SAFETY IMPLICATIONS OF THE INTRODUCTION OF A SPECIALLY TESTED ASSEMBLY INTO THE SOUTH AFRICAN NATIONAL STANDARD FOR LOW-VOLTAGE ASSEMBLIES

By

Mark James Bonner

UNIVERSITY OF KWAZULU-NATAL

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Supervisor: Professor N.M. Ijumba

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Dedicated to my Father for all the support he has given me throughout my life and for always believing in me.

Declaration

I, the undersigned, hereby declare the material presented in this dissertation is my own work, except where specific acknowledgement is made in the form of a reference.

MJ Bonner

Abstract

Low-voltage switchgear and controlgear assemblies with a rated short-circuit withstand strength above 10 kA, are required, by law, to conform to the South African standard, SANS 1473-1 (Low Voltage Switchgear and Controlgear Assemblies: Part 1: Type-tested, partially type-tested and specially tested assemblies with rated short-circuit withstand strength above 10kA). Standard SANS 1473-1 stipulates three categories of assemblies i.e. type-tested, partially type-tested and specially tested assemblies. The specially tested assembly is unique to the South African market, while the other two categories are stipulated in standard SANS IEC 60439-1 (Low Voltage Switchgear and Controlgear Assemblies: Part 1: Type-tested and partially type-tested assemblies), which is internationally accepted in many countries as the applicable low-voltage assembly standard.

Standard SANS 1473-1 specifies seven type-tests for certification as a type-tested assembly (TTA), but specifies, at most, three type-tests for certification as a specially tested assembly (STA).
The underlying purpose of a technical standard is to provide for the safety of people and property, with the purpose of the research being twofold:

1. To investigate if the testing requirements specified for a specially tested assembly (STA), in accordance with standard SANS 1473-1, are correctly applied, and do not pose any safety risks.
2. To investigate any safety risks that stem from the fact that four type-tests are excluded for verification as a specially tested assembly (STA), as opposed to the seven type-tests required for verification as a type-tested assembly (TTA).

The document highlights the technical inadequacies of an assembly that is certified as a STA, in accordance with standard SANS 1473-1, and the potential safety risks associated with this type of assembly classification.

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Abbreviations

SANS	South African National Standard
SABS	South African Bureau of Standards
IEC	International Electrotechnical Commission
NEMA	National Electrical Manufacturers Association
UL	Underwriters Laboratory
OHS	Occupational Health and Safety (Act)
AC	Alternating Current
DC	Direct Current
MCC	Motor Control Center
LV	Low-voltage
STA	Specially tested assembly
TTA	Type-tested assembly
PTTA	Partially type-tested assembly
IP Code	Ingress Protection (Code)

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Chapter 1: Problem Identification and Background

1.1 Introduction:

New manufacturing methods developed in industry in recent years have brought a notion of industrial dependability to light. This concept, which covers two different aspects, safety of persons and equipment, and availability of electrical power, shows when it is applied to complex processes, the critical points whose operation must be thoroughly mastered. The electrical switchgear and controlgear assembly is one of these critical points (Low Voltage switchgear and controlgear assemblies are defined as a combination of one or more low-voltage switching devices together with the associated control, measuring, signaling, protective, regulating equipment etc., completely assembled under the responsibility of the manufacturer with all the internal electrical and mechanical interconnections and structural parts [1]). Electrical switchgear is increasingly technical and requires a certain number of basic studies in order to master, in the design phase, the operating conditions of its components in a specific environment.

Many South African switchgear and controlgear assembly manufacturers have historically been manufacturing low-voltage assemblies more by 'rule-of thumb' than by a technically calculated and tested manner. As unsafe conditions became more apparent, the South African Bureau of Standards (now known as Standards South Africa) decided to adopt the standard SANS IEC 60439-1 (Low Voltage Switchgear and Controlgear Assemblies: Part 1: Type-tested and partially type-tested assemblies [1]) in 2001 as the official standard to which all low-voltage assemblies with a short-circuit withstand greater than 10kA will conform to. The South African Bureau of Standards (SABS) is affiliated to the International Electrotechnical Commission

(IEC). SABS official policy is to adopt the IEC specifications either unchanged, or where deemed necessary, to adapt them to suite South African conditions by the introduction of a front-end standard detailing any deviations from the original IEC standard. The latest South African National Standard, SANS 1473-1:2003 (Low Voltage Switchgear and Controlgear Assemblies: Part 1: Type-tested, partially type-tested and specially tested assemblies with rated short-circuit withstand strength above 10kA) [2] has been included as a front-end specification to standard IEC 60439-1, which is renumbered as SANS IEC 60439-1 [3]. With this standard comes the introduction of the Specially Tested Assembly (STA) in addition to the Type-tested and Partially type-tested assemblies specified in standard IEC 60439-1[1].

1.2 Problem Identification

A specially tested assembly (STA), tested in accordance with standard SANS 1473-1[2], will at most, only require three of the seven type-tests specified in standard IEC 60439-1[1]. Standards are written to ensure conformity, integration with other products, and above all, safety of persons and equipment. The exclusion of a number of the type-tests specified in standard IEC 60439-1[1], deserves closer inspection to determine if a specially tested assembly fulfills the safety and performance requirements of the IEC 60439-1[1] standard, particularly since it has been included for use in power systems with short-circuits of magnitude greater than 10kA.

1.3 Main objectives of the dissertation

The main objective of the dissertation is to establish if a Specially Tested Assembly conforms to the safety and performance requirements set out by standard IEC 60439-1[1], and does not pose any danger to personnel.

The scope of the study shall be limited to low-voltage assemblies with short-circuit withstand greater than 10kA, and will thus focus on local standard SANS 1473-1 [2] exclusively.

The study will not be related to standard SANS 1765 [4] which is applicable to low-voltage assemblies with short-circuit withstand up to and including 10kA.

1.4 Specific objectives of the dissertation

The specific objectives of the dissertation are:

- To technically access if the type-tests stipulated in standard SANS 1473-1 [2] for a Specially Tested Assembly (verifying temperature rise limits, dielectric properties and short-circuit withstand) fulfill the requirements set out by IEC 60439-1[1].
- To technically access if the type-tests excluded from standard SANS 1473-1 [2] for a Specially Tested Assembly (verifying protective circuit effectiveness, clearances and creepage distances, mechanical operation and degree of protection) have any safety related impact relating to the requirements set out by standard IEC 60439-1[1].
- To propose remedial measures from the conclusions drawn from the technical assessments of the STA type-tests.

Chapter 2: Literature Review

2.1 Standards

One of the main aims and benefits of standardization is maintaining and improving the quality of life of society, by paying attention to such matters as safety, health and the environment, and by providing a basis for legislation needed for the protection of persons [5]. A precise knowledge of standards is the fundamental premise for a correct approach to the problems of the electrical plants, which shall be designed in order to guarantee that an acceptable safety level is achieved and maintained. The standards can be divided into two separate types:

Juridical Standards [6]

These are all the standards from which derive rules of behavior for the juridicial persons who are under the sovereignty of the State.

Technical Standards [6]

These standards are the whole of the prescriptions on the basis of which machines, apparatus, materials and the installations should be designed, manufactured and tested so that the efficiency, functionality and safety are ensured. The technical standards, published by national and international bodies, are circumstantially drawn up and can have the force of law when it is attributed by a legislative measure.

Standard SANS 10142-1 [7] ,also know as the 'wiring code', is a prime example of a South African standard that has the force of law through the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) [8].

Standard SANS 10142-1 [7] is regarded as a compulsory safety specification [5] and has been declared to be compulsory by the Minister of Labour in terms of the Standards Act, 1993 (Act 29 of 1993) [9].

One of the most recognized standards in the world that influences the design of low-voltage switchgear and controlgear are those issued by the International Electrotechnical Commission (IEC), and they have had a positive and profound influence over the design, manufacture and qualification of low voltage electrical equipment used in the distribution and control of electrical power. The underlying purpose of the standards is to provide for the safety of persons, animals and property. A major element of the IEC 60439-1[1] standard is to ensure that switchgear and controlgear assemblies are safe in operation and designed, manufactured and tested in such a way as to guard against hazards which may arise from the equipment itself or by external influences on it. Such hazards include contact with live parts, high temperatures, overloading, short-circuit, mechanical failure or environmental influences.

The work of this body has been adopted by code making agencies throughout the world.

2.2 Applicable standards for low-voltage assemblies:

Low voltage control panels, motor control centres and distribution boards are collectively known as 'assemblies' in the relevant standards.

Standard SANS 1765 [4] is the applicable South African standard for low-voltage switchgear and controlgear assemblies with a rated short circuit withstand strength below or equal to 10 kA.

Standard SANS 1473-1 [2] is the applicable South African standard for low-voltage switchgear and controlgear assemblies with a rated short circuit withstand strength above 10 kA. Standard SANS 1473-1 is a front-end specification that can only be read in conjunction with Standard SANS 60439-1 [1] (IEC 60439-1).

Both Standards SANS 1765 [4] and SANS 1473-1 [2] are referenced in Standard SANS 10142-1 [7] and therefore are compulsory safety standards according to the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) [8].

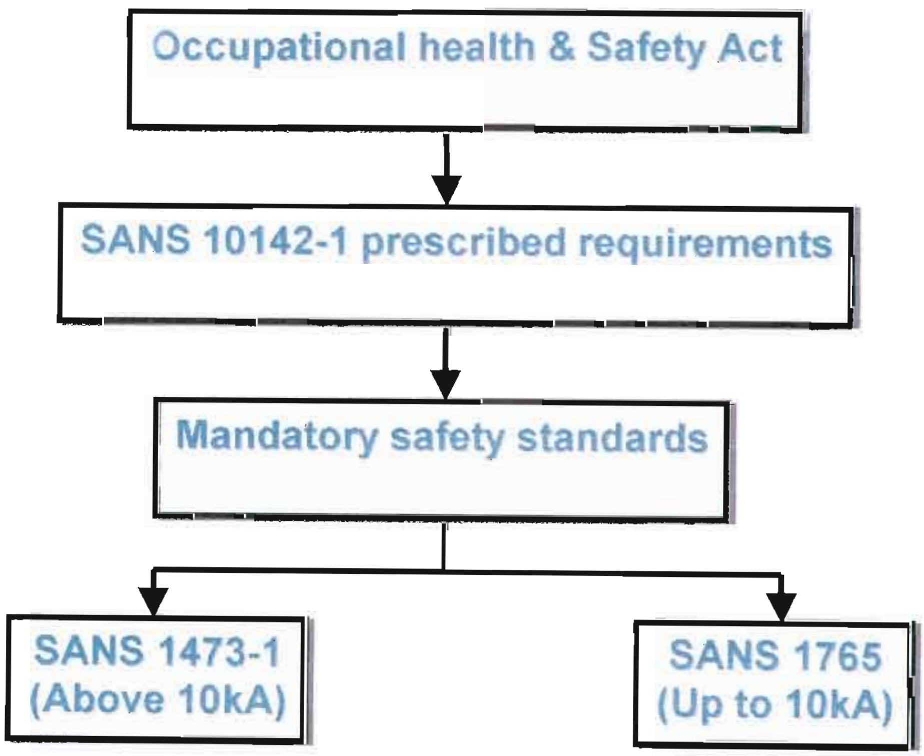


Figure 1: Applicable standards for low voltage assemblies

2.3 Tests specified in standard IEC 60439-1

Electrical safety tests can be divided into two areas: those tests carried out during the approvals process known as type-tests, and those carried out at the end of the assembly phase, known as routine tests.

