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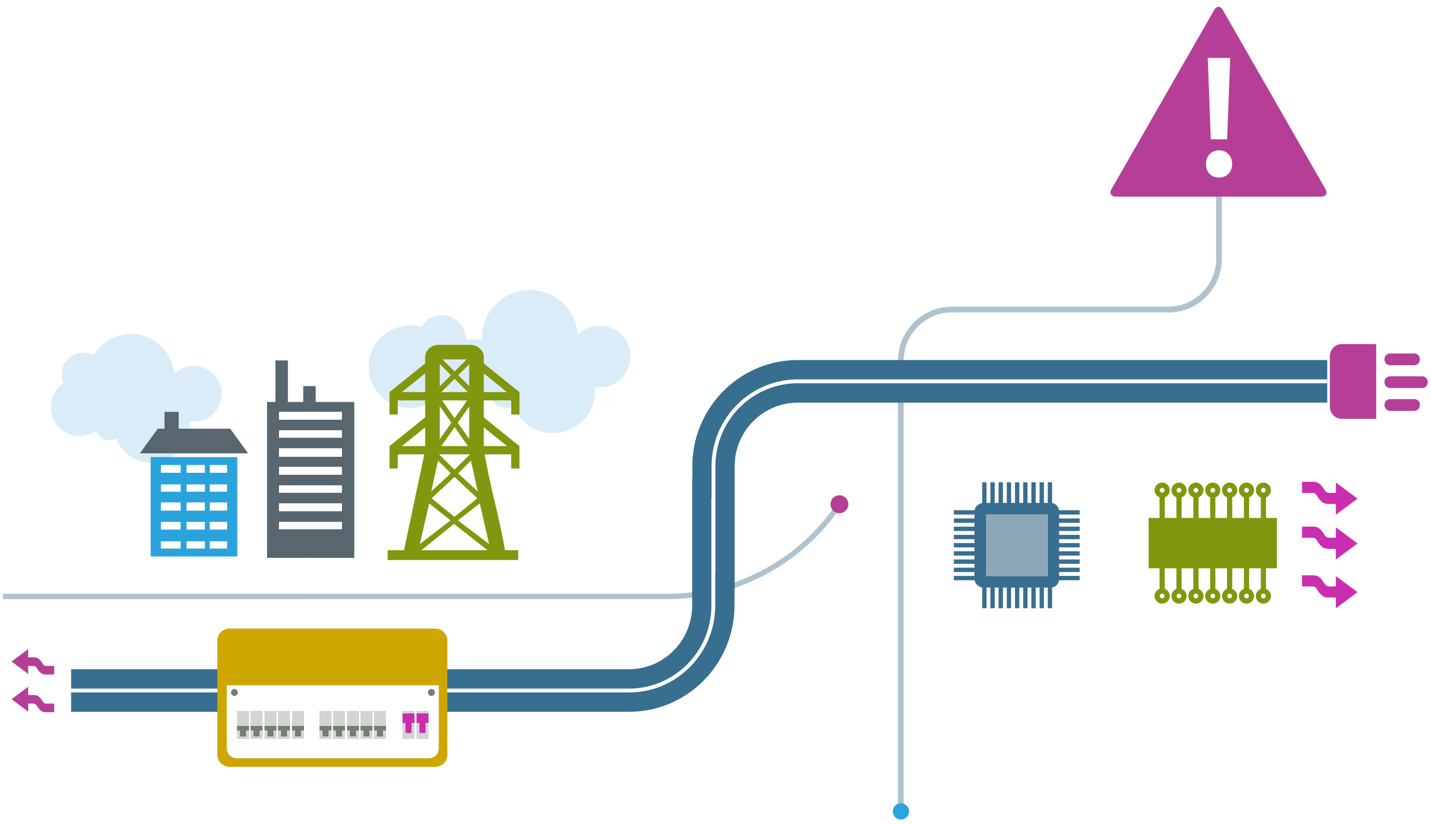
BEAMA GUIDE ON COORDINATION BETWEEN DESIGN CURRENT OF AN INSTALLATION AND RATED CURRENTS IN PANELBOARDS, SWITCHBOARDS AND MOTOR CONTROL CENTRES (BS EN IEC 61439-2)



January 2022

ABOUT BEAMA

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 guidance on coordination between design current of an installation and rated currents in Panelboards, Switchboards and Motor Control Centres conforming to BS EN IEC 61439 -2 and on how the coordination between the assembly current ratings and those of the electrical installation can effectively and reliably be achieved.

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

Details of other BEAMA Guides can be found on the BEAMA website **www.beama.org.uk**

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COMPANIES INVOLVED IN THE PREPARATION OF THIS GUIDE

APD Limited
12a Willie Snaith Road, Newmarket,
Suffolk, CB8 7SU
Tel: +44 (0) 1638 669 399
Email: sales@apd.ltd.uk
www.apd.ltd.uk

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

BGEN Limited
Firecrest Court, Centre Park,
Warrington WA1 1RG
Tel: +44 (0) 333 240 90 80
Email: info@b-gen.co.uk
https://b-gen.co.uk

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

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

Michael Smith Switchgear Limited
4 Elland Road, Braunstone Frith Industrial Estate
Leicester LE3 1TU
Tel: +44 (0) 116 275 4100
Email: info@mssl.uk.com
www.mssl.uk.com

Electrium Sales Limited (a Siemens Company)
Walkmill Lane, Bridgetown
Cannock, WS11 0XE
Tel: +44 (0) 1543 455000
Email: info@electrium.co.uk
www.electrium.co.uk

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

Elsteel UK Limited
Off Davy Way, Llay Industrial Estate,
Llay, Wrexham LL12 0PG
Tel: 01978 855909
Email: sales@elsteel.co.uk

