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GAMBICA TECHNICAL GUIDE: Current Rating of Low Voltage Electrical Switchgear Assemblies.

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What's it all about?

'What you see is what you get' is a principle that most people could empathise with and can happily work around. However, even such a seemingly unequivocal statement is not always as straightforward as it would appear at first glance when used in the context of Low Voltage Switchgear.

This article will address the issue of temperature rise of equipment both at component level and when incorporated in a switchgear assembly and how the current rating of an assembly including installed components is derived in accordance with the relevant Standards.

Where do we start?

The BS EN 60947 series of standards establish the basic performance levels of Low Voltage Switchgear and Controlgear devices, setting minimum requirements for performance of devices under specific operating and other predictable or extraordinary operating conditions such as short circuit.

Take, for example, a moulded case circuit-breaker[1]; BS EN 60947-2[2] is specifically directed to the performance of circuit-breakers when read in conjunction with the General Rules document, BS EN 60947-1[3]. Together, these two standards inform the designer of the device exactly what minimum performance levels the device must attain to be able to be described as being compliant with the standards, and how to verify that they have been met. These include, amongst others:

- Short circuit capacity
- Continuous current rating
- Mechanical operation
- IP rating
- Dielectric performance
- Switching duty

Device Current Ratings

To establish a device current rating a specific test, 'Verification of temperature rise limits'[3] is performed. This requires a current source to be connected to the device under test, using specific sizes and lengths of conductor depending on the test current, at both input and output terminations. The test is conducted at a controlled and recorded ambient temperature in a test facility that is effectively draught free and with other parameters such as altitude, humidity and so on being both controlled and recorded. The sample is bolted to a supporting

BS EN 60947-1 defines, amongst others, the following characteristic current values, some of which are required to be marked on the device.

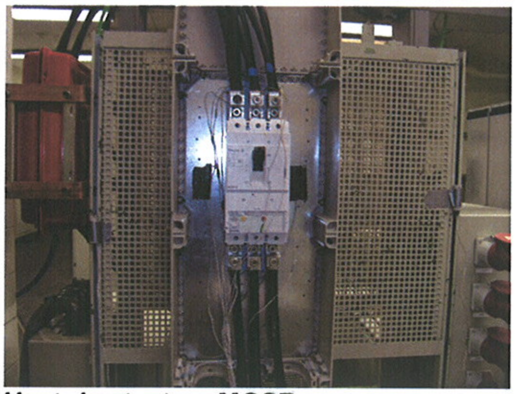
I_{th}	Conventional free air thermal current
I_{the}	Conventional enclosed thermal current
I_n	Rated current
I_e	Rated operational current
I_u	Rated uninterrupted current

The key characteristic that is commonly used to describe the capability of the device is I_e (Rated operational current), which takes into account the operational voltage, frequency, utilization category and type of protective enclosure (if applicable). For devices intended to be enclosed, either I_{th} or I_{the} should be established through test and the enclosure size used declared. The enclosure in this case is for enclosing the single device. Given the multiplicity of enclosure systems freely available, for simplicity, it is common for manufacturers to declare only I_e and offer some de-rating indication for elevated ambient temperatures. Note this does not infer any claim for capability when installed in a switchgear assembly, especially where the device in the assembly is only one of many.

BS EN 60947-2, clause 4.3.2.3 is very specific about the applicable test:

"For circuit-breakers, the rated current (I_n) is the rated uninterrupted current (I_u) (see 4.3.2.4 of Part 1) and is equal to the conventional free-air thermal current (I_{th})."

frame in open air and the test current is applied (see picture).


Heat rise test on MCCB

Thermocouples are fixed to the device at various critical points such as on the operating handle, the cable termination points, on the device surface etc. in order to record the temperature rise because of the current flow. Depending on the device characteristic to be established, (I_n, I_e, I_u etc.) the test is run for a time to allow thermal equilibrium to be reached (a change of temperature of less than 1 Kelvin[5] per hour is accepted as stable) or for a maximum period of time as dictated by the duty required, 8 hours for eight hour duty for example, whichever is the shorter.

The current passing through the natural impedance inherent in the device contacts, conductors, etc. creates heat in accordance with the well-known relationship $W = I^2R$. (Where W = Watts lost in proportion to the square of current (I) acting through Resistance (R) of the device).

It can be seen that as current rises, the amount of heat lost through the device increases according to the square of the current so that the heat generated by a current of 100 A is 100 times greater than the heat generated by a current of 10 A. The Watts lost as heat throughout the device under test is typically not evenly distributed and the device inevitably develops hot spots with the highest temperatures usually recorded at (relatively) high resistance points such as the main internal contacts and at the cable terminations. The centre conductor (L2) also tends to become hotter than the outside conductors L1 and L3 due to various mutual effects.

The thermocouples are connected to a recording device (chart recorder or PC logger for example), which allows a view of the rate of change of temperature and to see when, and at what temperatures, stability is attained.

