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TECHNICAL NEWS

INDUSTRIAL SWITCHGEAR & AUTOMATION SPECIALISTS

The Power of Copper

The Statue of Liberty stands proudly on Liberty Island, New York. The statue itself is 46 m tall, and is entirely clad in copper. In fact, the largest copper deposit in the world is New York City itself - with millions of tonnes of power and communications cables networked beneath the city.

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Man first came to understand the value of copper around 10000BC. The Romans, Greeks, Aztecs and Egyptians were quite innovative in their use of copper and copper-tin alloys such as bronze and brass. Here was a metal that was readily accessible, very ductile and malleable, making it relatively easy to smelt. It also had a natural resistance to corrosion. Copper does not react to water, but when exposed to oxygen, a layer of copper oxide is formed which protects against further corrosion. The wonderful green tinge that is often found on copper fixtures and statues is a layer of copper carbonate – also known as verdigris.

The Bronze Age accelerated the use of copper alloys for items such as jewellery, pendants, coins, tools and weapons, cooking and eating utensils, and various structural features in buildings such as doorknobs and decorative fixtures. The pyramids have elaborate copper plumbing systems that are 5000 years old, and in fact copper was the material of choice for drain pipes and gutters right well into the 20th century before cheaper alternatives were found. Many heritage listed buildings in Australia still use the original copper plumbing which will last for centuries.

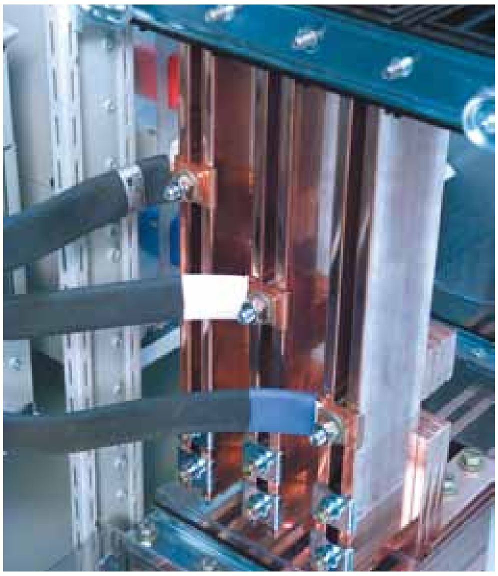
However, not even the ancient Romans and Egyptians could have foreseen the significance of copper's value in our modern society – as the prime distribution medium for power. Of all the atomic elements, copper has the second highest thermal and electrical conductivity, behind silver by a very small margin. The current extraordinary rate of development in China and India has significantly increased the demand on this resource, driving the cost of copper to record levels. As the lifeblood of all electrical systems, it is essential that designers and engineers are efficient in their use of copper to produce an economical solution without jeopardising the integrity of the electrical supply system.

CABLES, COPPER BAR AND FLEXIBLE BAR

Whatever the method of transmission, pure copper properties are constant:

- Electrical resistivity = 16.78 nΩ·m at 20 °C
- Thermal Conductivity = (300 K) 401 W·m^{-1}·K^{-1}

The cross sectional area of copper determines its current carrying capacity, as does its installation environment. The exposed surface area, the ambient temperature and various types of insulation all affect the amount of current that copper can carry before it starts to melt. The fuse is the simplest example of using these copper properties to define a "breaking point" to protect a circuit by forcing it to melt when exposed to preordained conditions. Due to its predictable nature, designers and engineers can select the appropriate size copper for applications and can be confident that it will perform as intended. It is important to note that copper properties do not change, irrespective of how the copper is formed into a current carrying conductor. Cables, solid bars and flexible bars of similar cross sectional areas tend to carry the same amount of current for similar conditions. The standards have been created to clearly define what copper sizes should be used to maintain maximum operating temperatures for specific load currents.



APPLYING THE STANDARDS

The most commonly used standards for panel board designs or cabling installations are:

- AS/NZS3008.1.1:2009
- AS4388 - 1996 (currently under review), AS/NZS3439.1:2002 and AS/NZS3000 also contain references to these standards.