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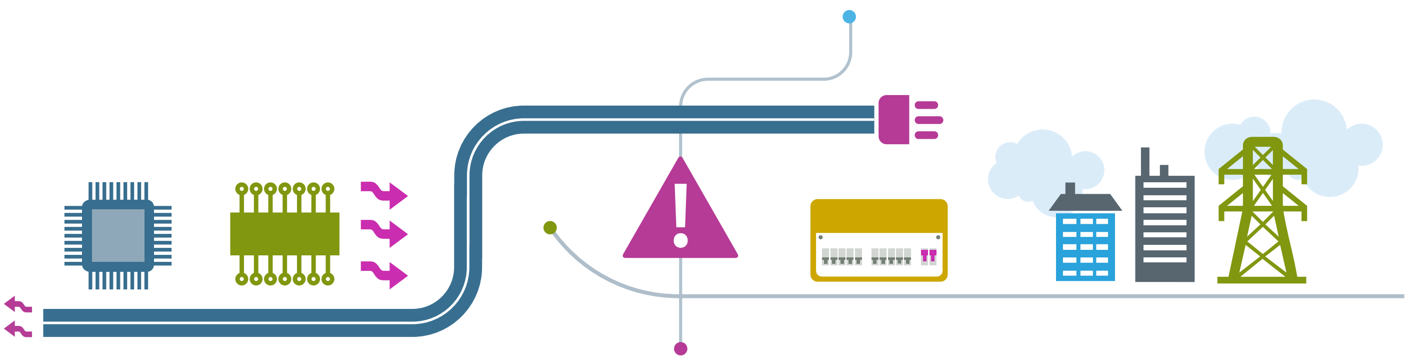


BEAMA GUIDE ON COORDINATION BETWEEN DESIGN CURRENT OF AN INSTALLATION AND RATED CURRENTS IN PANELBOARDS, SWITCHBOARDS AND MOTOR CONTROL CENTRES (BS EN IEC 61439-2)

1. Introduction

With the release of Edition 3 of BS EN IEC 61439-2 there is a significant change in the way in which the current rating of circuits within an assembly are defined. This provides an opportunity for greater optimisation between the performance of a low-voltage assembly and the needs of an electrical installation. To fully realise these benefits, the requirements of the electrical installation must be clearly identified and defined in the assembly specification. The rating of circuits within low-voltage assemblies can be defined by any one of several currents. Therefore, a clear understanding of how these relate to each other and to the electrical installation by those who determine the arrangement of the assembly is essential.

BS EN IEC 61439-2 applies to products commonly referred to as: Switchboards, Panel boards and Motor Control Centres.

This document provides guidance on how the coordination between the assembly current ratings and those of the electrical installation can effectively and reliably be achieved.

2. Symbols, definitions and terminology

Several symbols, definitions and terminologies used in the applicable standards are pertinent to the considerations in this guide. These are summarised below.

2.1. BS 7671: 2018 IET Wiring Regulations: Requirements for Electrical Installations defines I_n and I_b as follows:

I_n rated current or current setting of protective device

For adjustable protective devices, the rated current (I_n) is the current setting selected.

I_b design current of the circuit

The magnitude of the current (rms value for AC) to be carried by the circuit in normal service.

Note: the symbol I_b is used in BS 7671, and I_B is used in the IEC wiring regulations IEC 60364 and IEC 61439 series.

2.2 BS EN IEC 61439-2: 2021 (Low-voltage switchgear and controlgear assemblies – Part 2: Power switchgear and controlgear assemblies used in conjunction with BS EN IEC 61439-1: 2021 (Low-voltage switchgear and controlgear assemblies. General rules) provides the following definitions:

I_{nA} Rated current of an assembly (BS EN IEC 61439-1, clause 3.8.10.7)

Rated current which can be distributed by an assembly without the temperature-rise of any of the parts exceeding specified limits.

Note: The rated current of the assembly is not to be exceeded if further circuits are added in the future.

I_{ng} Group rated current of a main circuit (BS EN IEC 61439-1, clause 3.8.10.6)

Rated current which a main circuit can carry considering the mutual thermal influences of the other circuits that are simultaneously loaded in the same section of the assembly.

Note 1: I_{ng} can equal I_{nc} in some designs of assembly.

Note 2: An assembly can comprise only a single section.

I_{nc} Rated current of a main circuit (BS EN IEC 61439-1, clause 3.8.10.5)

Rated current which a main circuit can carry when it is the only main circuit within a section of an assembly that is carrying current.

The test arrangements for I_{nc} relate to it being the only main circuit that is carrying current during the test. However, it is important to note, as explained later in this guide, that the application of I_{nc} can result in it being used with other simultaneously loaded circuits within a section e.g.

- when the circuit loaded to I_{nc} only carries current for a short time
- when the adjacent circuits are lightly loaded such that their mutual heating is of no significance

Note 1: The rated current of a main circuit can be lower than the rated currents of the devices installed in the main circuit, according to the respective device standards.

Note 2: Due to the complex factors determining the rated currents, no standard values can be given.

Note 3: An assembly can comprise of only a single section.

RDF Rated diversity factor

Value, calculated by dividing the group rated current of an outgoing main circuit I_{ng} by the rated current I_{nc} of the same outgoing main circuit, where I_{ng} and I_{nc} are derived by test

Note 1: RDF therefore represents the per unit value of I_{nc}, to which two or more outgoing circuits in the same section of an assembly can be continuously and simultaneously loaded taking into account the mutual thermal influences.

Note 2: For a group of circuits that are continuously and simultaneously loaded, the rated current of a circuit (I_{nc}) multiplied by the rated diversity factor (RDF) normally is not less than the design current (I_b) of the circuit normally provided by the user i.e., $I_{nc} \times \text{RDF} \geq I_b$.

I_n Rated current (rating defined in relevant product standard) (BS EN 60947-1, clause 3.10)

Within BS EN IEC 61439-1 this is assumed to be the free air rating of the device under defined conditions in accordance with the devices product standard, e.g., BS EN 60947-2 in the case of a circuit-breaker.

Note: I_n in accordance with BS 7671 can be a different value to I_n in accordance with BS EN IEC 61439-2 due to the differing definitions. See definitions above.

3. Assembly and electrical installation compatibility requirements

The applicable standards provide some guidance on matching the requirements of the electrical installation to the assembly. This guidance is summarised below.