2.3.1 Type-tests

'Type tests are intended to verify compliance with the requirements laid down in this (IEC 60439-1 [1]) standard for a given type of assembly. Type tests are carried out on a sample of such an assembly or such parts of assemblies manufactured to the same or similar design. They shall be carried out on the initiative of the manufacturer' [1] Type-tests, therefore, allow for actual verification of designs through a series of tests, and do not rely on subjective engineering assessments or calculations. Table A1 shows the various type-tests specified for certification as a TTA, PTTA or a STA in accordance with standards IEC 60439-1[1] and SANS 1473-1 [2].

2.3.2 Routine tests

These tests have a totally different function to Type-tests:

'Routine tests are intended to detect faults in materials and workmanship. They are carried out on every assembly, after its assembly, or on each transport unit. Another routine test at the place of installation is not required.' [1]

Routine tests include:

- Inspection of the assembly including inspection of wiring and, if necessary, electrical operation test.
- Dielectric test.
- Checking of protective measures (against direct and indirect contact) and of the electrical continuity of the protective circuit.

See standard IEC 60439-1 [1] sections 8.1.2 and 8.3 for further information.

2.4 Categories of assemblies specified in standard IEC 60439-1 and SANS 1473-1

Standard IEC 60439-1[1] distinguishes between two categories of switchgear assemblies:

- TTA (Type-tested assemblies)
- PTTA (Partially type-tested assemblies)

There are no other classifications of assemblies in standard IEC 60439-1[1] and the standard does not provide for assemblies that has fulfilled only some of requirements (type tests).

Standard SANS 1473-1 [2] distinguishes between three categories of switchgear assemblies:

- TTA (Type-tested assemblies)
- PTTA (Partially Type-tested assemblies)
- STA (Specially tested assemblies)

The specially tested assembly (STA) is a unique category of assembly only found in the relevant South African standard i.e. SANS 1473-1 [2], and nowhere else in the world. It is common for some countries to amend the IEC standards to suite specific requirements, but perhaps not as significant or extensive as SANS 1473-1.

It must however be noted that SANS 1473-1 [2] also deviates from the requirements specified in IEC 60439-1 [1] for Type-tested and Partially Type-tested assemblies in certain instances, but these deviations are outside the scope of this study (A number of changes in the design, construction and test specification requirements of standard IEC 60439-1 are specified in standard SANS 1473-1 e.g. a minimum fault level for TTA, PTTA and STA of 10kA is specified only in the South African standard).

2.4.1 Type-tested assemblies (TTA)

A Type-tested assembly (TTA) is defined as 'A low-voltage switchgear and controlgear assembly conforming to an established type or system without deviations likely to significantly influence the performance, from the typical assembly verified to be in accordance with this standard (IEC 60439-1)' [1]

The design verification of the assemblies shall be via stringent testing and does not rely on subjective assessments, calculations and engineering judgments. This means that the generic design of the assembly, including all the various elements used in its construction, have complied with the type-tests specified in IEC 60439-1[1].

2.4.2 Partially Type-tested assemblies (PTTA)

A Partially Type-tested assembly (PTTA) is defined as 'A low-voltage switchgear and controlgear assembly, containing both type-tested and non-type-tested arrangements, provided the latter are derived (e.g. by calculation) from type-tested arrangements which have complied with the relevant tests' [1]

Deviations from the tested configuration are only permitted provided they can be verified by calculation, extrapolation, design rules or equivalent methods. The methods must be thoroughly understood and documented and, if applicable, sufficient safety margins be incorporated into the design.

2.4.3 Specially tested assemblies (STA)

A Specially tested assembly (STA) is defined as 'Unpopulated assembly that has been tested for the verification of the short-circuit withstand strength, dielectric properties, and, where applicable, temperature-rise limits' [2]

The pertinent sections from the definition of an STA states that the assembly shall be 'unpopulated' and that the temperature rise tests are only required 'where applicable', warrants closer inspection as this is clearly non-compliant with standard IEC 60439-1[1].

2.5 Basic comparison between the Type-tests specified in standard IEC 60439-1 and SANS 1473-1

Standard IEC 60439-1[1] details seven type-tests (see Appendix A, Table A1) which are carried out to verify equipment designs. The type-tests may at first appear to be associated only with the constructional aspects of the assemblies, but upon closer inspection, the tests are very much safety related as will be identified in the chapters to follow. Standard IEC 60439-1[1] is the basic standard for assemblies and only considers those assemblies which can be classified as TTA or PTTA. There are no other classifications. The standard does not cater for assemblies built to less stringent design and test requirements, or which satisfy only some requirements of the standard. Table A1 lists the various type-tests required to be performed on TTA, PTTA and STA.

It is clearly evident that the type-tests specified for a STA are not in compliance with those specified in Standard IEC 60439-1[1]. The following chapters will investigate if the type-tests specified for a STA are correctly applied, and whether the exclusion of four type-tests (according to IEC 60439-1[1], assembly classification TTA) provide a concern for the safety and performance requirements of the assembly.

Chapter 3: Technical study of the type-tests included in standards IEC 60439-1 and SANS 1473-1

3.1 Introduction

The applicable standards establish the criteria for achieving the qualified status of the product being tested. This is done by establishing safe guidelines within which the product must operate. The guidelines are fundamentally physical limits determined by the operational voltage, rated continuous current and short-circuit current. The concerns for voltage are with regards to the suitability of the insulation material and its capability to withstand voltage gradients and potential differences. The concern for continuous current is with regards to the maximum operating temperature of the assembly switchgear components, while the switchgear assembly must be able to withstand the effects of the prospective short-circuit current. The aim of this chapter is to analyze the suitability of the temperature rise, short-circuit and dielectric tests included for qualification as a specially tested assembly (STA), specified in standard SANS 1473-1 [2].

3.2 Temperature rise test

The purpose of the temperature rise type-test is to provide a method of verification of the operating current of an assembly. The design of low-voltage switchgear and controlgear assemblies has progressed from the basic 'open-type' assembly of a few decades ago to the modern compact units in use today. As the packing density, rated current, form of internal separation and degree of protection of the assembly increases, the verification of the temperature-rise within the enclosures becomes an issue of ever increasing importance. Excessive temperatures within assemblies are potentially damaging to electrical and electronic devices, and can result in premature ageing of components and insulation which can ultimately lead to catastrophic failure. Temperature rise verification by calculation alone is an involved and complex subject since components operate and thermally interact with one another at different temperatures for a given load. Standard IEC 60439-1[1], therefore, specifies that actual temperature rise tests (type-tests) are undertaken on the assemblies, thus eliminating any possible errors that can result from poor engineering judgments or incorrect calculations.

3.2.1 Busbar temperature rise phenomenon:

The busbars are the major current carrying component of an assembly. Before an assembly is operated, the busbars are at the temperature of the surrounding air. This is known as ambient temperature. Temperature rises in the assembly busbars during operation as current flow in a conductor always generates a power loss in the form of heat. As current increases, the conductor must be sized appropriately in order to compensate for higher power losses. The methods of heat loss of a busbar system are by convection, radiation or conduction. Since the busbars are predominantly mounted on insulators of high thermal resistance, heat loss by conduction is a very small portion of the total heat loss of the busbar system. Most of the heat loss from the busbar system is, therefore, as a result of convection or radiation with the surrounding air.

The Copper Development Association handbook 'Copper for Busbars' [10] provides an in depth description of the aforementioned methods of heat loss.

The current carrying capacity of a busbar is determined by the maximum temperature at which the busbar is allowed to operate. The upper temperature limits have been chosen because at higher maximum operating temperatures the rate of surface oxidation in air of conductor materials increases rapidly and may give rise in the long term to excessive local heating at joints and contacts. The busbar must also be designed to have sufficient capacity to carry the rated current without inducing a temperature rise in the bars that may damage the supporting insulators. The factors that can have a direct influence on the current carrying capacity of a busbar are listed below, and a brief description of each is included for clarity and completeness.

3.2.1.1 Busbar Cross-section:

The smaller the cross sectional area of a busbar, the greater the resistance for any given length, all other factors being equal. A busbar with greater resistance will dissipate a greater amount of heat energy for any given amount of current, the power loss being essentially equal to I^2R.

3.2.1.2 Busbar Material:

Busbars are manufactured predominantly from copper or aluminum due to their high conductivity and mechanical strength. Copper is the most common material used for low voltage applications due to its high conductivity and physical strength.

3.2.1.3 Number of laminations used (parallel busbars):

Multiple busses also affect the current carrying capacity in a nonlinear relationship. The total current carrying capacity decreases with an increasing number of laminations and is not simply calculated as the current carrying capacity of a single bar, multiplied by the number of bars used. This is due to the restricted heat flow between the bars as opposed to a single bar with unrestricted heat flow. Table 2 below gives the d.c. ratings for a different numbers of laminated bars (6.3 mm thick with 6.3 mm spacings between bars) [10]. All bars are arranged on edge with spacing equal to the bar thickness, installed in free air and painted black for maximum emissivity.

