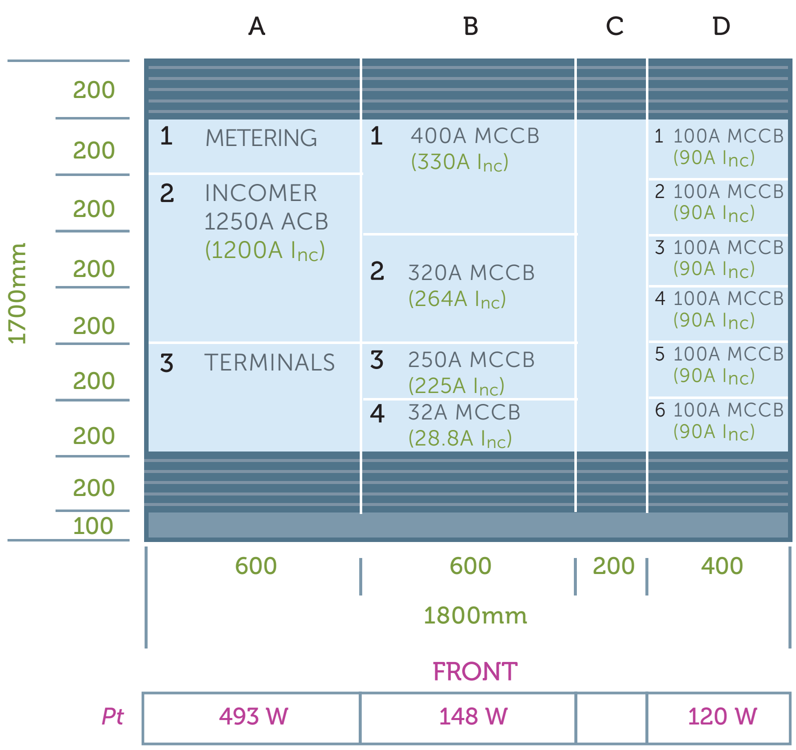



FIGURE 3 – VARIANT ASSEMBLY

Individual functional unit power losses calculated from Original Equipment Manufacturer (OEM) published data and BS EN 61439-1 Annex H & N, IEC TR 60890 Annex B, in accordance with their rated currents, $I_{nc}$.

Note, for the tested assembly $I_{nc}$ values are from the test results, for the variant assembly $I_{nc}$ values are calculated where the functional unit referred has not been tested (i.e. is a similar variant – refer to 4.4)

## 4.3 FOR BUSBARS OF PSC ASSEMBLIES (MAIN BUSBARS, INCOMING CIRCUIT, DISTRIBUTION BUSBARS)

- Current ratings for aluminium busbars are applicable for copper busbars with the same cross-sectional dimensions and arrangement.
- Current ratings for copper busbars cannot be used to establish ratings for aluminium busbars
- Variants which are not tested can be determined by multiplication of their cross-sectional dimensions with the current density of a larger, tested busbar, of the same arrangement (i.e. same physical design and configuration):

*Example 2 – Calculating the current rating of the variant assembly main and distribution busbars*