3.1. BS 7671

Regulation 536.4.202 states: The relevant design current shall not exceed the rated current of an assembly (I_{nA}) or the rated current of a circuit (I_{nc}) of the associated assembly, having taken any applicable diversity/loading factors into account.

3.2. BS EN IEC 61439-1

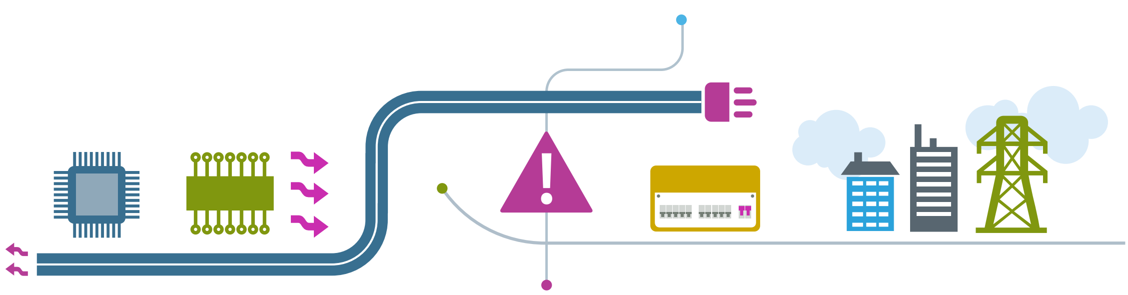
BS EN IEC 61439-1 states that the characteristics of the assembly should be compatible with the ratings of the circuits to which it is connected and the installation conditions. The relevant assembly interface characteristics shall be declared by the assembly manufacturer, for rated current interface characteristics, see section 2 above e.g., I_{nA}, I_{nc}, I_{ng} and RDF.

3.3. PD IEC TR 61439-0

PD IEC TR 61439-0: 2021 (Low-voltage switchgear and controlgear assemblies – Part 0: Guidance to specifying assemblies) provides guidance on specifying assemblies manufactured in accordance with the BS EN IEC 61439 series of standards.

Clause 13.1 of PD IEC TR 61439-0 states: Where the circuits are not loaded continuously and simultaneously and the adjacent circuit(s) are not fully loaded at the same time, I_b should not be greater than the rated current of the circuit (I_{nc}), that is $I_{nc} \geq I_b$. Where adjacent circuits are continuously loaded the group rated current of a circuit of an assembly, (I_{ng}) should be at least equal to I_b, ($I_{ng} \geq I_b$).

Both of these documents are very clear that I_b should never exceed I_{nc}, and the latter that with adjacent circuits loaded to I_{ng}, I_b for the circuit being considered should not exceed its I_{ng}. However, neither is clear on how to optimise the loading of circuits in the most likely scenario where circuits are not fully loaded for the majority of the time, they may be intermittently loaded, pairs of circuits with duty/standby function, etc.



4. Principles

A number of principles need to be understood in the context of the standards being considered. These are detailed below.

4.1. Continuous load

A steady load current where the ON period is sufficient for thermal equilibrium to be reached.

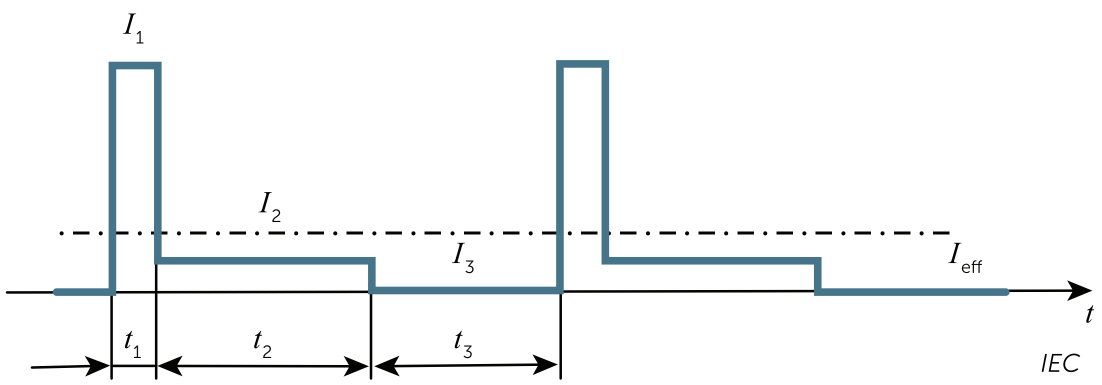
4.2. Cyclic loads

Many processes lead to cyclic loads, for example, metal presses, moulding machines. It is important to understand that a cyclic load is a "predictably varying load" i.e., it has a repeatable load profile with a start, run, and interval time.

Cyclic loading and the concept of thermally equivalent constant load being considered as I_b is recognised in Regulation 533.2.1 of BS 7671, but without any guidance on how to determine the thermal equivalence and it does not stipulate an OFF period.

Limiting the ON period to 30 minutes and requiring the OFF period to be greater than the ON period can be conservative, particularly when considering circuits with higher rated currents. The guidance from BS EN IEC 61439-1 requires an OFF period. Alternatively, where more precise thermal time constant characteristics are known, an OFF period may not be required.

The Informative Annex I in BS EN IEC 61439-1 provides more specific guidance. For predictably varying loads, when the ON time does not exceed 30 minutes and the OFF time is longer than the ON time, the thermally equivalent current is determined as follows:



$$I_{eff} = \sqrt{\frac{I_1^2 \times t_1 + I_2^2 \times t_2 + I_3^2 \times t_3}{t_1 + t_2 + t_3}}$$

Key

I_{eff}	Thermal equivalent current equal to I_b
t_1	Starting time at current I_1
t_2	Run time at current I_2
t_3	Interval time at $I_3 = 0$
$t_1\, t_2\, t_3$	Cycle time

Also, a cycle with high current for a short time followed by a low current for a long time and no OFF period will result in a thermally equivalent current that is much lower than the short high current duration and which can be considered as equivalent to I_b for the purposes of the design of the assembly.