These standards contain worked examples and a tables that identify the environmental factors that effect the final selection of a conductor. It is essential that the designer understands the significance of environmental conditions when selecting the appropriate copper conductor size for an application.

Consideration must be given to the following variables:

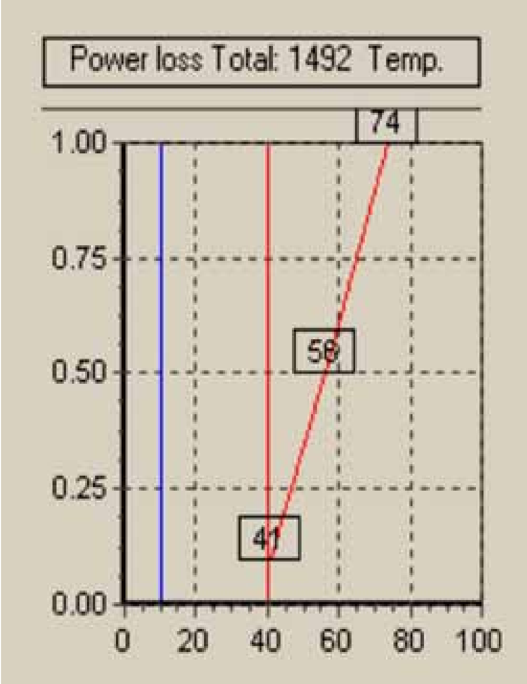
- Ambient Temperatures
- Derating for connection to switchgear
- Conductor installation
- Eddy currents (high current installations)

AMBIENT AND MAXIMUM OPERATING TEMPERATURES

AS/NZS3439.1:2002, Table 2 – "Temperature Rise Limits" stipulates that the maximum permissible bus bar temperature rise for built in components is 70° K. However, it should be noted that there is a fundamental difference between AS/NZS3439.1:2002 and IEC61439-1 when specifying maximum bus bar temperatures. IEC61439-1 allows a maximum temperature rise of 105° K. As a consequence, European ratings for bus bar connections to apparatus can be higher than Australian ratings for identical conductor cross sectional areas.

The tables in AS4388:1996 are quite comprehensive and clearly defines the maximum permissible current draw for a conductor of specific dimensions and cross sectional area, within a specific ambient, for use with low voltage apparatus. Copper has a watts loss value that can be calculated on a watts/meter basis for a specific load current for a specific cross sectional area. The heat dissipated by the copper as well as the peripheral switchgear all contribute to the watts losses accumulated within an enclosure. It is then necessary to understand the heat dissipation characteristics of the enclosure to understand the steady state ambient temperature that can be expected within a panel board operating at its rated maximum current carrying capacity. This is illustrated in the heat rise calculation chart (*above right*). Ultimately, the operating temperature of the bar is determined by the heat dissipated by the enclosure compared to the heat being generated within the enclosure. If a copper conductor exceeds the maximum permissible temperature then there are really only three solutions:

1. increase the amount of copper used to transmit current
2. alter the ventilation characteristics of the enclosure and/or
3. reduce the load current



Circuit breaker chassis are usually given a nominal current rating which is based on "free to air" tests. Therefore, it is necessary for the designer to consider the impact of the ambient temperature within an enclosure and de-rate the nominal current value of the chassis accordingly. For normal power distribution configurations, a factor of diversity is often applied and this may allow the designer to use the chassis for de-rated applications. It is essential that the engineer is aware of the need to de-rate standard chassis nominal values to prevent overheating and possible premature failure of low voltage circuit breakers fitted to the bus bar.

DE-RATING REQUIREMENTS FOR SWITCHGEAR

It is a fact that modern switchgear is significantly more compact than in previous generations, and as a consequence tend to operate at higher temperatures. It is not uncommon for air circuit breakers to demand a substantial cross sectional area of copper bus to be connected to its main tags to perform at the rated current. In the case of moulded or air circuit breakers, the devices could fail to clear a fault if the contact temperature is not maintained within appropriate limits. Manufacturer's recommendations must be followed to ensure that the apparatus performs as intended and does not suffer from deteriorated lifespan or pre-mature failure.