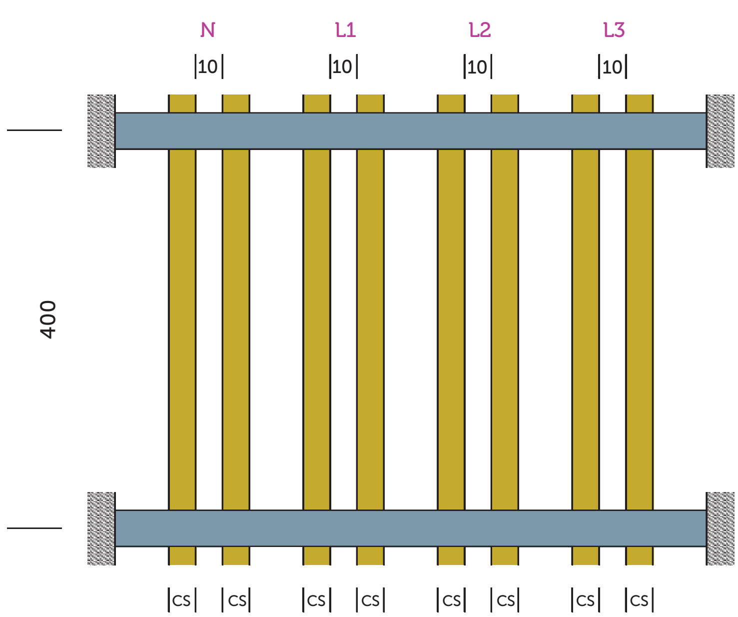



FIGURE 4 – PLAN VIEW

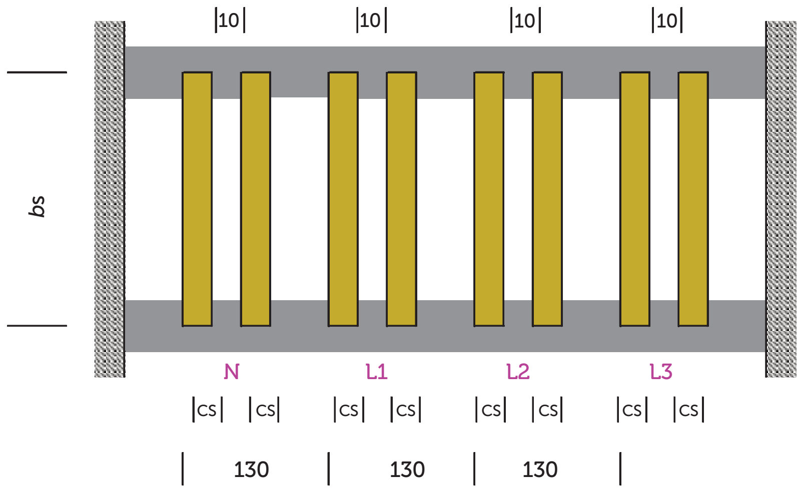



**FIGURE 5** – END VIEW

[Representative arrangement of tested and variant busbars]

Where;

*bs* = Height of conductor in mm
*Cs* = Depth of conductor in mm

Calculation – *Rated current of variant busbars*

- Variant busbars = 2x30x10 mm per phase
- Tested busbars = 2x40x10 mm per phase, rated 1600 A
- Variant busbars cross-sectional dims. = 2x30x10 = 600 $mm^2$
- Tested busbars current density = 1600 / ( 2x40x10 ) = 2.0 $A/mm^2$

Resultant rated circuit current of variant busbars:
(Variant busbars cross-sectional dimension) x (Current density of larger tested busbars)

$I_{nc}$ = 600 x 2.0
**= 1200 A**

## 4.4 FOR FUNCTIONAL UNITS OF PSC ASSEMBLIES

The 'critical variant' of each group (e.g. feeder circuit, motor-starter circuit) is required to have previously been tested in order for untested, variants to be rated in terms of current, $I_{nc}$

Each tested critical variant (e.g. largest rated current in available frame size of that OEM device) is assigned a 'de-rating' factor, which is the rated current of the circuit as verified by temperature-rise test, divided by the maximum possible current of the device (i.e. the rated current, $I_n$, according to its product standard).

*Example 3 – Calculating the rated circuit currents of the variant assembly functional units*

*Critical variant, forming part of a tested arrangement:*

630 A MCCB ($I_n$)
520A ($I_{nc}$)

[Representative cubicle from tested arrangement]

- Functional unit group = Feeder circuit
- Assembly construction = Form 4b (compartmentalised)
- Cubicle dimension = 600x400x400 mm (Width x Height x Depth)
- Device details = $I_n$ = 630 A, Type = MCCB (to BS EN 60947-2)
- Device connections = 1x30x10 mm rigid bare copper connections from adjacent distribution busbars
- Rated circuit current = 520 A ($I_{nc}$)

*Similar variants, forming part of a variant assembly arrangement:*

400 A MCCB ($I_n$) 320 A MCCB ($I_n$)

[Representative cubicles from variant assembly]

- Functional unit group = Feeder circuits
- Assembly construction = Form 4b (compartmentalised)
- Cubicle dimension = 600x400x400 mm (Width x Height x Depth)
- Device details = [Similar variant 1] – $I_n$ = 400 A, Type = MCCB (to BS EN 60947-2)
  = [Similar variant 2] – $I_n$ = 320 A, Type = MCCB (to BS EN 60947-2)
- Device connections = As critical variant for both similar variants
- Rated circuit current(s) = As calculations