Assembly manufacturers may have knowledge of the thermal behaviour and time constant of their equipment to extend the cycle time, consider other cyclic current profiles, etc., when determining suitable thermal equivalent currents consistent with the assembly being provided. Regardless of the profile of the cycle, care is always necessary to ensure any peak current does not cause the overload protective device to operate.

4.3. Intermittent loads

In cases where circuits are only loaded for short periods, generally not more than 30 minutes with an ON-time less than the OFF-time, it is acceptable to load the circuits to their rated currents I_{nc}. This is because the circuit in question, is not classified as continually loaded and their respective time constant is unlikely to be exceeded. These circuits would represent an intermittent load, as the load is not a predictable cycle.

For an intermittent load i.e., a circuit not continually loaded, I_b is the current derived from the steady state load characteristics without further reduction, for example, moving an air bridge at an airport. These circuits require a significant current for a short period, several minutes, and then negligible current for a period of hours or days. In such cases I_b can only be based on the short-term significant current of this intermittent load.

4.4. Peak currents

The characteristics of some loads are such that they demand an inrush current for a few cycles when they are energised, for example, transformers and motors when started direct-on-line. Generally, this inrush current can be ignored when determining I_b, unless the inrush occurs very frequently as can be the case with a motor subjected to a plugging and inching duty.

4.5. Group rated current

BS EN IEC 61439-1 defines the group rated current of a main circuit of an assembly as detailed above. This is amplified in clause 5.3.3 where it is stated: The group rated current of a main circuit is the current that can be carried by this circuit when it is loaded continuously and simultaneously together with at least one other circuit in the same section of the assembly, in a specific arrangement as defined by the original manufacturer.

When defining the I_{ng} for a specific circuit, as a minimum, one other circuit within the same section must be assumed to be carrying an unspecified current. There are no requirements given for the relative rating or position of the two circuits. As a result, each design of circuit can have a multitude of values of I_{ng}, depending on the arrangement and loading of the circuits within the same section.

4.6. Diversity

Diversity is a term frequently used within BS 7671, but it is not a defined term. It relates to the process of determining the maximum demand of an installation or part thereof. This recognises that for some arrangements, not all the loads will be on at the same time or fully loaded at the same time.

It is important to understand that, RDF in BS EN IEC 61439-1 has a specific meaning in relation to an assembly circuit current carrying capacity under conditions of simultaneous operation. Fundamentally, RDF is a de-rating factor applied to I_{nc} to account for the mutual heating effect of continuously and simultaneously loaded adjacent circuits in the same section or complete assembly.

BS EN IEC 61439-1 determines RDF as a calculated value, RDF = I_{ng} /I_{nc} when I_{ng} and I_{nc} have been established by test. As I_{ng} can be established on the basis of an individual circuit and the loading arrangement of circuits in the same section, RDF can be a multitude of values for any given design of a circuit.

4.7. Assumed loading

In the absence of the actual load currents or I_b having been specified by the electrical installation designer, BS EN IEC 61439-2 permits, but does not mandate, a manufacturer to assume that the loading on each outgoing circuit is the rated current of the protective device, I_n, multiplied by the assumed loading factor given in Table 1 below.

Type of Load	Assumed loading factor
Distribution – 2 and 3 circuits	0.9
Distribution – 4 and 5 circuits	0.8
Distribution – 6 to 9 circuits	0.7
Distribution – 10 or more circuits	0.6
Electric actuator	0.2
Motors ≤ 100 kW	0.8
Motors > 100 kW	1.0

Table 1: Values of assumed loading (loading factors to derive the assumed load current)

Note: RDF and assumed loading factor (ALF) are different parameters, RDF is fundamentally a group rated factor and ALF is a factor to determine the design current in the absence of other design information by the electrical installation designer.

4.8. Relative current ratings of circuits within an assembly

The three rated currents, I_n, I_{nc} and I_{ng}, associated with a circuit within an assembly can all have the same value, but this is very unlikely as the effects of enclosing a device and mutual heating lead to different values. Figure 1 below illustrates the likely relative ratings.