Table 2 Multiplication factor for laminated bars, d.c. current ratings (Source: Copper Development Association)

No. of laminations	Multiplying factor
2	1.8
3	2.5
4	3.2
5	3.9
6	4.4
8	5.5
10	6.5

3.2.1.4 Skin Effect:

The Copper Development Association, Copper for Busbars, publication 22 [10] , provides the following explanation of the phenomena: "The alternating magnetic flux created by an alternating current interacts with the conductor generating a back e.m.f. which tends to reduce the current in the conductor. The centre portions of the conductor are affected by the greatest number of lines of force, the number of line linkages decreasing as the edges are approached. The e.m.f. produced in this way by self-inductance varies both in magnitude and phase through the cross-section of the conductor, being larger in the centre and smaller towards the outside. The current therefore tends to crowd into those parts of the conductor in which the opposing e.m.f. is a minimum i.e. into the skin of a circular conductor or the edges of a flat strip, producing what is known as the 'skin' effect". The skin effect tends to increase the a.c. resistance of the conductor which in turn will increases the heating (I^2R losses) of the conductor. The skin effect is frequency dependent and accentuated at higher frequencies.

3.2.1.5 Proximity Effect:

The interaction of the magnetic fields of other conductors within close proximity will cause a distortion of magnetic fields in comparison to the magnetic field of an isolated singular conductor. This distortion of the magnetic field will result in a non-linear current distribution in the conductor. The proximity effect in most cases tends to increase the a.c. resistance of the conductor which in turn will increases the heating (I^2R losses) of the conductor.

3.2.1.6 Emissivity of the busbar surface:

Emissivity is defined as: "All surfaces emit thermal radiation. However, at any given temperature and wavelength, there is a maximum amount of radiation that any surface can emit. If a surface emits this maximum amount of radiation, it is known as a blackbody. There are well known equations, such as Plancks Law that can be used to calculate the amount of radiation emitted as a function of wavelength and temperature. Most surfaces are not blackbody emitters, and emit some fraction of the amount of thermal radiation that a blackbody would. This fraction is known as emissivity. If a surface emits ½ as much radiation at a given wavelength and temperature as a blackbody, it is said to have an emissivity of 0.5. If it emits 1/10 as much as a blackbody, it has an emissivity of 0.1 and so on. Obviously, a blackbody has an emissivity of 1.0 at all temperatures and wavelengths.

The treatment of the busbar surface has a direct effect on the emissivity of the bar varying from as low as 0.1 for bright metal to as high as 0.9 for dull non-metallic painted busbars. Table 3 shows the effect of emissivity and number of busses on the current carrying capacity of busbars i.e. higher emissivity improves the current carrying capacity of busbars" [11].

Table 3: The effect of emissivity and multiple busses (laminations) on copper busbar current carrying capacity (source: www.copper.org website)

Number of 1/4x4 in. Busses*	Ampacity, Amp											
	30 °C Rise Emissivity				50 °C Rise Emissivity				65 °C Rise Emissivity			
	0.15	0.4	0.7	0.9	0.15	0.4	0.7	0.9	0.15	0.4	0.7	0.9
1	1100	1250	1400	1600	1500	1700	1900	2000	1700	1950	2200	2300
2	1900	2050	2200	2300	2550	2750	2950	3100	2950	3200	3400	3600
3	2500	2700	2850	3000	3400	3600	3850	4000	3950	4200	4500	4600
4	3100	3300	3450	3600	4200	4400	4700	4800	4900	5100	5400	5600

* 1/4 in. spacing. Ampacities of bus bar systems of other configurations must be calculated, taking into account size, spacing, number of bus bars and overall skin-effect ratio.

3.2.1.7 Maximum permissible busbar temperature:

The combination of ambient temperature and allowable temperature rise equals the maximum temperature of the busbars. There is at present no South African standard stipulating the maximum permissible busbar temperature limit. The international standards authorities and organizations also do not concur with one another on this issue for example, NEMA suggests a maximum temperature rise of 65°C above an ambient temperature of 40°C, for a maximum operating temperature of 105°C, while UL limits temperature rise of 50°C above an ambient temperature of 40°C for a maximum operating temperature of 90°C (electrical equipment bearing a UL mark must meet or exceed this standard). Operating temperatures above these limits are considered uneconomical as they are not energy efficient and are thus not recommended.

It must, however, be noted that standard IEC 60439-1 [1] is also in effect silent on the issue of busbar temperature rise, and tends to focus more on the maximum permissible temperatures of external interfaces with the busbars. It is suggested that the maximum temperature rise of the busbars be stipulated by manufacturers since this can have an impact on the equipment selection e.g. insulators that are installed in the busbar chamber. This is also important to specify when components are selected for installation within the cubicles, especially electronic equipment that are sensitive to high temperatures.

3.2.1.8 Profile selection and arrangement:

The current carrying capacity will also vary depending on the orientation, shape and spacing of the bars. Different profiles of conductors of the same cross section give different current carrying capacities under the same conditions. Figure 2 below shows the current carrying capacity percent of various busbar arrangements of the same cross-sectional area. It compares the current carrying capacity of various arrangements and shapes of busbars as a percentage of the current carrying capacity of a closely spaced busbar arrangement on the left-hand side of the figure. Any profile, other than rectangular poses difficulty in manufacturing, assembly and maintenance.

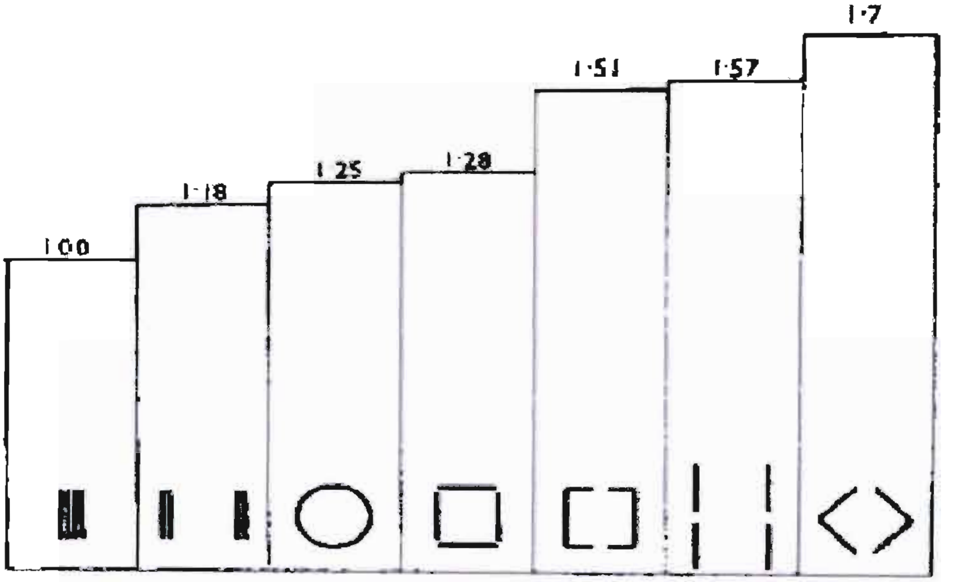


Fig 2. Comparative a.c. ratings of busbars for various conductor arrangements (Source: Copper Development Association).

3.2.1.9 Busbars installed in enclosures

Busbars are predominately installed within enclosures to provide both mechanical protection and to prevent unauthorized access to them. When busbars are installed in enclosures, the air circulation and radiation losses are restricted in comparison to those installed in free air, and as a result the busbars have to be further de-rated. Figure 2 shows how the current carrying capacity of a busbar decreases as the enclosure IP rating increases from busbars installed in free-air to those installed in busbar trunking.

3.2.2 Main and distribution busbars – Verification of the rated current by temperature rise testing:

From the above factors that may directly influence the current carrying capacity of a busbar, it follows that the design of busbars must attempt to select the appropriate profile and arrangement so as to minimize the factors that tend to decrease the current carrying capacity e.g. skin effect, while maintaining a large, unrestricted heat-emitting surface area. The current carrying capacity is further reduced when the bars are installed in enclosures, which is applicable to most modern applications, with IP ratings of IP4X not uncommon. With reference to Table A1, Standard IEC 60439-1 [1] stipulates that the temperature rise test shall normally be carried out at the values of rated current in accordance with Section 8.2.1.3, with the apparatus of the assembly installed (unless the main and auxiliary circuits have comparatively low-rated currents where heating resistors may be used to simulate the heat loss) [1]. Standard SANS 1473-1 [2] exclusively employs the use of heating resistors for the verification of the temperature rise of the busbars for a STA (assuming that the temperature rise test is actually required) regardless of the magnitude of the rated current. This can result in a practical problem of finding the correct declaration of the power loss for a STA, since the various combinations of switchgear components are not required to be tested in the assembly, as it is tested in the unpopulated state. The actual temperature rise test carried out on an assembly being verified as a STA will be of very little use since verification will be done in accordance with Table 2, IEC 60439-1[1]. This will only be the verification of the temperature rise limit of accessible external enclosures and covers of the busbar chamber of an unpopulated assembly.

It will become obvious in Section 3.1.3 of this chapter that it is necessary to test the various combinations of switchgear components that are installed in an assembly due to the interaction and varied temperature rises of components under differing installation methods.

Standard SANS 1473-1 [2] provides a restriction of predetermined current densities, for various operating currents, above which the main and / or distribution copper busbars shall be subjected to a temperature rise test. The maximum current density stipulated in standard SANS 1473-1 [2] is as follows:

- 2 A / mm^2 for a busbar rating up to 1600A [2].
- 1.6 A / mm^2 for a busbar rating above 1600A [2].

The above current density limits are applicable to copper busbars, which is the most common material currently used, and temperature rise testing is required for busbars manufactured from any other material. Should the busbar current density not exceed the above values, standard SANS 1473-1 [2] does not require temperature rise tests.

This is in direct contradiction with the requirements of standard IEC 60439-1[1] which specifies temperature rise testing for all assemblies. There is a fundamental anomaly with this requirement because IEC 60439-1[1] is the document against which temperature-rise testing is done, but no value for busbars is stipulated so how is the testing requirement to be met? The busbar current densities stipulated in standard SANS 1473-1 [2] are based on well established values, but are only applicable for certain types of installation set-ups and are essentially only guide values. Bearing this in mind, it can be reasonably assumed that certain main and distribution busbars will be correctly selected according to the current density limitations specified in Standard SANS 1473-1 [2], but will actually be operating outside the prescribed operating temperature range of the busbars. The assumption by standard SANS 1473-1 [2] that the prescribed current density limits will be suitable for all cases is fundamentally flawed as the following test data shows. Figure 2 is taken from the Copper Development Association publication "Copper for Busbars" [10], and represents the maximum permissible current allowed per cross sectional area for a maximum busbar temperature of 90°C, for busbars installed in various enclosures. Busbars installed in the majority of assemblies will be categorized somewhere between the 'Switchboard cubicle ventilated' and the 'Busbar trunking' trends shown in figure 3. Table 4, 5 and 6 show the interpolated values from figure 2, and the figures obtained for busbar current densities for busbars installed in ventilated switchboards and busbar trunking, are not in agreement with the current density limits stipulated in standard SANS 1473-1 [2]. Should the ventilated busbar be enclosed, a further de-rating of approximately 20% may be required.