*Calculations – Rated current of similar variants*

*Calculating critical variant de-rating factor:*

(Critical variant $I_{nc}$) / (Critical variant $I_n$)

= 520 / 630
**= 0.825**

*Calculating similar variants rated circuit currents:*

(Critical variant de-rating factor*) x (Similar variant maximum possible current, $I_n$)

For similar variant 1 (400 A MCCB)

Inc = 0.825 x 400
**= 330 A**

For similar variant 2 (320 A MCCB)

Inc = 0.825 x 320
**= 264 A**

## 4.5 FOR SUBSTITUTION OF TESTED DEVICES OF PSC ASSEMBLIES

Tested devices may be substituted with similar devices from the same manufacturer, including devices from a different series.

In order to verify suitability, the power loss values and terminal temperature-rise value of both the substitute and tested device must be compared – the values (in accordance with OEM published data according to the relevant product standard) are to be the same or lower for the substitute device.

Additionally, the physical arrangement and rated circuit current of the tested functional unit is to remain unchanged for the substitute device.

* Based on the testing of the critical variant, this factor may be unity (1.0) in which case there is no de-rating based on the critical variant and similar variant being the same frame size.

*Example 4 - Substitution of the variant assembly incoming unit short-circuit protective device (SCPD)*

| Device details | Product standard | Power losses (W) | Terminal temp-rise (K) | Physical arrangement |
|---|---|---|---|---|
| Verified device 1600 A ACB $I_{nc}$ = 1600 A *OEM Same Series* | BS EN 60947-2 | 390 | 120 | Cubicle dimensions: 600x400x400 mm (WxHxD) Device connections: Horizontally orientated rigid conductors to adjacent vertical supply conductors |
| Substitute device 1250 A ACB $I_{nc}$ = 1250 A *OEM Same Series* | BS EN 60947-2 | 230 | 120 | Cubicle dimensions: 600x400x400 mm (WxHxD) Device connections: Horizontally orientated rigid conductors to adjacent vertical supply conductors |

Additional requirements for the substitute device as per BS EN 61439-1 Table 13 (verification of short-circuit withstand strength) are applicable as below;

- If from same series, confirm the same or better performance characteristics for the substitute device are met, ($I^2t$, $I_{pk}$).
- If from a different series, confirm the above and same or better breaking capacity ($I_{pk}$) and critical distances when installed are met (i.e. clearance distances from device to adjacent non-metallic, metallic, and energised parts of the assembly).

# 5 SHORT-CIRCUIT WITHSTAND STRENGTH VERIFICATION

BS EN 61439-1 allows verification of short-circuit withstand strength by exemption, or comparison with a tested reference design. This route to verification reduces the requirement for repetitive testing.

## 5.1 ASSEMBLIES EXEMPT FROM SHORT-CIRCUIT WITHSTAND STRENGTH VERIFICATION

The exemptions to verification, where a test to prove short circuit withstand strength are not required, are:

1. Auxiliary circuits intended to be connected to transformers whose rated power does not exceed 10 kVA for a rated secondary voltage of not less than 110 V, or 1.6 kVA for a rated secondary voltage less than 110 V, and whose short-circuit impedance is not less than 4 %.

   It is accepted practice that auxiliary circuits connected to main circuits do not require short circuit testing when protected by a short circuit protective device which limits the cut-off current to 17 kA or less