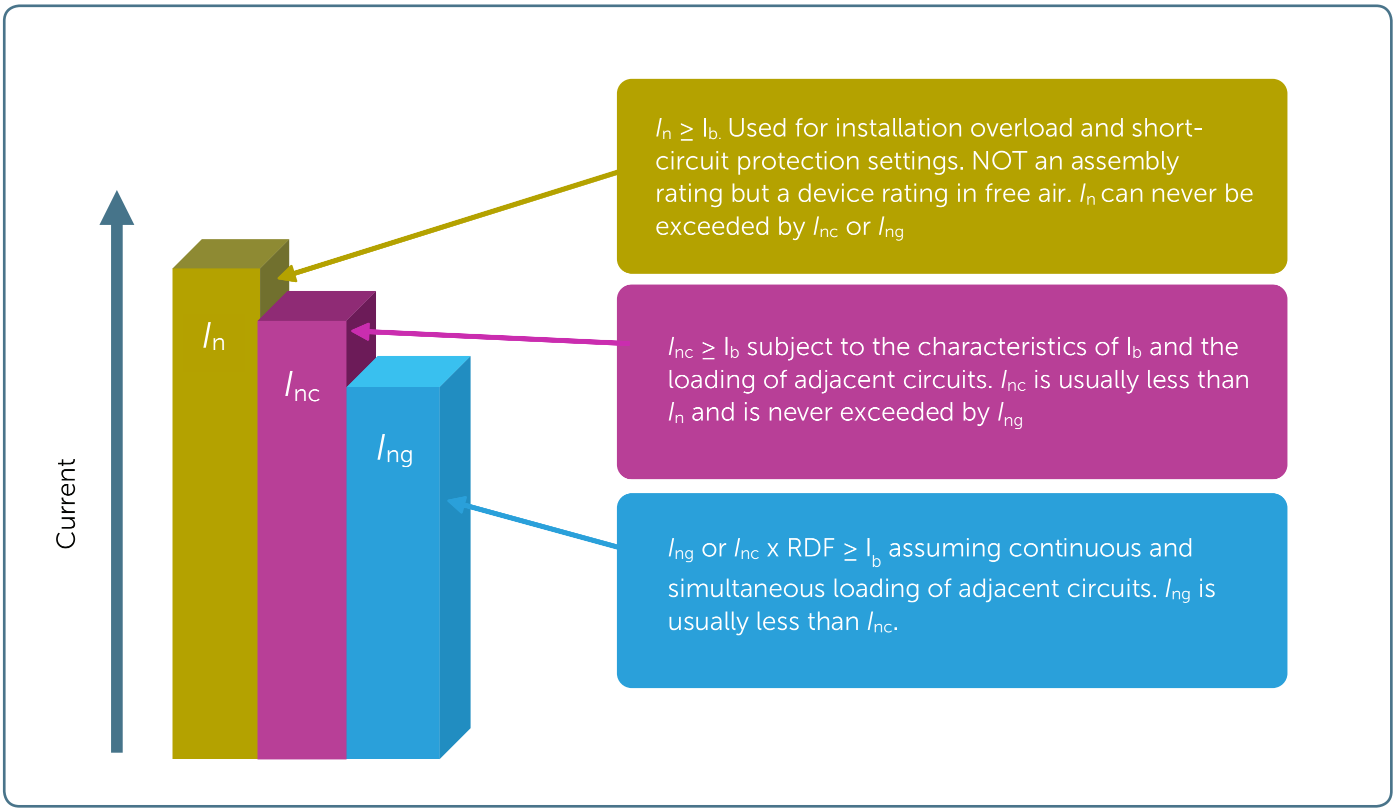


Figure 1: Relative values of current ratings associated with a circuit within an assembly

IEC TR 61439-0 provides guidance on an assembly and its application ratings as shown in Table 2 below.

Assembly	Application
Device rating I_n	Current rating used to establish overload and short-circuit protection settings (coordination)
Rated current of a circuit I_{nc}	Design current I_b (of an outgoing circuit of the assembly that is not continuously and simultaneously loaded)
Group rated current of a circuit of an assembly I_{ng}	Design current I_b (of an outgoing circuit of the assembly that is continuously and simultaneously loaded)

Table 2: Assembly and application summary

5. Manufacturers obligations and options

In accordance with BS EN IEC 61439-1 an assembly manufacturer is obliged to declare either the group rated current of each main circuit, I_{ng}, for the stated arrangement, or the rated current of each circuit, I_{nc}, and the RDF. If I_{ng} is established and declared, the manufacturer does not have to declare I_{nc}.

There are several ways in which this data can be obtained and presented; some are more conservative than others. Table 3 below summarise the common options.

Option	Approach	Assembly manufacturer's specification	Remarks
Historical data	Temperature rise verifications in accordance with BS EN 61439-1 and 2: 2011 established the rated current for each circuit, I_{nc}, and an RDF for each section and/ or each assembly.	When I_{nc} and RDF are known for each type of circuit, the assembly manufacturer calculates and declares I_{ng} for each type of circuit and the conditions under which it applies as an RDF for each section and/or each assembly. ($I_{ng} = I_{nc}$ x RDF)	The assembly manufacturer knows the I_{nc} for each type of circuit. At their discretion it can be declared and used to optimise the loading of the assembly.
Generalised approach	Assembly manufacturer conducts temperature rise verification considering a 'worst case' arrangement and the assumed loading given in BS EN IEC 61439-2.	Assembly manufacturer derives its declared rated current I_{ng} from the current used in the tests for each type of circuit and the conditions under which it applies. The manufacturer may use an assumed loading factor for each section and/ or each assembly to derive the test current used to verify the rated current I_{ng}. I_{ng} is the group rated current for each circuit.	Without further design verification I_{nc} is not available to enable optimisation of loading of the assembly.
Optimised approach	Assembly manufacturer conducts temperature rise verifications considering section arrangements and loadings they have defined. The assembly manufacturer also determines I_{nc} for each type of circuit.	Assembly manufacturer declares I_{ng} for each type of circuit and the detailed conditions under which it applies. For example: **a)** For a given type of circuit I_{ng} = 'X' A when the circuit is in the bottom compartment of a section and 'Y' A in any other position. **b)** For a given type of circuit in any position, I_{ng} = 'Z' A when all other circuits in the same section are not simultaneously loaded to more than 50% of I_{ng}.	A given design of circuit can have a multitude of I_{ng} values depending on the section arrangement and the loading of other circuits in the same section. As the assembly manufacturer has established I_{nc} it is available to aid further optimisation of loading within the assembly.

Table 3: Options for declaring rated currents

6. Installation designer obligation

In accordance with BS 7671 the installation designer should establish a design current for each circuit. When applicable this should take into account cyclic loading and the determination of a thermal equivalent current, I_b.

7. Guidance for specifiers

PD IEC TR 61439-0 provides the following guidance for specifiers:

a. Preferably, the design current, I_b, for each circuit connected to the assembly together with any known loading arrangements for groups of circuits, e.g., circuit not fully loaded at the same time, should be included in the assembly specification.

b. The specific current rating specified for each circuit, I_b, I_{ng}, I_{nc} or I_n should be clearly identified in the assembly specification. If not, the assembly manufacturer will assume it is I_n that is being specified.

c. If device ratings, I_n, are specified or assumed, devices with the same I_n from different manufacturers can result in differing values of I_{nc} and I_{ng} being provided for the same specification.

d. When I_n without further details, rather than I_b, is specified, the manufacturer may assume continuous loading values as given in Table 1.

8. Matching the assembly to the installation design current

The simple approach is to ensure $I_{ng} \geq I_b$. However, this can lead to a conservative arrangement of an assembly for many applications. Some circuits may be only intermittently loaded, some may deliver a low current for the majority of the time but have to be sized on the basis of a high current for a short time, some may only be delivering load at night while others are only loaded during the day, other circuits may be in duty/standby pairs, etc.