The IEC60947 standard series defines the test regime for all low voltage electrical apparatus. Table 2 in IEC60947-1 states that 70° K temperature rise is permissible on Silver or Nickel plated terminals of low voltage apparatus within an ambient of 35° C, thereby achieving the maximum permissible conductor temperature of 105° C. Once the ambient temperature within an enclosure is identified, the designer can select the conductor size from table B3 from AS4388:1996 with confidence, knowing that the apparatus will perform as tested.

CONDUCTOR INSTALLATION AND INSULATION PROPERTIES

The physical orientation of a conductor can affect its current carrying capacity. For example, horizontally installed flat copper conductors tend to "trap" hot air. In comparison, vertical flat copper conductors allow better air flow across the surface area. It is normal for the main connection tags of an air circuit breaker to operate at a lower temperature when mounted in a vertical configuration. Spacing between cables has a similar effect. Additional forms of mechanical protection, e.g. conduits, create another thermal barrier to heat dissipation, thereby reducing the current carrying capacity of the conductor.

Cable manufacturers offer a wide variety of insulation ratings for their cables. For example, V90 rated insulation allows a cable to operate at a higher temperature than a similarly sized cable with V75 insulation. The inference is that you can opt to use a smaller diameter cable for a similar load current. However, the switchboard designer must always consider the cable current carrying capacities as listed in Table 6 of AS/NZS3008. This table specifies the cable cross sectional areas that are used to complete the tests as defined in IEC60947 for low voltage apparatus, whilst maintaining the maximum permissible temperature at the switchgear terminals. It is essential that the designer complies with the conductor cross sectional area recommendation of this table to ensure the lifespan and intended operation of the apparatus, irrespective of the cable manufacturers insulation rating.

EDDY CURRENTS – HIGH CURRENT INSTALLATIONS

At very high currents, e.g. 3500 A and above, circulating currents can be generated in closed paths within the body of a ferromagnetic enclosure, causing an undesirable heat loss. These eddy currents are created by the differences in potential existing throughout the body of the metallic enclosure owing to the action of the changing flux. Experienced switch board builders advise that greater clearances are required between current carrying conductors and the enclosure openings between tiers for these applications. Ultimately, heat rise tests will determine how eddy currents affect the final design of a switch board as this is not covered by the standard.

EXAMPLES OF CONDUCTOR SELECTIONS FOR USE WITH LOW VOLTAGE SWITCHGEAR

Whilst AS/NZS3008 and AS4388 cover the selection of cables and solid conductors for specific current carrying capacities in specific conditions, flexible bus bars are not listed. However, the same principles apply, as illustrated in the two following examples.

EXAMPLE 1:

How to select flexible bar for "busbar to busbar" connections

The ratings in the chart above are based on the ambient temperature around the bar within an enclosure - i.e. you must first define your maximum permissible temperature rise and select the bus bar accordingly. For example, if we have a switch room ambient of 35º C and the equipment mounted within an enclosure contributes another 25º K temperature rise, this results in a micro ambient around the bus bar of 60º C. The bus bar is only permitted to operate at a maximum of 105ºC, which allows us a total temperature rise (ΔT) of 45º K, (i.e. the difference between the maximum of 105ºC and the micro ambient of 60º C). According to the chart adjacent, for a ΔT of 45º K the FB25 busbar will achieve the maximum permissible 105º C conductor temperature (as per AS/NZS3439) if it is loaded to 175 A continuously. Conversely, using the same chart, the FB25 busbar is only capable of carrying 145 A continuously if the ambient within the enclosure is 75º C, which translates to a ΔT of only 30º K, as identified in the table extracted from NHP Part A Price List Catalogue, Section 12-114.

Cu-flex flexible copper busbars

Current ratings

Cu-flex Selection chart

Cat. No.		FB25	FB50	FB50	FB50	FB100	FB100	FB240	FB240
No. of busbars		1	1	2	3	1	2	1	2

Maximum permissible conductor temperature, 105 °C
Connection: Busbar to busbar

ΔT Busbar		Current Rating							
Amps (A) @	65 K	215	325	550	630	495	800	835	1285
	60 K	205	310	530	600	475	770	800	1235
	45 K	175	270	460	525	410	665	695	1070
	30 K	145	220	375	430	335	545	565	870

Extract from NHP Part A Price List Catalogue – Section 12–114

It is necessary to calculate the ambient temperature within the enclosure (based on the net sum of watts losses and watts dissipation for a compartment) before selecting the appropriately sized bar from this chart, for a specific current carrying capacity.