2. The assembly is to be used in a system where it is known the short circuit fault current cannot exceed 10 kA rms;

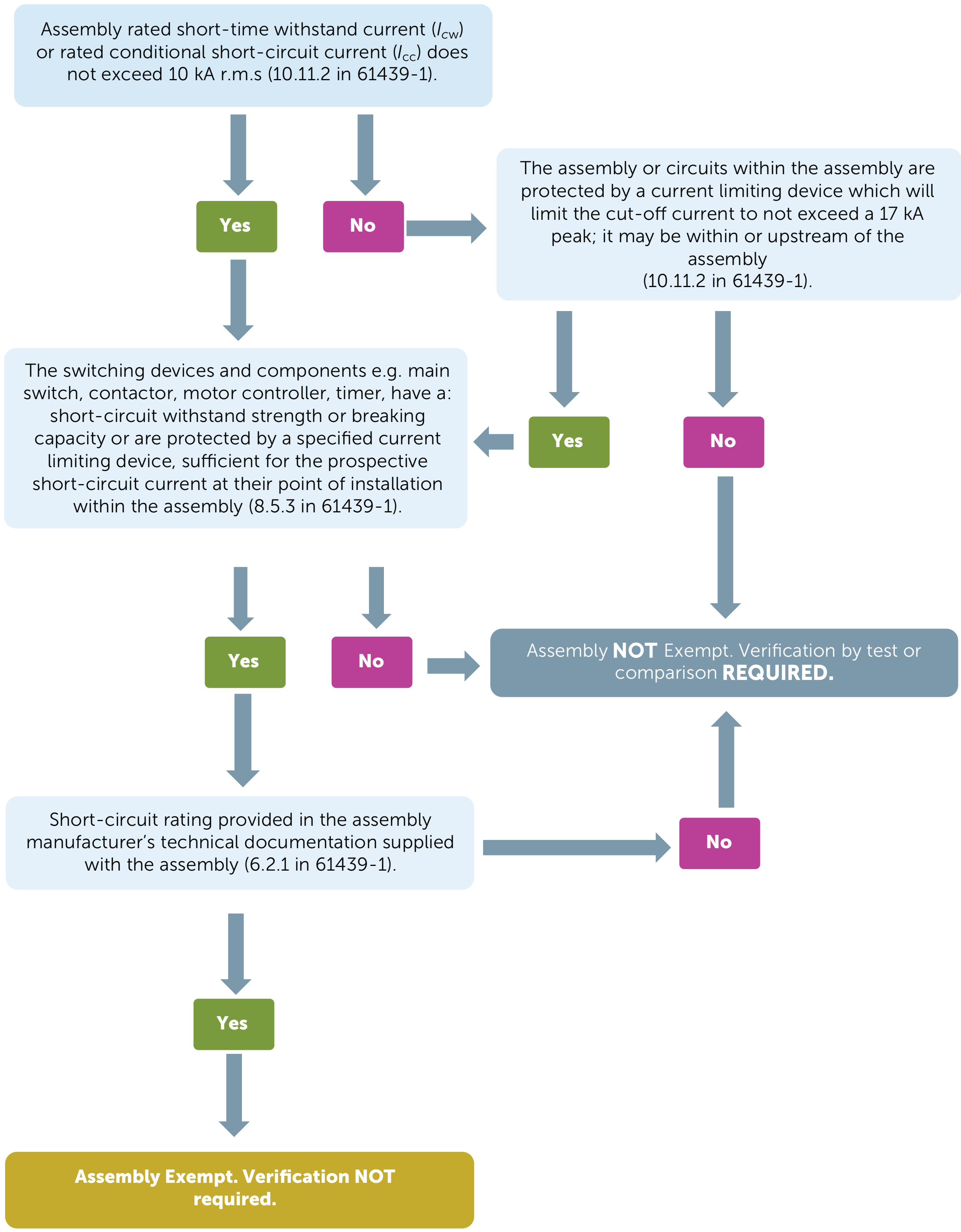
3. The assembly or circuits within the assembly protected by a current limiting device which will limit the cut-off current to below 17 kA; (it may be within or upstream of the assembly).

When selecting switching devices and components for incorporation within the Assembly, manufacturer's advice should be adhered to. In some instances, the application may require additional current limiting protection and/or devices with enhanced breaking capacity. In any case, **where the 10 kA rms and 17 kA exemptions apply, the switching devices and components must have a short-circuit withstand strength or a breaking capacity or a conditional short-circuit rating in relation to the prospective fault current that can occur at the point of installation within the Assembly.**

Co-ordination of switching devices and components, for example co-ordination of motor starters with short-circuit protective devices, must comply with the relevant IEC standards.