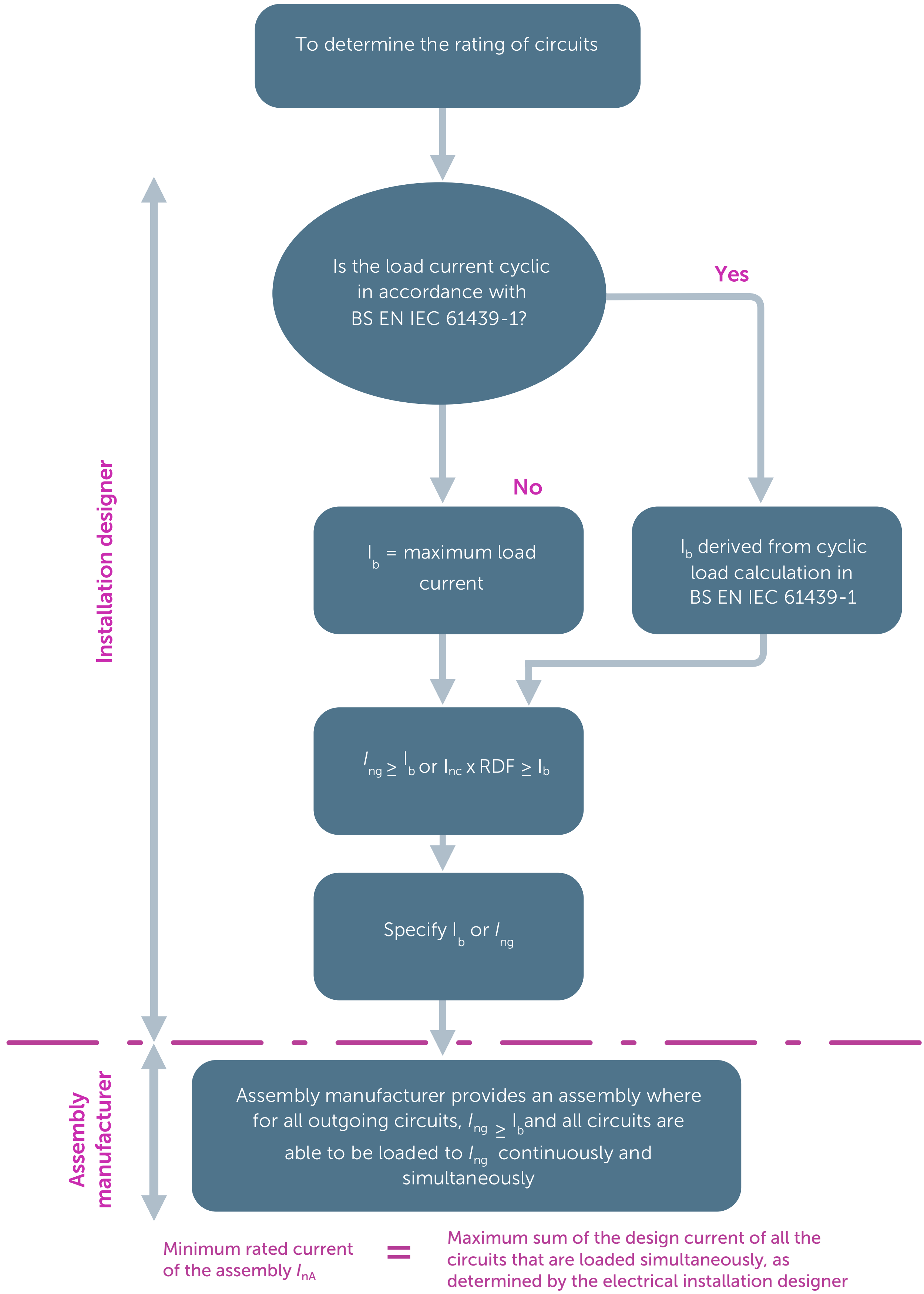
To take account of these variables requires a detailed knowledge of the applications and the capabilities of the assembly. If a heavy load current is delivered for a short period, e.g. up to 30 minutes and then a negligible load for several hours it is safe to allow the design current to be equal to the rated current of the circuit, $I_{nc} \geq I_b$. More difficult to determine is when it is safe to allow the design current to be greater that the group rated current due to the adjacent circuit(s) being lightly loaded at the same time.

What can be considered as light loading to the extent where it will allow I_b to be greater than I_{ng} is very dependent on the design of the assembly and the thermal margin, if any, of the circuit to be heavily loaded. If a manufacturer has suitable detailed test results available, they may be able to provide this data.

With so many variables, fully optimising every assembly is not practical. It requires time and a lot of detailed interaction between the installation designer and the assembly manufacturer. In some instances, a more pragmatic and/or conservative approach is expedient. The following outlines three possible approaches.