Table 4: Busbar current densities for busbars installed in free air.
(Source: Copper Development Association)

Cross Section (mm^2)	Busbar Current (A) Free Air	Current Density (A / mm2) Free Air
500	1333	2.7
1000	2266	2.3
1500	2933	2.0
2000	3666	1.8

Table 5: Busbar current densities for busbars installed in a ventilated switchboard. (Source: Copper Development Association)

Cross Section (mm^2)	Busbar Current (A) Ventilated Switchboard	Current Density (A / mm2) Ventilated Switchboard
500	1000	2.0
1000	1800	1.8
1500	2400	1.6
2000	2800	1.4

Table 6: Busbar current densities for busbars installed in busbar trunking. (Source: Copper Development Association)

Cross Section (mm^2)	Busbar Current (A) Busbar Trunking	Current Density (A / mm2) Busbar Trunking
500	800	1.6
1000	1333	1.333
1500	N/A	N/A
2000	N/A	N/A

Table 7 shows results obtained at a local testing authority for various busbar configurations. The busbars of the various test specimens were installed in assemblies of differing dimensions and busbar arrangements, and the results obtained differ due to the factors mentioned previously. The results obtained unquestionably show that the current densities stipulated in standard SANS 1473-1 [2] for currents exceeding 1600A will be exceeded, resulting in busbar temperatures exceeding the 90°C limit recommended by the Copper Development Association [10].

Table 7: Temperature rise type test data for busbars installed in various enclosures for currents exceeding 1600A (Source: Mr.Bill Graham, Graham Golding and Associates)

Busbar configuration (per phase)	Test Current (A)	Busbar current density (A/mm^2)	Busbar temperature rise (K)	Ambient Temperature (°C)	Busbar surface temperature (°C)	Busbar chamber air temperature rise (K)
1x125mmx16mm	3000	1.5	76	27	103	44
2x100mmx10mm	2500	1.25	52	25	77	31
2x120mmx10mm	3000	1.25	40	30	70	-
1x100mmx16mm	2200	1.375	64	27	91	32
1x100mmx16mm	2000	1.25	69	26	95	48
1x120mmx12.5mm	2000	1.333	65	17	82	49
2x80mmx10mm	1700	1.063	82	29	111	38

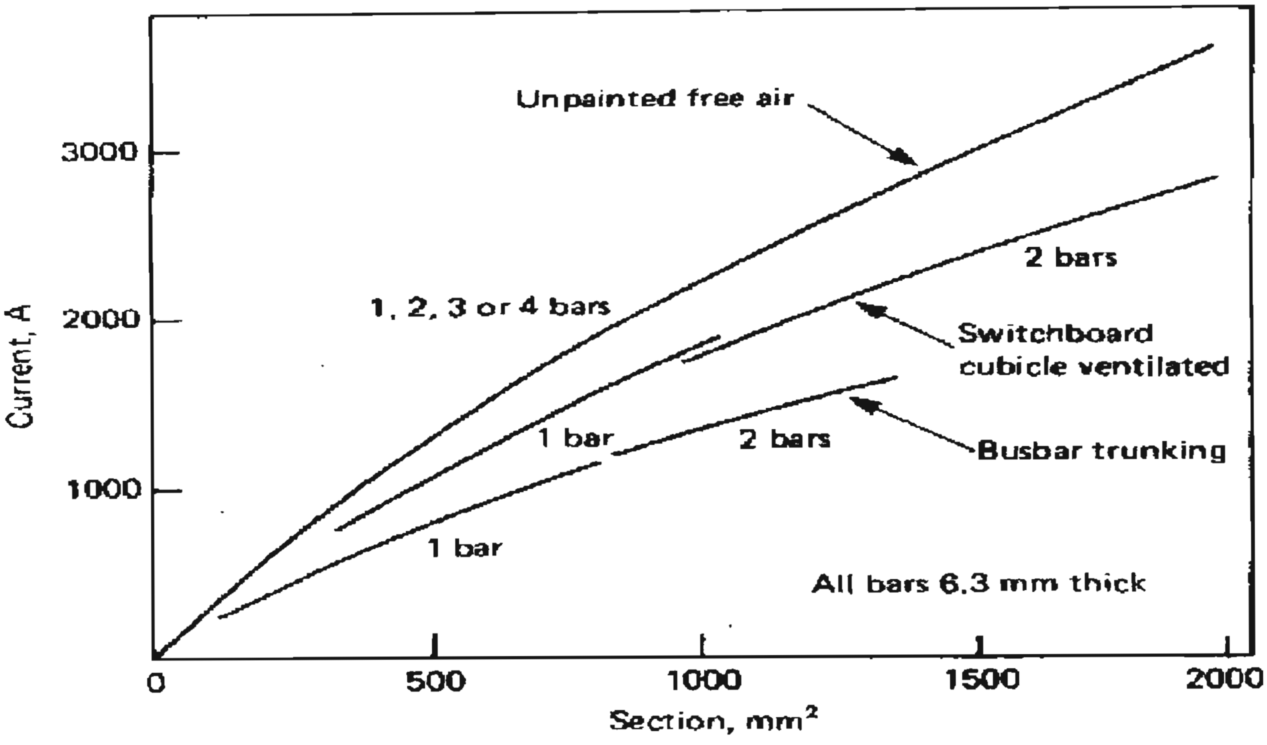


Fig 3: Comparison of approximate current ratings for busbars in different enclosures for a maximum permissible busbar temperature of 90°C
(Source: Copper Development Association)

Figures 4 and 5 are a collection of catalogued data of the current-densities for eleven different types of (TTA) switchboards. It is difficult to compare such data because of the design variations and no information is available about the applied temperature rise limits, but it can be clearly seen that there is general tendency, and they concur with Figure 2 of the Copper Development Association tests results.

Even with a good design it is evident from the data presented that the current density tends towards 1A / mm^2 for currents above 3000A.

The current densities specified in SANS 1473-1 [2] should only be used as a basic guide to estimate the likely size of busbar, and the standard should absolutely state that the final size be determined by testing. Temperature rise tests cannot be avoided if confirmation of an assembly's performance is required.

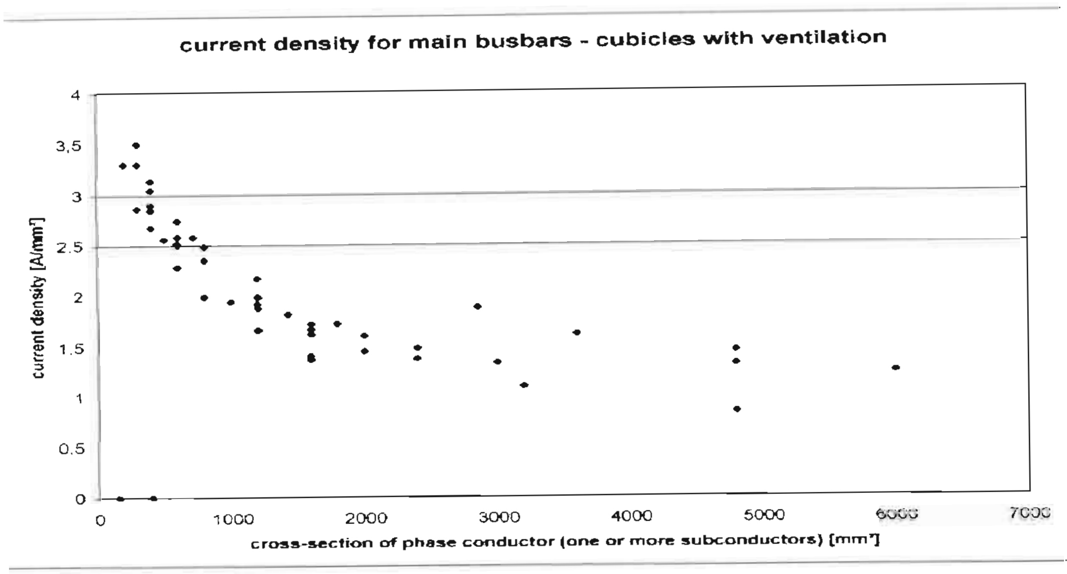


Fig 4: Current density for main busbars – cubicles with ventilation (source: Dr. Drebenstedt, Siemens AG, Germany)

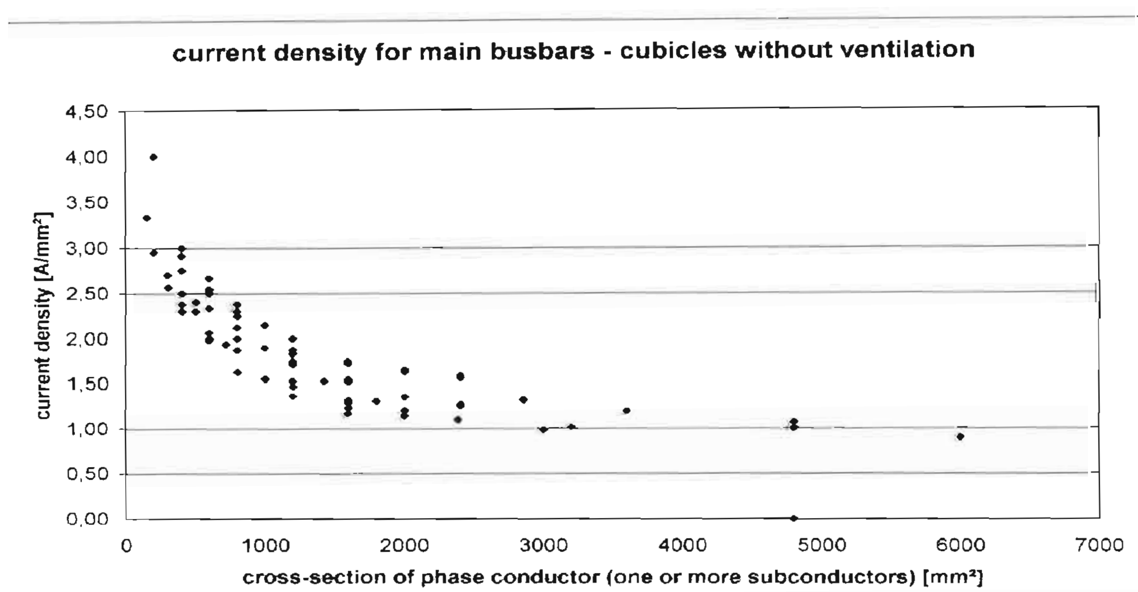


Fig 5: Current density for main busbars – cubicles without ventilation (source: Dr. Drebenstedt, Siemens AG, Germany)

3.2.3 Temperature rise of switchgear and controlgear components installed within assemblies:

Each component / device within an assembly has a specific function to serve. Accordingly, a standard is written for each type of equipment. For example, where circuit interruption is the function of the device, a standard prescribes a qualification schedule that assures that the product will interrupt current without creating an environment that will compromise safety. The relevant product standards applicable to South Africa are the IEC 60947 series for low voltage switchgear and controlgear (Series IEC 60947 is the standard to which low-voltage switchgear components are manufactured. The standard also defines the manufacturing and testing parameters for determining the performance characteristics of the various component types).