*NOTE Guidance is given in IEC/TR 61912-1 and IEC/TR 61912-2.*

## Flow Chart – Assemblies Exempt from Short-circuit withstand strength verification



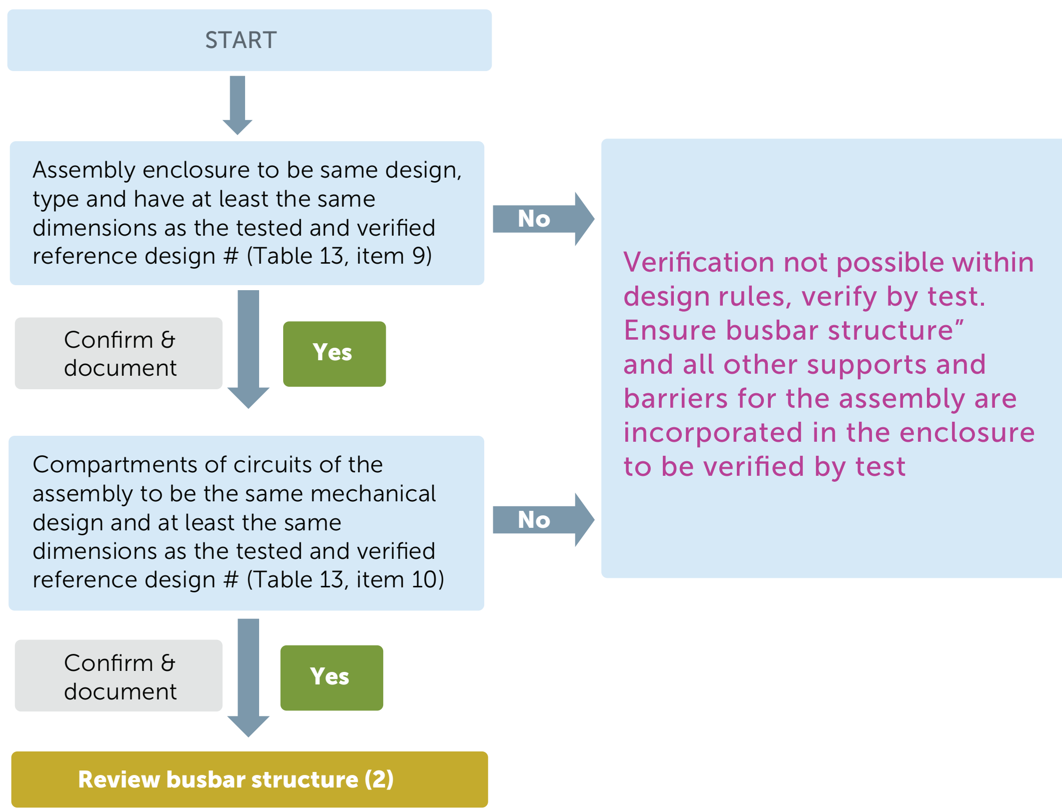
## 5.2 VERIFICATION BY COMPARISON WITH A REFERENCE DESIGN UTILISING A CHECKLIST AND OR CALCULATION METHOD

Verification of an assembly using a tested reference design (including device substitution)