8.1. Conservative approach

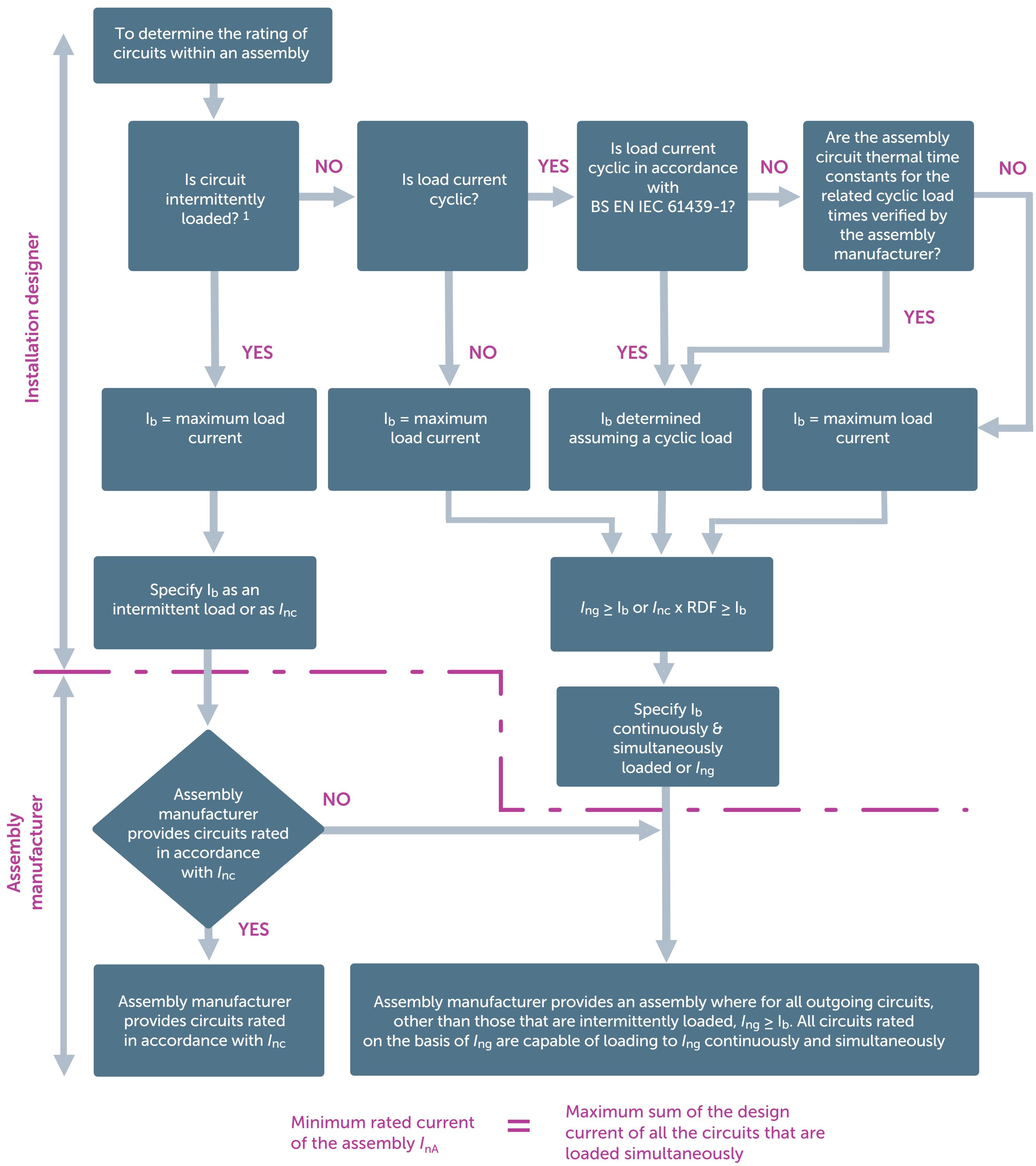
Flowchart 1 shows how to the determine and specify the rating of circuits within an assembly with minimal knowledge of the assembly and consideration of the characteristics of the loads.



Flowchart 1: Conservative approach to specifying the rating of circuits within an assembly

8.2. Pragmatic approach

Flowchart 2 below shows an approach with some of the conservatism removed.



Flowchart 2: Pragmatic approach to specifying the rating of circuits within an assembly

[1] For example, loaded for not more than 30 minutes with an ON-time less than the OFF-time or as verified by the assembly manufacturer taking into consideration their time constant data.

8.3. Optimised approach

Full optimisation of the rating of a circuit within an assembly to the requirements of the installation, requires an in-depth knowledge of the installation and of the thermal behaviour of the assembly. In addition, the arrangement of the assembly and the position of a circuits relative to all the other circuits must be known. The arrangement of the assembly and relative position of circuits is usually determined by the assembly manufacturer when engineering the assembly.

Determining which circuits should be based on I_{ng} and which can operate at the higher current I_{nc} is best approached in a tabular format with input from both the installation designer and the assembly manufacturer as shown in Table 4 below.

Installation designer		**Assembly Manufacturer** [c]				
Circuit	**I_b determined as in the pragmatic approach (A)**	**Circuit intermittently loaded (Y/N)**	**Load profile** [d]	**Adjacent circuits lightly loaded** [a] **(Y/N)**	**Circuit rating I_{ng} or I_{nc}** [b]	**Comments**
Incoming	1305	N		N	I_{ng}	
Outgoing No. 1	368	N	Continuous	N	I_{ng}	Must be in bottom compartment
Outgoing No. 2	93	Y	10 minutes on, off for a minimum of 2 hours	N	I_{nc}	
Outgoing No. 3	695	N	Reduces to 230A 6:00PM to 6:00AM	N/A	I_{nc}	Only circuit in section
Outgoing circuit No. 4	78	N	6:00PM to 6:00AM only	Y	I_{nc}	Assuming no other circuits in the same section are operating during its duty cycle
Outgoing circuit No. N	23	N	Continuous	N	I_{ng}	

a. Determining if the adjacent circuits can be considered as lightly loaded depends on the arrangement of the assembly and the thermal margin in the particular circuit being considered. The assembly manufacturer is not obliged to provide this data.

b. A circuit can operate with a load current of I_{nc} if the circuit is intermittently loaded or the adjacent circuits are lightly loaded.

c. The installation designer may determine the arrangement of the assembly and complete these columns if they have sufficient knowledge of the assembly being considered.

d. Installation designer to provide details of load profile, e.g. duty/standby for a pair of circuits, day or night loading, 100% load between 7:00AM and 10:00AM, not more than 50% load at all other times.

Minimum rated current of the assembly I_{nA} = Maximum sum of the load currents of all circuits that are loaded simultaneously

Table 4: Optimised loading of assemblies

9. Specifying the rated current of a device I_n

The rating of a device, or more specifically the protection setting, or the fuse link rating is very important in respect of protection coordination for the circuit, but if used alone to specify the rating of a circuit (and this is the assumed rating if nothing else is specified), it can lead to many different ratings for the circuit within the assembly. The manufacturer is not mandated to use the assumed loading factors given in Table 1. They can declare values of their choosing.

If a specifier wishes to specify I_n to minimise adverse effects on the protection coordination for a circuit it should be qualified with the assumed loading factor they have used when designing the installation.

10. Specifying the rating of the incoming circuit(s) of an assembly

The defining of the rating of the incoming circuit(s) of an assembly requires particular attention. BS EN IEC 61439-2 permits it to be given a group rated current, I_{ng}, exactly the same as the outgoing circuits. If only a rated current is stated, the manufacturer will assume this is I_n, and define their own I_{ng} for the incoming circuit, alternatively they can apply the assumed loading factor from Table 1 to I_n. For an assembly with 10 or more distribution circuits the assumed loading factor is 0.6.