When components are installed in an assembly, the surrounding conditions differ considerably from the component type tests specified in IEC 60947-1 [12]

As a result, the specified rated currents of the components are not applicable when they are installed in a low voltage assembly, since the components are 'bench-tested' in free-air. It is of utmost importance for assembly designers to have a thorough knowledge of the operating temperatures within the assembly and apply the correct derating factors to the devices.

Figure 6 details the test conditions applicable for the testing of a device in accordance with IEC 60947-1 [12]. Heat is easily dissipated away from the device by natural convection and thermal radiation into the surrounding air, as well as by conduction through the test conductors. When these components are installed inside an assembly, the enclosure surrounding the equipment, combined with complex interactions between equipment and the surroundings, significantly impair the cooling of the devices as detailed in Figure 7.

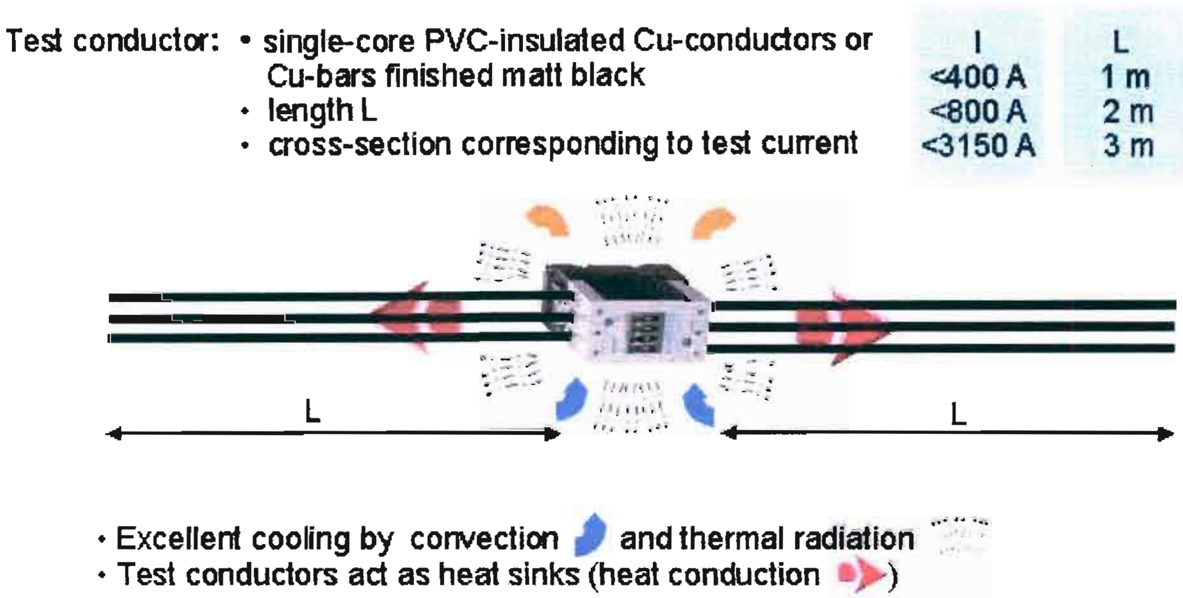


Fig. 6: Temperature rise test: Type test for devices (IEC 60947-1)
(source: Dr. Drebenstedt, Siemens AG, Germany)

It is for this very reason that standard IEC 60439-1[1] specifies a temperature rise test for the complete assembly, including all components, albeit that the components have previously been type tested to the relevant product standard.

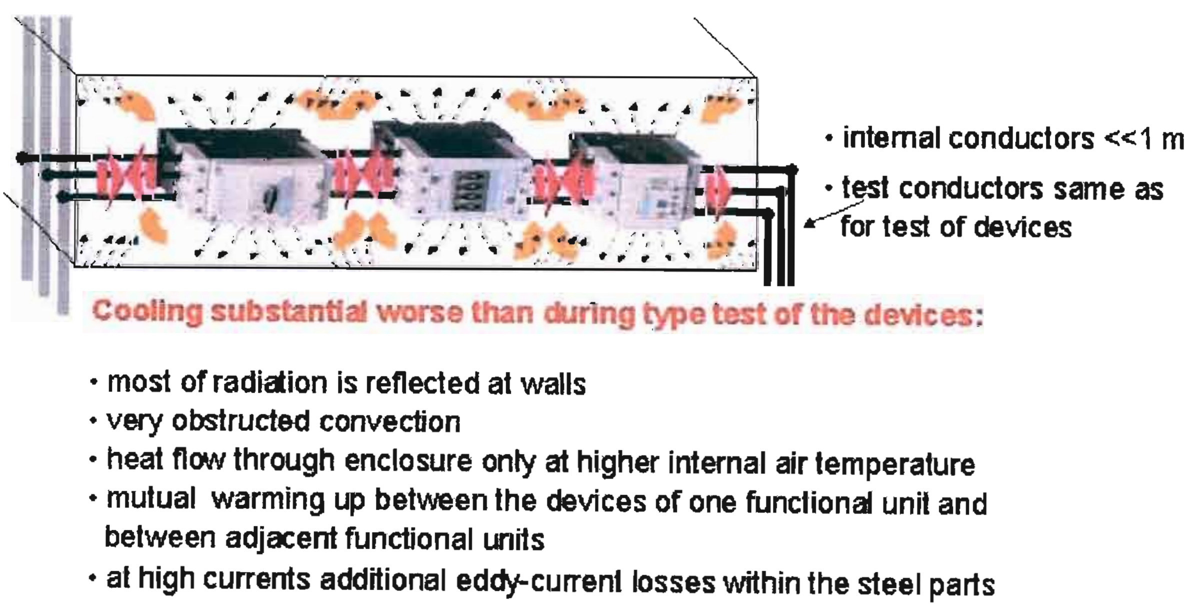
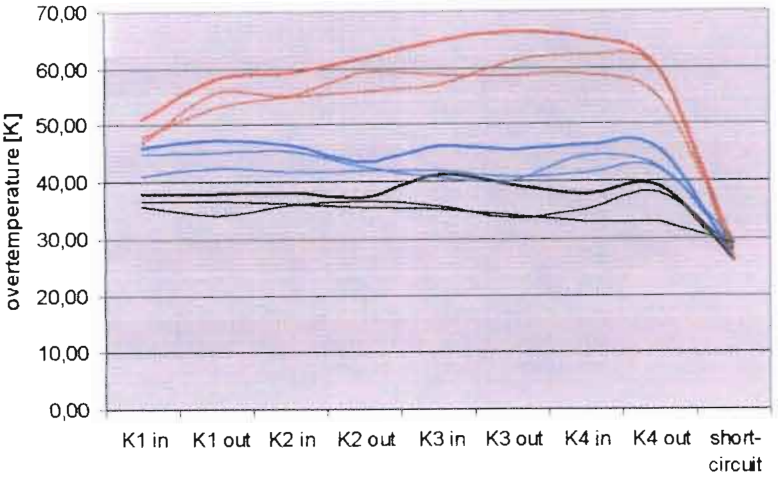


Fig. 7: Temperature rise test: Type test for assemblies (IEC 60439-1)
(source: Dr. Drebenstedt, Siemens AG, Germany)



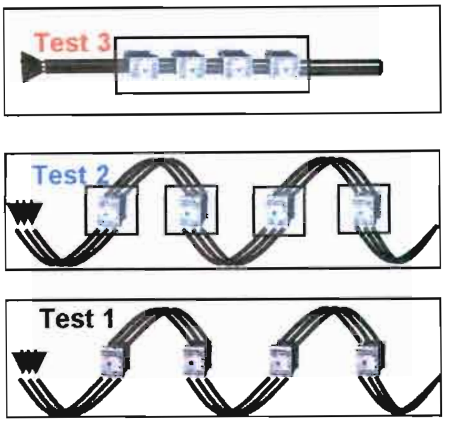


Figure 8: Temperature rise – influence on arrangement and conductor length

(source: Dr. Drebenstedt, Siemens AG, Germany)

Actual tests undertaken by Dr. Drebenstedt of Siemens AG, Germany, show the temperature rise for a number of devices installed in conditions varying for fee-air to all devices enclosed, a shown in figure 8. The tests were conducted with contactors, identified as K1 to K4, and rated 12A (AC3) / 20A (AC1) at a test current of 20A. The devices were placed on a table in a row and interconnected with 2.5mm^2 copper conductors. Temperatures of the devices were measured for three separate tests that were conducted as follows:

Test 1: Devices in free air, distance 40 cm apart, conductor length 1,2 m between devices (test results indicated by black curve of Fig 8)

Test 2: Devices in separate boxes, distance 40 cm, conductor length 1,2 m between devices (test results indicated by blue curve of Fig 8)

Test 3: Devices in one box, distance 10 cm, conductor length 5 cm between devices (test results indicated by red curve of Fig 8)

If one compares the actual temperature rise from test 1 to that of test 3, the temperature rise is vastly different due to the enclosure, which is representative of an assembly cubicle.