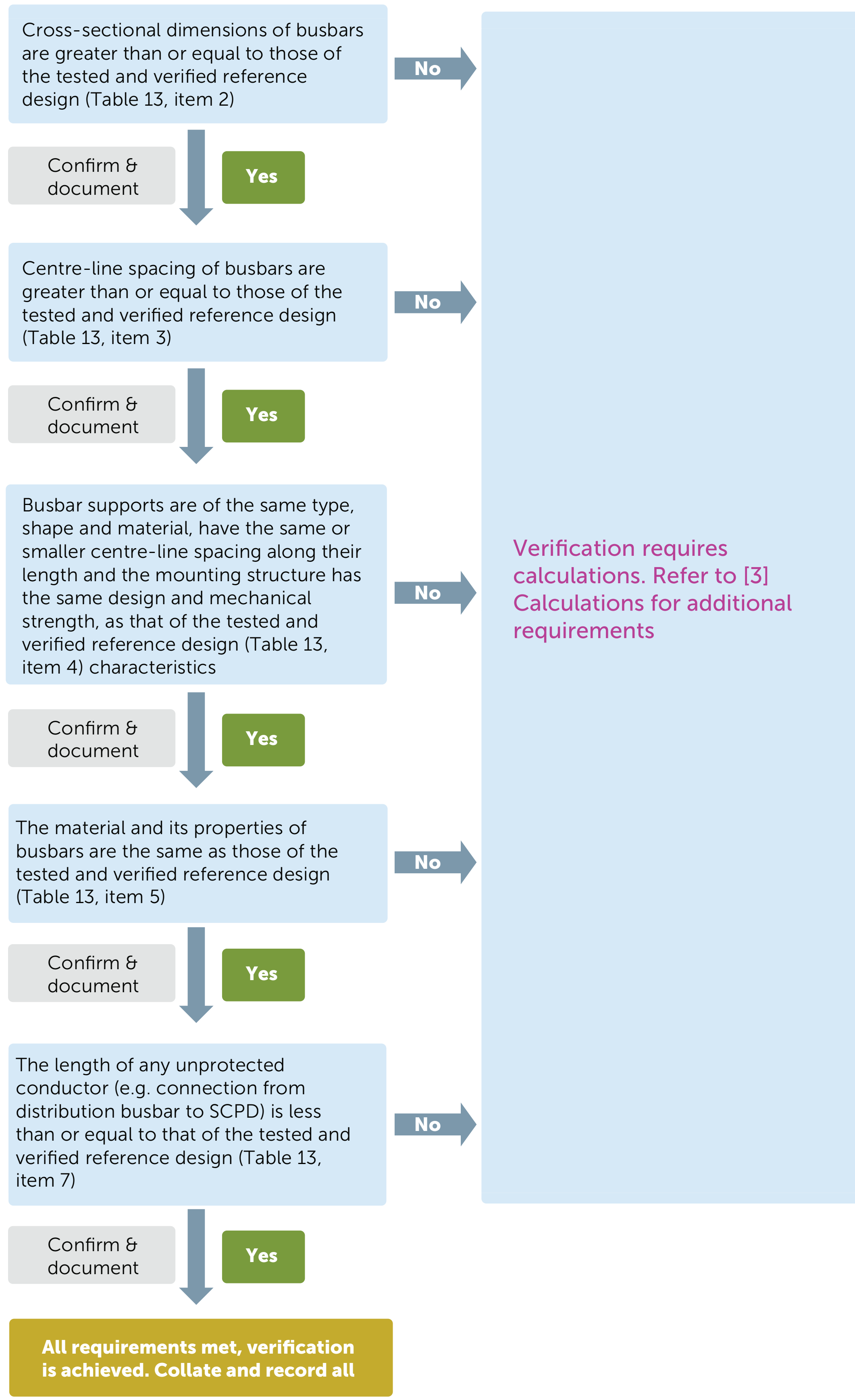
*NOTE When considering device substitution all other performance criteria, in particular that dealing with short circuit capability, should be considered and satisfied, in accordance with the IEC 61439-1, before an assembly is deemed to be verified.*

Flow Chart – Verification by comparison with a reference design

**[1] Assembly design**



**[2] Busbar Structure**



Change of parameters (e.g. busbar material, clearances, cross-section and configuration) necessary for calculation in accordance with IEC 60865-1 are permissible only based on adherence to the following:

- Peak short-circuit current may only be changed to a lower value
- Thermal short-circuit strength of a NTS is to be calculated and the temperature-rise value no higher than that of the TS
- Change of material or shape of busbar supports taken from a tested and verified reference design are not permitted. Other supports may be used if they have previously been tested for the required mechanical strength
- Connections to busbars and other equipment must have been previously tested and verified

Angular busbar configurations may be considered where supports are provided at each corner

**No** → Verification not possible within design rules, verify by test. Ensure applicable conditions can be met verify by test.

**Yes** ↓

Undertake calculation of **electro-magnetic forces** during a three-phase short-circuit across main conductors in accordance with IEC 60865-1 Clause 5.

Record calculated values for TS & NTS for the following:

- Fm3 - Peak value of force between main conductors during a three-phase short-circuit
- Fm2 - Peak value of force between main conductors during a line-to-line short short-circuit
- Fs - Peak value of force between coplanar sub-conductors

Evaluate: Calculated forces for the NTS must be less than or equal to those for the TS.
Refer to IEC 60865-2 for examples of calculation.

→

Undertake calculation of **thermal equivalent short-circuit current** in accordance with IEC 60865-1 Clause 7 (referring IEC 60909-0).