BS EN 60947 lays down maximum values for temperature rise at various points on the device and, for maximum efficiency. The challenge for the device design engineer is to balance three variables:

a) The temperature rise at the critical points must remain within the limits set by the standard, whilst
b) The device passes the current required and
c) With the minimum use of expensive materials

Should, for example, any of the temperature limits set by the standard be exceeded during the test, the device designer has two main options:

(i) To reduce the test current until the temperature limits are NOT exceeded (effectively reducing the rating of the device) or
(ii) Redesign the device to more effectively deal with the heat generated by the test current – a potentially expensive exercise.

Current Rating of Switchgear Assemblies

When the device is used in a switchboard, another level of design and test criteria assumes relevance.

A new series of standards, BS EN 61439 Low-voltage switchgear and controlgear assemblies, comprising a general rules document (BS EN 61439-1) and associated product specific parts, such as BS EN 61439-2 Low-voltage switchgear and controlgear assemblies – Part 2: Power switchgear and controlgear assemblies (PSC), are the standards that define performance of switchgear assemblies and similar constructions in a similar manner to the way that the provisions of BS EN 60947-2 apply to circuit-breakers.

BS EN 61439-1 defines rated current (In) as:

'value of current, declared by the ASSEMBLY Manufacturer taking into consideration the ratings of the components, their disposition and application, which can be carried without the temperature-rise of various parts of the assembly exceeding specified limits under specified conditions '.

BS EN 61439-2 offers the switchboard manufacturer alternative routes to declaring a rated current for a switchboard to satisfy this requirement, one of which is validation via a testing programme. Other options include a process of calculation based on known device performance parameters and including large safety margins, typically of the order of 20%.

Using the testing route, the manufacturer of the switchboard will typically assemble a test panel and subject it to a very similar temperature rise test as for the individual devices under BS EN 60947, circuit by circuit. The conditions under which the validation tests are performed are very specific and the performance criteria defined precisely. The board must be assembled as if it were in service, any devices fitted declared as part of the test report.

Typically, a switchboard would have a main incoming circuit-breaker or other protective device connected to the main busbar system, which would, in turn, be connected, perhaps through a distribution busbar system, to smaller devices configured as outgoing feeders.

The busbars themselves may have a declared current rating based solely on the current that can be passed through the conductors. However, such a declared rating (in all likelihood also a rating established by a 'free air' test) would be worthless if aspects of the enclosure system in which it is installed such as orientation, and, for example, the main incoming device which connects to it, are not factored into the equation.

The incoming circuit-breaker, with its nominal BS EN 60947-2 declared current rating, is now installed in conditions far removed from those 'free air' conditions used to establish that nominal current rating. The installation conditions must be taken into account to be able to be confident that the device will operate at the current level required.

The temperature rise test defined in BS EN 61439-2[6] sets maximum temperature rise values (K) for specific points within the system. The locations and maximum temperatures relate to areas of potential danger to operators of the equipment or to the limiting values of materials used. Typically, the operating handles (as per BS EN 60947), exposed metalwork surfaces (enclosure doors etc), cable termination points, conductor insulators and so on have temperature rise limits established in the standard[7].

What's the bottom line and what can be done about it?

It is obvious that testing a circuit-breaker inside an enclosure to satisfy BS EN 61439-2 is somewhat different to the equivalent 'free air' test found in BS EN 60947-2. In the latter, ventilation for example, afforded by the 'free air' mounting position, is generally not available to anything like the same degree within a switchboard. Consequently, the performance of the enclosed circuit-breaker will almost certainly be affected when installed as part of a switchgear assembly. In this case, of course, what you now see on the rating label of the device is NOT necessarily what you would reasonably expect to get from your switchgear assembly. So, for example, a 3200 A nominal rated circuit-breaker would not necessarily be expected to pass 3200 A when enclosed in a switchboard where the heat rise characteristics are very different to those in free air. The current that can be passed by the circuit-breaker at the limiting temperatures can be as low as 2800 A, a reduction of 12.5% of the nominal free air current rating.

Constructional measures may be employed to diminish the potential effects of reduced ventilation inside the switchgear assembly. An example of such measures would be to extend the connection lugs of a circuit-breaker using large copper connections and re-locating the connection point for insulated cables into a separate compartment physically removed from the circuit-breaker itself. The temperature rise at the end of these extension coppers is now the limiting criterion (provided all other critical temperatures remain within limits), rather than that measured directly at the circuit-breaker which would have been employed to establish free-air rating. Such measures of course, must be verified by test. Other exceptional measures may also be taken to address this reduction in equipment performance: larger cross sections of conductors, heat sinks, forced ventilation of the interior of the switchboard etc., may be used to yield higher operating currents at the limiting temperatures but, inevitably, at increased equipment cost.

To clarify: the device rating label is a declaration of capability to BS EN 60947 series of standards. The same device installed in an assembly is rated as part of the complete assembly in accordance with BS EN 61439-2, which, because of the different conditions of test, can well indicate a lower current rating. The upshot is that the switchgear designer can be forced to specify a device one (or more) ratings/frame sizes larger than that nominally indicated by a device manufacturer's catalogue which quote, of course, the 'free air' BS EN 60947 ratings. In the case of the example above, a 4000 A circuit-breaker can be needed to achieve a 3200 A current rating of the switchboard. Alternatively, other extraordinary means may be employed as previously described.