The interaction of the various functional units, incomers, busbars etc, all contribute to the overall temperature rise of an assembly and, therefore, cannot be viewed in isolation, but rather as a complete system. Calculation of the effective power loss should be made for the complete assembly i.e. the sum of the power losses (heat) produced by the installed equipment including busbars and power conductors. Specially Tested Assemblies, tested in accordance with standard SANS 1473-1 [2], completely ignore this important fact, as only the busbars require temperature rise verification, even though the majority of assembly failures occur on the functional units and incomers.

In the case of components installed in an assembly, it has been shown that the type tests performed for temperature rise verification by standards IEC 60439-1[1] and IEC 60947-1 [12] are not equivalent. The exclusive use of heating resistors to simulate actual running conditions of an assembly also has its shortfall (as used in the temperature rise verification for a STA, in accordance with standard SANS 1473-1 [2]). If correct functional unit temperature rise tests are not made, how will one determine the equivalent functional unit losses for a declared heating resistance value? Therefore the functional unit temperature rise tests will in any case have to be done, to overcome the practical problem of declaring the maximum power loss for the heating resistors.

3.2.4 Busbar economics and standard SANS 1473-1 current density limitations

Assembly manufacturers face two choices when busbar operating current densities exceed the prescribed values stipulated in standard SANS 1473-1 [2] i.e. perform a temperature rise type test or upgrade the size of the busbars. With these considerations in mind it can be reasonably assumed that the majority, if not all, assembly manufacturers will opt to upgrade to larger busbars as this would be more economical and less time consuming than a costly temperature rise test.

It has been shown that the current density limitations imposed by standard SANS 1473-1 [2] for higher currents are not feasible for all installations, but what about the current density limit of 2 A/mm^2 imposed for lower operating currents? If one has to bring economics into the picture, at low currents the current density limit of 2 A/mm^2 is very conservative and results in an unnecessary wastage of copper, since the actual tested permissible current densities can exceed this value significantly, as shown in figure 2 and figure 4 Consideration must however be taken of the trade-off between initial cost savings as a result of installing smaller busbars versus the installation of larger busbars which will run cooler.

3.2.5 Summary of conclusions (temperature rise test)

The following important points are highlighted with reference to the temperature rise test and it's application to the STA:

- The predetermined current densities for busbars, stipulated in standard SANS 1473-1 [2], do not hold true for all possible installation methods and operating currents, due to factors like the busbar orientation, number of busbar laminations used, enclosure de-rating factors etc. As a result, it can be reasonably assumed that certain main and distribution busbars will be correctly selected according to the current density limitations specified in Standard SANS 1473-1 [2], but will actually be operating outside the prescribed operating temperature range of the busbars.

- The current density values is standard SANS 1473-1 [2] should only be used as a rough guide to estimate the likely size of a busbar, after which a temperature rise type-test is required for actual verification of the temperature rise limits.

- The individual component type tests for temperature rise, in accordance with the IEC 60947 standard series, are not representative of the many possible combinations of components installed together in different enclosures. The declaration of power loss of a functional unit is not simply the summation of all individual component power loss values, due to the many complex interactions between the components installed in these assemblies.

- The exclusive use of heating resistors to simulate actual apparatus is incorrectly applied to all specially tested assemblies. This can result in a practical problem of finding the correct declaration of the power loss for a STA, since the various combinations of switchgear components do not require testing in the assembly, as it is tested in the unpopulated state.

3.3 Short-circuit withstand test

3.3.1 Introduction

The principle concern over high fault currents in the busbar chamber is centered around the busbar structure and supports to withstand the magnetic forces accompanying the current peaks. Withstanding these stresses is first and foremost in avoiding danger i.e. flying of broken components, arc generation and propagation outside the switchboard. These forces are a function of the square of the current (peak short-circuit current value) and the linear distance between the parallel current paths. It is this current peak that occurs generally in the first cycle of a fault that generate the highest stresses on the busbar due to the asymmetry of the short-circuit current. The closer the current paths are, the stronger the accumulative force is. This force will cause the conductors to be pulled together if the current in both paths is flowing in the same direction. The force will push conductors apart for currents flowing in opposite directions. Figure 9 shows the relationship between the prospective fault current and the force experienced on a busbar system with busbar spacing 80mm and Busbar support spacing 400mm. It can be seen that as one approaches a fault current of 50 kA, the forces experienced on the busbar system is measured in tons. Busbars are also stressed thermally under short-circuit conditions and it is therefore necessary to check that the conductors are suitably sized for the short-circuit current not only mechanically, but also thermally.

Standard IEC 60439-1[1]states that "Assemblies shall be constructed as to be capable of withstanding the thermal and dynamic stresses resulting from short-circuit currents up to the rated values". Essentially, the short-circuit tests that are carried out on the main and distribution busbars for certification as a STA are done in accordance with standard IEC 60439-1[1]. The short-circuit tests are carried out by using bolted connections at the ends of the main or secondary busbars.

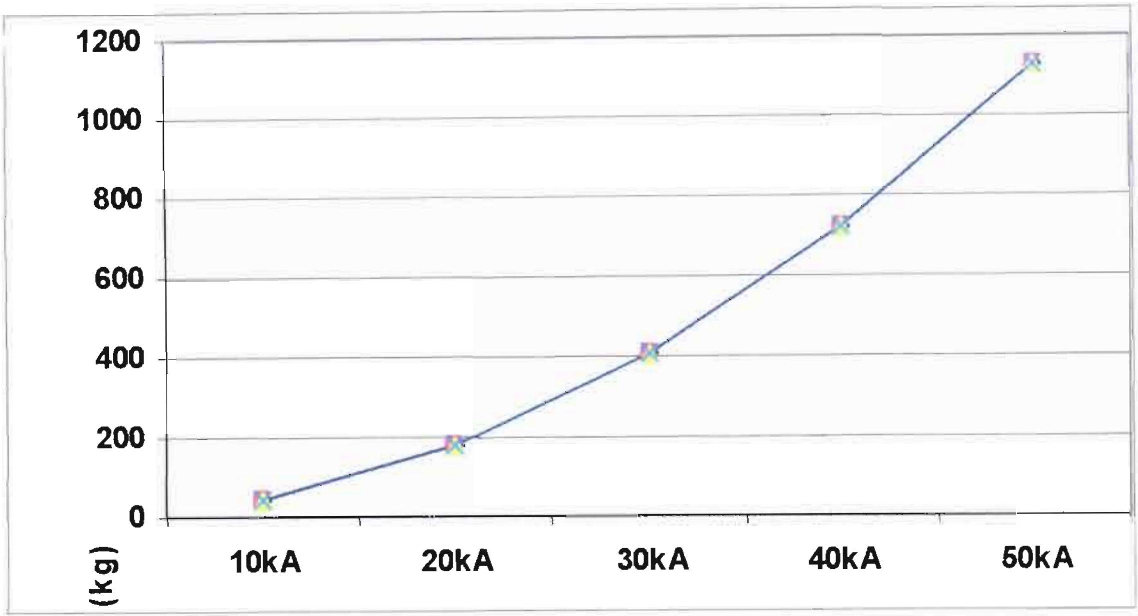


Figure 9: Forces exerted on a 1x100x10 mm / phase busbar structure
(Source: Mr Bill Graham, Graham, Golding and Associates)

3.3.2 Short-circuit tests on functional units

As shown in table A1, the verification of the short-circuit withstand strength by test (type-test) is only required in the case of an unpopulated assembly in accordance with standard SANS 1473-1 [2], for the category of Specially Tested Assembly. In the practical situation when a functional unit develops a short-circuit, the short-circuit protective device is required to clear this fault and this must be verified for a number of reasons:

- Every Circuit Breaker provides a pressure increase in the functional unit cubicle due to the exhausting of hot gas under a fault condition. The increase in pressure may cause the dislodging of devices within the cubicle and may cubicle doors to fly open or dislodge.

- Should the short-circuit protective device in the cubicle fail, the upstream incomer circuit breaker will be required to clear the fault either at a much slower time than what the functional unit protective device would have operated at or not at all if the fault is below the incomer circuit breakers minimum fault pick-up level.

- The switching off of a circuit breaker should not initiate an internal arc in the cubicle as a result of the hot gasses.
- The circuit breaker should remain in place and be re-usable after a fault has occurred.

As previously highlighted, the majority of faults occur in the functional units and incomers. Standard SANS 1473-1 [2] does not perform short circuit tests on the functional units (break test under power frequency) to verify the above concerns, which may result in a safety hazard to those exposed to a Specially Tested Assembly. This is a true test of safety as it is carried out with all the doors of the assembly closed, and confirms that under short-circuit that components do not dislodge and doors fly-off, with the possibly of seriously injuring personnel.

3.3.3 Summary of conclusions (short-circuit test)

The following important points are highlighted with reference to the short-circuit test and it's application to the STA:

- Short-circuit faults on functional units are extremely dangerous. They are a common cause of electrical switchboard accidents, often resulting in severe injuries to personnel. The functional unit through-fault tests should never have been excluded from standard SANS 1473-1 [2] due to its important safety implications.

3.4 Verification of Dielectric Properties test

3.4.1 Introduction

Commonly referred to as 'flash tests', the dielectric type-test is used to verify the dielectric properties of insulating materials within the assembly. The test voltage is applied between all live parts and interconnected exposed conductive parts (frames), as well as between each pole and all the other connected poles. Two fundamental properties of insulating materials are insulation resistance and dielectric strength. These are two entirely different and distinct properties. Insulation resistance is the resistance to current leakage through the insulation materials. Insulation resistance can be measured with a 'megger' without damaging the insulation. Dielectric strength is the ability of an insulator to withstand potential difference. It is usually expressed in terms of the voltage at which the insulation fails because of the electrostatic stress. A dielectric test measures the withstand capability of an insulator. Insulation resistance tests measures the resistance of an insulator or insulation during a test. Standard 10142-1 [7] specifies insulation resistance tests in section 8.7.8 of the standard, and these tests must not be confused with the dielectric properties test required for certification as a TTA. Standard IEC 60439-1[1] requires that each circuit of the assembly be capable of withstanding the power-frequency withstand voltage and impulse withstand voltage, for values specified in the standard.

3.4.2 Safety concerns with respect to a STA

Tests in accordance with IEC 60439-1[1] (section 8.2.2) require that main and auxiliary circuits undergo a type-test to verify the dielectric properties of the complete assembly, by application of a specified test voltages between all live parts and the interconnected exposed conductive parts of the assembly.