Record calculated values for TS & NTS for the following:

- *Sthr.√Tkr/Tk - Short-circuit current density relation for Sth and Tk values*
- *Sth - Thermal equivalent short-time current density*
- *$\Delta t$ - Temperature-rise of the conductors*

Evaluate: The conductors have sufficient thermal short-time strength if Sth is less than Sthr.√Tkr/Tk.

Also, the temperature-rise of the NTS must be less than or equal to the TS.
Refer to IEC 60865-2 for examples of calculation.

↓

Record & document

↓

Verification of short-circuit withstand strength of a NTS is achieved if the calculations demonstrate that the NTS is not subjected to higher mechanical and thermal stresses than the TS.

↓

**Collate and record all documentation**

**Notes to the [3] Calculation flowchart:**

Legend: TS = Tested Structure; NTS = Non-Tested Structure

i. If the calculation requirements or requirements as indicated are not met, then the busbar structure is to be verified by test.

ii. Manufacturer is to confirm, collate, record and store all applicable documentation to demonstrate verification

iii. With regard to conductor oscillation, IEC 60865-1 calculations for the TS, the following values of the factors Vσ, Vσs and Vf are referred:

Vσ = Vσs = Vf = 1.0

Where

Vσ is the ratio between dynamic and static main conductor stress
Vσs is the ratio between static sub-conductor stress
Vf is the ratio between dynamic and static force on supports

For the NTS: Vσ = Vσs = 1.0
Vf is from IEC 60865-1 calculations, however where Vf <1.0, replace with Vf = 1.0

**TABLE 1** – SHORT-CIRCUIT WITHSTAND STRENGTH VERIFICATION BY COMPARISON WITH A REFERENCE DESIGN: CHECK LIST (10.5.3.3, 10.11.3 AND 10.11.4)

| Item No. | Requirements to be considered | Yes | No |
|---|---|---|---|
| 1 | Is the short-circuit withstand rating of each circuit of the ASSEMBLY to be assessed, less than or equal to, that of the reference design? | | |
| 2 | Is the cross-sectional dimensions of the busbars and connections of each circuit of the ASSEMBLY to be assessed, greater than or equal to, those of the reference design? | | |
| 3 | Is the center line spacing of the busbars and connections of each circuit of the ASSEMBLY to be assessed, greater than or equal to, those of the reference design? | | |
| 4 | Are the busbar supports of each circuit of the ASSEMBLY to be assessed of the same type, shape and material and have, the same or smaller center line spacing, along the length of the busbar as the reference design?<br>And is the mounting structure for the busbar supports of the same design and mechanical strength? | | |
| 5 | Are the material and the material properties of the conductors of each circuit of the ASSEMBLY to be assessed the same as those of the reference design? | | |
| 6 | Are the short-circuit protective devices of each circuit of the ASSEMBLY to be assessed equivalent, that is of the same make and series[a] with the same or better limitation characteristics ($I^2t$, $I_{pk}$) based on the device manufacturer's data, and with the same arrangement as the reference design? | | |
| 7 | Is the length of unprotected live conductors, in accordance with 8.6.4, of each non-protected circuit of the ASSEMBLY to be assessed less than or equal to those of the reference design? | | |
| 8 | If the ASSEMBLY to be assessed includes an enclosure, did the reference design include an enclosure when verified by test? | | |
| 9 | Is the enclosure of the ASSEMBLY to be assessed of the same design, type and have at least the same dimensions to that of the reference design? | | |
| 10 | Are the compartments of each circuit of the ASSEMBLY to be assessed of the same mechanical design and at least the same dimensions as those of the reference design? | | |
| 'YES' to all requirements – no further verification required. | | | |
| 'NO' to any one requirement – further verification is required. | | | |
| [a] Short-circuit protective devices of the same manufacturer but of a different series may be considered equivalent where the device manufacturer declares the performance characteristics to be the same or better in all relevant respects to the series used for verification, e.g. breaking capacity and limitation characteristics ($I^2t$, $I_{pk}$), and critical distances. | | | |

# 6 FURTHER VERIFICATION

In addition to temperature rise and short-circuit withstand strength requirements, other relevant design verifications must be undertaken. See the BEAMA Guide to Verification.

Rotherwick House
3 Thomas More Street
London E1W 1YZ

www.beama.org.uk