Electronic Devices

This scenario is repeated across the whole range of current-rated devices when they are installed in switchgear assemblies, for exactly the same reasons. Electronic devices and control products with power switching capabilities, such as soft starters and variable speed drives are increasingly being used to control high power loads – motors, furnaces etc. Significant amounts of heat can be generated by the passage of currents through such devices. Thyristors, for example, generate about 1 watt of heat per ampere of current passing through them, so a soft starter with thyristors in each phase feeding a motor load drawing 330 A generates about 1 kilowatt of heat - continuously. Variable-speed drives have even greater heat dissipation per amp of current in each phase. Commonly, such devices are fitted with fan assisted heat sinks which serve to pump excess heat into the surrounding environment – fine when installed in free air but adding to the mounting thermal load inside a switchboard when enclosed.

The thermal performance characteristics for these products are defined in BS EN 60947-4-2 for soft starters and BS EN 60947-4-3 for semiconductor load controllers. The BS EN 61800 series of standards prescribes the requirements for variable speed drives. Broadly speaking, their approach to thermal performance testing is similar to that for similar electromechanical products – the tests are carried out in free air with a similar consequent need to de-rate when installed in enclosed situations.

Clearly, incorporating electronics can seriously affect the performance of any circuit-breakers, contactors, etc, that are built into the assembly. Where electronic power and control products are used, the switching assembly designer needs to be especially vigilant and might need to consider using forced cooling systems or even lowering the IP rating of the enclosure. Consideration of the potential effects on other installed equipment such as electronic overload protection relays in starter assemblies for example or on the operation of computing equipment might also have to be made. Separation of heat-sensitive devices from major heat sources can be necessary.

Who cares where devices are installed?

Of course, the designers of the devices (circuit-breakers, soft starters etc) don't have any idea who is going to buy their products or where they are going to be installed. The plethora of design variations of switchgear assemblies makes it impossible for the device designer to be specific about what rating should be expected in an enclosure system. However, the 'ideal' conditions under which their devices are tested are merely a starting point for users of the equipment to make proper engineering decisions, supported by appropriate calculations and, ultimately, testing, to create safe and effective switchgear assemblies.

Reputable manufacturers of switchgear, being fully aware of the limitations of the declared device ratings, willingly undertake the necessary testing to prove the ratings of devices *within their enclosure systems*. Notwithstanding this rigorous approach, BS EN 61439-2 offers the assembly manufacturer equally valid alternatives to testing using calculation methods based on the known operating parameters of the devices and enclosure systems. This method validates adequate and safe assembly ratings typically by building in safety margins (in the order of 20%), which will generally have the same effect of derating the installed devices when installed in an assembly, as one would expect.

Concerned purchasers of switchgear assemblies should be aware of the potential risks of installing assemblies in their premises that have not undergone relevant validation and consider very carefully the implications of doing so before placing any orders.

What happens when it all goes wrong?

Not doing the validation job properly can have serious consequences.

A switchboard operating over limiting temperatures puts the user at risk of burns, progressive insulation breakdown with subsequent risk of short circuit, increased risk of fire and increased costs of creating waste heat. The lifespan of the equipment is likely to be dramatically reduced and the opportunity costs of lost utility, subsequent to a complete breakdown, can only be judged on each application's merit.

This isn't to say that a warm switchboard is necessarily running into problems. BS EN 61439-2 sets a maximum temperature rise limit for accessible external metallic surfaces of + 30K. From an ambient start point of, say, 30 degrees C, it infers that an external temperature of 60 degrees C at maximum temperature rise is acceptable. Of course, to attain such a temperature, installed equipment may well be running considerably hotter, with other potential consequences, efficient use of the available power being only one.

Conclusion

This short overview of the single issue of the effects of Temperature Rise on device and equipment current rating has considered just a few of the applicable BS EN standards. Although the standards themselves are at pains to point out that compliance with a British Standard does not of itself confer immunity from legal obligations, it is an accepted position that compliance with the relevant standards, European Directives and other relevant legislation (Electricity at Work Regulations for example) goes a long way to protecting the diligent engineer from the unwanted consequences of accidental damage or injury (or worse) to users, or others, of the switchgear assembly he has designed or specified.

Those responsible organisations that spend an appropriate proportion of their time and other resources in validating the performance of their equipment rigorously don't do so for the exercise. It is done because they know that not to do so places them and their customers at risk and exposes them to potentially onerous legal issues if something goes wrong.

Notes:

1 *Whilst this discussion uses the example of circuit-breaker performance, similar requirements exist for all switchgear devices such as contactors or fuses.*
2 *BS EN 60947-2, Low-voltage switchgear and controlgear Part 2. Circuit-breakers*
3 *BS EN 60947-2, Low-voltage switchgear and controlgear Part 1. General Rules*
4 *See BS EN 60947-1 Sub-clause 8.3.3.3.*
5 *Kelvin is the SI unit for absolute temperature. 1K is equivalent to 1 degree Celsius rise in temperature.*
6 *See BS EN 61439-1, Clause 10.10.2*
7 *See BS EN 61439-1, Table 6*