Standard SANS 1473-1 [2], for qualification of as a STA, requires that the assembly be in the unpopulated state, and is therefore not in accordance with the IEC standard [1]. Ignoring this test could result in faulty insulation only being exposed when the switchgear assembly is placed in service and subjected to a voltage transient of sufficient magnitude to cause insulation breakdown of the insulating material. Depending on the construction of the switchboard, the breakdown of dielectric material may further develop into an arc within the switchboard. The results of such arcs are often devastating. Unlike a bolted fault where the energy is dissipated in the equipment, an arc fault results in the energy being dissipated into the surrounding environment, in the form of heat, ionized materials and poisonous gasses. The heat energy and intense light at the point of the arc is termed 'arc flash'. Air surrounding the arc is instantly heated and conductors are vaporized causing a pressure wave termed 'arc blast'. "Exposure to an arc flash frequently results in a variety of serious injuries and in some cases death. Equipment can be destroyed resulting in downtime and expensive replacement or repair of equipment may be required. Nearby flammable materials may be ignited resulting in secondary fires that can destroy entire facilities. An arc flash not only includes intense heat and light but also loud sounds and blast pressures. The arc blast often causes equipment to literally explode ejecting parts, insulating materials, and supporting structures with life threatening force. Heated air and vaporized conducting materials surrounding the arc expand rapidly causing effects comparable to an explosive charge. As conductors vaporize they may project molten particles" [13] An interesting statistic from the USA is that an estimated 75% - 80% of all serious electrical injuries are related to electrical arcs [14].

3.4.3 Summary of conclusions (dielectric properties test)

The following important points are highlighted with reference to the dielectric properties test and its application to the STA:

- Failure of the dielectric materials within an assembly may result in an electric arc, which can have severe consequences, to both equipment and injure personnel. The dielectric properties verification test for a STA is only applicable to unpopulated assemblies. The dielectric properties should not only be verified for an unpopulated assembly, as this in no way representative of the assembly that will be connected into the power system by the end user. Verification of part of the assembly obviously does not infer that the complete assembly is safe for installation.

Chapter 4: Technical study of the type-tests included in standard IEC 60439-1 and excluded from standard SANS 1473-1

4.1 Introduction

The aim of this chapter is to analyze whether the exclusion of four type-tests (for verification as a TTA, in accordance with standard IEC 60439-1[1]) provides a safety concern, as they are excluded for qualification as a STA, as specified in standard SANS 1473-1 [2]. The type-tests under scrutiny will be the verification of creepage and clearances, effectiveness of the protective circuit, mechanical operation and degree of protection, as shown on table A1.

4.2 Effectiveness of the Protective Circuit

Earthing of an electrical infrastructure can be classified into two categories i.e. protective and system earthing. "Protective earthing is the earthing of a conductive component not forming part of the normal electrical circuit in order to protect personnel from unacceptable touch voltages. System earthing is the earthing of a point in the normal electrical circuit in order that apparatus or systems can be maintained properly" [15].

Correctly sized and connected protective circuits are essential for the safe operation of an assembly. The protective circuit in an assembly consists of either a separate protective conductor or the conductive structural parts, or both. The principal function of the protective circuit in an assembly is to protect personnel from any shock hazards that may result in the non-current carrying part of an assembly accidentally becoming live. This is achieved by interconnecting all exposed conductive parts of the assembly together and to the protective conductor of the supply (or via an earthing conductor to the earthing arrangement). The protective conductors must therefore be correctly sized to carry the prospective short-circuit current of the assembly. The effectiveness of the protective circuit is verified by two tests:

- Short-circuit withstand performed between the protective conductor and the nearest phase.
- Resistance measurement of the connection between the exposed conductive parts and the protective circuits.

The short-circuit test on the protective circuit verifies that the earthing system is capable of withstanding the thermal and elecrodynamic stresses effected by a short-circuit. The resistance measurement confirms that an effective connection between the exposed conductive parts of the assembly and the protective circuit is achieved.

If the assembly is poorly earthed, protection systems may not operate correctly which may cause further damage to the installation. Standard SANS 10142-1 [7] does however specify the testing requirements and values for verification of the resistance of earth continuity conductors, but does not specify that the short-circuit withstand strength of the protective conductor be tested. It is therefore possible for a conductor to be verified as correctly sized by resistance measurement, but the conductor may in fact be incorrectly sized according to the fault current requirements of the system. The cross-sectional area of the protective conductors in an assembly to which external conductors are to be connected should be calculated with the aid of formula using the value of the highest fault current and fault duration that may occur.

These tests are not required for certification as a STA. The safety related concerns from a poorly earthed assembly are self-evident.

4.3 Creepage and Clearances

It is not unusual for manufacturers to find that a product fails the creepage and clearance distance test because of miscalculations or simply because the distance between two components was overlooked. Creepage is defined as 'the shortest distance along the surface of an insulating material between two conductive parts'[12] measured along the surface of the insulation. Clearance is defined as 'the distance between two conductive parts along a string stretched the shortest way between these conductive parts'[2].

The correct creepage distance protects against tracking, a process that produces a partially conducting path of localized deterioration on the surface of an insulating material as a result of the electric discharges on or close to an insulation surface.

Tables 14 and 16 of standard IEC 60439-1 [1] specify the minimum distances.

These distances are verified by actual measurement. The IEC standard [1] also specifies that both main and auxiliary circuits shall be verified, but this test is excluded by default for assembly certification as a STA, since the assembly is specified in the unpopulated state.

Clearance distance helps prevent dielectric breakdown between electrodes caused by the ionization of air. The dielectric breakdown level is further influenced by relative humidity, temperature, and degree of pollution in the environment. Should the creepage and clearances of the assembly not be verified, one runs the risk of a flashover, which may generate further effects as severe as an internal arc within the assembly that may cause severe damage or injury. Standard SANS 10142-1 [7] does specify a minimum clearance distance of 8mm (section 6.6.4.2.4) between phases and between phase and earth, which corresponds with table 14 of standard IEC 60439-1[1] up to an impulse voltage level of 8 kV. Should the specified rated impulse withstand voltage be greater than 8kV, the clearances may be incorrectly specified using standard SANS 10142-1 [7]. Similarly, a minimum creepage distance of 16mm (section 6.6.4.3.2) is specified in standard SANS 10142-1 [7] between phases and between phase and earth, but has limited conformity with table 16 of standard IEC 60439-1 [1] for various degrees of pollution and material group. Measurement verification of creepage and clearance distances are among the most important parts of all safety standards, and therefore it is important for assembly manufacturers to provide verification of this fundamental electrical requirement.

4.4 Degree of Protection

Standard IEC 60439-1 [1] states that 'the degree of protection provided by an assembly against contact with live parts, ingress of solid foreign bodies and liquid is indicated by the designation IP.. in accordance with IEC 60529' (IEC 60529 specifies the degrees of protection provided by enclosures. It defines IP ratings and the measurement and verification therof). From the above description it is evident that the degree of protection of an assembly does have a safety implication with regards to preventing accidental contact with live parts.

It is not sufficient that an assembly only fulfills the functional requirements that it is designed for, but also to be protected against possible adverse external influences and likewise to ensure that it is not harmful to the user and the environment. A definition of the International Protection (IP) codes is presented in table 8 and table 9.

Although the design and construction requirements for protection against electric shock are treated as a separate issue in the standard, verification of protection against electric shock is embedded within the section dealing with degrees of protection.

The degree of protection is generally specified in an agreement between the user and assembly manufacturer, although standard IEC 60439-1[1] does specify minimum requirements for assemblies designed for indoor and outdoor use. The type test is required to be done in accordance with IEC 60529 [16] in order for an assembly manufacturer to specify an IP code for the assembly. The current standard SANS 1473-1 [2] does not require that the

IP ratings be verified for assemblies. Bearing in mind that although the user specifies the IP rating, an actual verification type test in accordance with IEC 60529 [16] should be a prerequisite for a declaration of a specified IP rating. The STA is only tested in the unequipped state and therefore no IP rating for the assembly can be specified until the assembly is populated. The test is not a requirement for certification as a STA.

Table 8: Degree of protection indicated by the first numeral (source IEC 60529)

First Characteristic numeral	Degree of Protection		
	Short Description	Definition	Symbol
0	Non-protected	No special protection	
1	Protected against solid objects greater than 50 mm	A large surface of the body, such as a hand (but no protection against deliberate access), Solid objects exceeding 50 mm in diameter.	
2	Protected against solid objects greater than 12 mm	Fingers or similar objects not exceeding 80 mm in length. Solid objects exceeding 12mm in diameter.	
3	Protected against solid objects greater than 2.5 mm	Tools, wires, etc. of diameter or thickness greater than 2.5 mm. Solid objects exceeding 2.5 mm in diameter.	
4	Protected against solid objects greater than 1.0 mm	Wires or strips of thickness greater than 1. 0 mm. Solid object exceeding 1.0 mm in diameter	
5	Dust-protected	Ingress of dust is not totally prevented, But dust does not enter in sufficient quantity to interfere with satisfactory operation of the equipment.	
6	Dust-tight	No ingress of dust.	