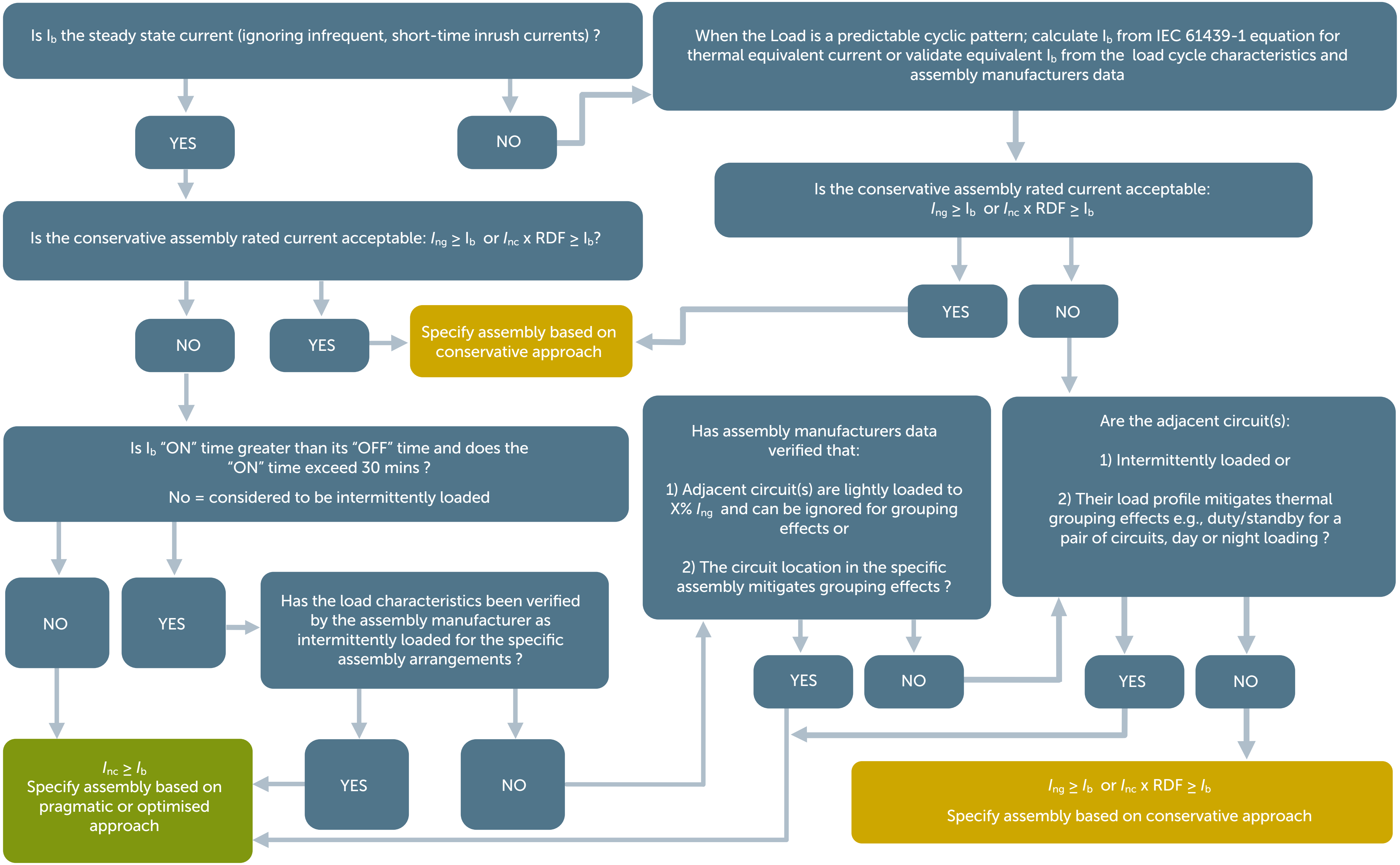
11. Summary of the methods of determining and specifying the rating of circuits within assemblies

Table 5 below provides a summary of the methods covered above.

Circuit	Specification	Assembly
Outgoing circuits: fully optimised	Define I_b for each circuit together with details of loading, e.g. continuous/intermittent, load profile with timing.	Enables the assembly manufacturer to use their knowledge of the design of the assembly and put forward the most competitive arrangement for the application.
Outgoing circuits: pragmatic rating	**Specify:** **1.** I_b for each outgoing circuit and identify any that are intermittently loaded; or, **2.** I_{ng} for each circuit deemed to be continuously loaded where I_{ng} is at least equal to I_b and I_{nc} for intermittently loaded circuits.	Considers intermittently loaded circuits and cyclic loading as defined in BS EN IEC 61439-1 and BS 7671. However, if the assembly manufacturer has not determined I_{nc}, over-rated circuits rated in accordance with I_{ng} must be provided for intermittently loaded circuits.
Outgoing circuits: conservative rating	**Specify:** **1.** I_b for each outgoing circuit; or **2.** I_{ng} for each circuit where I_{ng} is at least equal to I_b; or, **3.** I_n together with an assumed loading factor.	Quick approach that leads to a margin in the assembly rating in most applications.
Incoming circuits	**Specify:** **1.** I_b or **2.**. I_{ng} or **3.** I_n with an assumed loading factor.	Essential to be clear on the rating of incoming circuit(s) if misunderstandings are to be avoided.

Table 5: Summary of methods of determining and specifying the rating of circuits within an assembly.

Also see flowchart 3 below.



Flowchart 3: Summary of considerations for each incoming and outgoing circuit when specifying assemblies

12. Changes and additions

If additional circuits or changes to circuits are required to the assembly that were not taken into account at the initial design stage, there will be a need for re-evaluation of the thermal performance of the section considering the proposed new arrangement.

beama

Rotherwick House
3 Thomas More Street
London E1W 1YZ

www.beama.org.uk