Table 9: Degree of protection indicated by the second numeral (source IEC 60529)

Second Characteristic numeral	Degree of protection		
	Short Description	Definition	Symbol
0	Non-protected	No special protection	
1	Protected against dripping water	Dripping water (vertically failing drops) shall have no harmful effect.	
2	Protected against dripping water when tilted up to 150	Vertically dripping water shall have no harmful effect when the enclosure is tilted at any angle up to 150from its normal position.	
3	Protected against spraying water	Water failing as a spray at an angle up to 600 from the vertical shall have no harmful effect.	
4	Protected against splashing water	Water splashed against the enclosure from any direction shall have no harmful effect.	
5	Protected against water jets	Water projected by a nozzle against the enclosure from any direction shall have no harmful effect.	
6	Protected against heavy seas	Water from heavy seas or water projected in powerful jets shall not enter the enclosure in harmful quantities.	
7	Protected against the effects of immersion	Ingress of water in a harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time.	
8	Protected against submersion	The equipment is suitable for continuous submersion in water under conditions which shall be specified by the manufacturer. Note: Normally, this will mean that the equipment is hermetically sealed. However with certain types of equipment it can mean that water can enter but only in such a manner that it produces no harmful effects.	 ...m

4.5 Mechanical Operation

Standard IEC 60439-1 states 'that this type test shall not be made on such devices that have already been type tested according to their relevant specifications provided their mechanical operation is not impaired by their mounting'[1]. The standard goes on to specify that 'the operation of mechanical interlocks associated with these movements shall be checked'[1]. The mechanical operation type test seems at first sight to focus exclusively on the operational aspect of the assembly and its components. This is only true up to the point where, for example, a mechanical interlock failure due to poor workmanship may possibly result in an unsafe condition arising within the assembly for the user due to a mechanical maloperation of a switch or interlock. Verification could detect faulty switchgear operating mechanisms, which may prevent an accident. An electrician may have expected a certain switchgear component to have operated when he turned the handle. Although it is not good practice to perform work on any electrical equipment before verifying isolation, their exists a chance that the electrician can be electrocuted by accessing exposed conductive parts connected to the load side of the switchgear that he thought was successfully isolated. The likelihood of the aforementioned faults occurring are extremely small, nevertheless, one can never be too careful when operating any electrical equipment connected to high fault level systems. These examples of potential faults may be exposed when performing the mechanical operation type tests, and rectified prior to installation on site. This will increase the safety of the assembly by assuring that no dangerous failures occur, allowing a greater dependability of the low-voltage distribution network through the assembly. The only mechanical operation type test that can be done to a STA is on the incomer and busbar switches, as the assembly is specified as unpopulated.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

The proceeding chapters highlight, that although not immediately evident, the majority of the type tests specified in standard IEC 60439-1[1] are not exclusively related to the performance and constructional aspects of the assembly, but also have safety relevance. Conformity with established standards helps to ensure that the assembly will achieve acceptable levels of safety and reliability. The chapters go on to prove the inadequacies of an assembly that is certified as a STA, in accordance with standard SANS 1473-1 [2], and the potential safety risks associated with this type of assembly classification. The distinction between TTA and PTTA switchgear and controlgear assemblies has no relevance to the declaration of conformity with standard IEC 60439-1[1], in so far as the switchboard must comply with this standard. Using the same analogy, it can be reasonably assumed that this is implied by standard SANS 1473-1 [2] placing TTA, PTTA and STA switchgear and controlgear assemblies on a similar basis. It would appear that one cannot reasonably recognize a TTA and a STA as being equivalent with regards to the aspects of the performance, safety or reliability of the assembly, albeit that they share a common South African standard. A STA is basically a skeleton assembly with a busbar system that has been subjected to a bare minimum amount of tests. A summary of the technical / safety and commercial findings are summarized below:

5.1.1 Technical / safety results

Standards are written in such a manner that introduces a degree of subjectivity in the interpretation of the document. No matter how one looks at the type tests required for certification as a STA, the deliberate exclusion of a number of type tests by SANS cannot be misconstrued as misinterpretation of standard IEC 60439-1[1]. With this in mind, the safety related concerns highlighted in this document exposes the STA as a category of assembly, which neglects important safety and performance issues, while not conforming to any internationally accepted standard.

One major downfall of an assembly that is certified as a STA, in accordance with standard SANS 1473-1 [2], is that it is tested in the unpopulated state. It cannot be reasonably assumed that an assembly in the unpopulated state is representative of an assembly in a fully equipped operating form.

5.1.2 Commercial results

The STA was initially introduced to allow smaller manufacturers recognition for complying with some sort of minimum requirement, before which they had few restrictions and standards to comply with. A manufacturer of a STA is at a much greater commercial advantage than a manufacturer of a TTA, should the two categories be acceptable in the same tender document. It is not uncommon for engineering consultants, engineers and designers to make a blanket statement specifying only that the assembly shall conform to standard SANS 1473-1 [2], due to their limited knowledge of the standard. This leaves the door wide open as to the type of assembly that will be offered to the client. Invariably, the larger corporate companies will specify a TTA or PTTA as the only alternatives on offer, while many of the smaller companies will be at a financial advantage if they can offer a STA as an alternative. Even though the STA manufacturer follows the standard correctly, is it really safe and does it fulfill the safety and performance requirements outlined in standard IEC 60439-1[1] ? Type tests are costly to manufacturers, but safety should never be compromised for any reason whatsoever. There are several reasons highlighted in this document why customers should choose safety over cost when deciding whether to opt for a TTA instead of a STA.

With international trade opportunities being accessible to South African companies, it would be sensible for South Africa to conform to recognized international standards with respect to exporting our products to foreign shores. The dilution to a point beyond recognition of the requirements of standard IEC 60439-1[1] (applicable to certification as a STA), cannot do well for our reputation in the international market.

5.2 Recommendations

5.2.1 Safety and the OHS Act

The Occupational Health and Safety Act (85 of 1993) [8], along with the Electrical Installation Regulations and the Electrical Machinery Regulations, governs electrical work, as well as the certification that such work is safe. Standard SANS 10142-1 [7] is referenced herein and is therefore considered a mandatory safety standard (SANS 1473-1 [2] is referenced in SANS SANS 10142-1 [7], and hence also mandatory). The purpose of the OHS Act is "to provide for the health and safety of persons at work and for the health and safety of persons in connection with the use of plant and machinery; the protection of persons other than persons at work against hazards to health and safety arising out of or in connection with the activities of persons at work" [8]. It is the responsibility of the SANS committee members who compile the electrical standards, to ensure that safety is never compromised, and that the standard complies with the requirements specified in the Occupational Health and Safety Act [8]. The committee is obligated to provide an adequate safety standard and each member must be fully aware of their duty and responsibility to protect the manufacturer, end user and the public. The removal or incorrect application of type-tests, that have safety implications, contradicts the essence of the Occupational Health and Safety Act [8].

5.2.2 Future standard IEC 61439 series

In principle, the idea to give small manufacturers the possibility to manufacture assemblies, with a lesser amount of testing, is not incorrect. But the smaller the requirements for testing are, the bigger the required safety margins should be. This is also the general philosophy of the future IEC standard for low-voltage switchgear and control gear assemblies. The current series of IEC standards for low-voltage switchgear and controlgear assemblies, IEC 60439, is presently being revised by the IEC. This has been necessitated by the fact that the current series of standards do not cater for customized assemblies, and only allow for TTA or PTTA certification. This fact has also been recognized by SANS, which has possibly resulted in the present STA classification of assembly being included in standard SANS 1473-1 [2]. The proposed new series of standards will expand on the current requirement of design verification by type-test, in the case of an assembly being classified as a TTA, to include alternative design verification methods. The alternative methods include verification by non-destructive measurement, calculation and application of design rules [17]. An increasing conservative design approach will be allowed for as one proceeds through the verification options, from performing actual type tests through to the application of design rules. It is important to note that some actual type testing may still be required as the starting point for design verification of certain categories, for example, short-circuit verification may require a verified and tested reference design upon which design rules may be applied for subsequent designs. The concept of design verification by methods other than verification testing (type tests) is not entirely new. It is similar in many ways to the concept of verification of an assembly as a PTTA (in accordance with standard IEC 60439-1), as some of the tests require a verified and tested design as the starting point. The proposed new IEC series of standards, IEC 61439, seems like a more prudent route to follow than the modification / exclusion of important safety tests as in the case of STA classification. It is strongly recommended that SANS consider the implementation of the new IEC 61439 series upon official publication.

5.2.3 Suggested measures to be taken immediately

The anomalies exposed in the validity of the type-tests specified for a STA should necessitate a recall of standard SANS 1473-1 [2]. The major question thereafter is what standard should be applied in the interim, while the standard is being revised. Since some of the type tests can be potentially destructive it becomes obvious that for both pragmatic and cost reasons that it would become unreasonable for every assembly to be tested either as a TTA or PTTA. A suggestion may be to remove all references of standard SANS 1473-1 [2] from standard SANS 10142-1 [7]. This would effectively make compliance with standard IEC 60439-1[1] voluntary.

Due to the high forces experienced within an assembly for short-circuits of magnitudes above 20kA, and the associated safety concerns, it may also be reasonable to consider that all assemblies with rated short-circuit withstand strength above 20kA be tested for category TTA or PTTA.

The remedial work on standard SANS 1473-1 [2] is essential in ensuring that the category STA is both functional and safe, but the method of achieving this will be no straightforward task.

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Appendix A: Table A1

Table A1: Tests to be performed for assembly verification as a TTA and PTTA in accordance with IEC 60439-1, and a STA in accordance with SANS 1473-1.

No.	Characteristics to be checked	Subclauses IEC 60439-1	TTA	PTTA	Subclauses SANS 1473-1 for STA	STA	SANS 1473-1 for STA in accordance with IEC 60439-1
1	Temperature-rise limits	8.2.1	Verification of the temperature-rise limits by test (type-test)	Verification of the temperature-rise limits by test or extrapolation	4.4.1	Verification of the temperature-rise limits by test (type-test) - *Only required for busbar current density values exceeding those specified in 4.4.1.1, or for any busbar material other than copper*	NO
2	Dielectric properties	8.2.2	Verification of the dielectric properties by test (type-test)	Verification of the dielectric properties by test according to 8.2.2 or 8.3.2, or verification of insulation resistance according to 8.3.4.	4.4.2	Verification of the dielectric properties by test (type-test) - *Only required in the case of an unpopulated assembly*	NO
3	Short-circuit withstand strength	8.2.3	Verification of the short-circuit withstand strength by test (type-test)	Verification of the short-circuit withstand strength by test or by extrapolation from similar type-tested arrangements	4.4.3	Verification of the short-circuit withstand strength by test (type-test) - *Only required in the case of an unpopulated assembly*	NO
4	Effectiveness of the protective circuit	8.2.4			Nil		NO
	Effective connection between the exposed conductive parts of an assembly and the protective circuit	8.2.4.1	Verification of the effective connection between the exposed conductive parts of the assembly and the protective circuit by inspection or by resistive measurement (type-test)	Verification of the effective connection between the exposed conductive parts of the assembly and the protective circuit by inspection or by resistive measurement			
	Short-circuit withstand strength of the protective circuit	8.2.4.2	Verification of the short-circuit withstand strength of the protective circuit by test (type-test)	Verification of the short-circuit withstand strength of the protective circuit by test or by appropriate design and arrangement of the protective conductor (see 7.4.3.1.1; last paragraph)			
5	Clearance and creepage distances	8.2.5	Verification clearances & creepage distances (type-test)	Verification clearances & creepage distances	Nil		NO
6	Mechanical operation	8.2.6	Verification of the mechanical operation (type-test)	Verification of the mechanical operation	Nil		NO
7	Degree of protection	8.2.7	Verification of the degree of protection (type-test)	Verification of the degree of protection	Nil		NO