EXAMPLE 2:

How to select flexible bar for use with low voltage apparatus

We need to select the appropriate flexible busbar size for use with a standard 630 A MCCB (210 mm wide) that has 40 mm wide terminals, or the smaller 140 mm width frame 630 A MCCB fitted with spreader tags.

1. The switchboard designer completes the watts loss calculation for the compartment housing the MCCB, and determines that the internal air temperature is a maximum of 55º C when subjected to a maximum external ambient temperature of 40º C, i.e. ΔT = 15º C. This means that the sum of all watts losses within the compartment and the heat dissipation characteristics of the enclosure allow this installation to reach a steady state temperature – at full load current – of 55º C.

2. From AS4388, Chart B3 (*Table 1, right*), two copper busbar conductors of size (30 mm x 10mm) i.e. 600 mm² cross sectional area, will allow a continuous current flow of 780 A for the maximum air temp of 55º C. Alternatively, 1 x (50 mm x 10 mm) = 500mm² cross sectional area, will also carry 660A, but the width of the bar would not fit directly to the terminal of the 630 A MCCB, which is only 40 mm wide. However, it is important to note this smaller cross sectional area as it is useful when selecting the appropriately sized flexible conductor in step 3. It is also of value to note that AS/NZS60947 (*Table 2, right*) nominates 2 X (50mm X 5mm) bar for 630A-800A devices i.e. the same 500mm2 cross sectional area requirement.

1	2	3	4	5	6	7	8	9	10
Width x Thickness	Cross-section (Cu)	Maximum permissible temperature of the conductor 65 °C							
		Air temperature inside the enclosure around the conductor 35 °C				Air temperature inside the enclosure around the conductor 55 °C			
		50 Hz to 60 Hz a.c. and d.c.				50 Hz to 60 Hz a.c. and d.c.			
		operating current	power-losses 1)	operating current	power-losses 1)	operating current	power-losses 1)	operating current	power-losses 1)
mm x mm	mm²	A*	W/m	A**	W/m	A*	W/m	A**	W/m
30 x 5	149	288	11,6	492	16,9	233	7,6	402	11,3
30 x 10	299	482	17,2	960	32,7	402	11,5	780	21,6
50 x 5	249	413	14,7	805	27,9	338	9,8	655	18,5
50 x 10	499	805	28,5	1560	53,5	660	19,2	1280	36,0

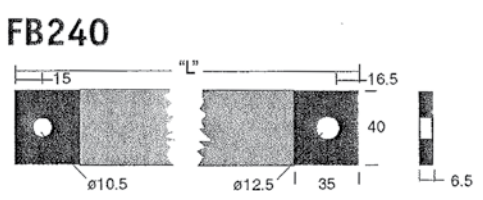
*) one conductor per phase
**) two conductors per phase
1) single length

Table 1: *Extract from AS4388:1996, Table B3, "Operating current and power losses of bare conductors used between apparatus and bus bars"*

Range of test current 1) A		Copper bars 2), 3), 4), 5), 6) Number	Dimensions mm	Dimensions inches
400	500	2	30 x 5	1 x 0.250
500	630	2	40 x 5	1.25 x 0.250
630	800	2	50 x 5	1.5 x 0.250

Table 2: *Extract from AS/NZS3947.1, Table 11, "Test Copper bars 400A – 800A"*

3. Once we've completed the selection analysis as detailed above, we select the appropriate combination of flexible busbar conductors to match the 500 mm² cross sectional area requirement. The nearest sized flexible busbar conductor solution is 2 x FB240 (i.e. 2 x 6.5 mm x 40 mm = 520 mm²) refer NHP Price List Catalogue Part A 2009: Section 12-115 (right).



As noted in this example, it is critical to maintain the cross sectional area of the conductor in accordance with AS4388 and AS/NZS60947 to achieve the desired nominal current rating of the device.

CONCLUSION:

Copper has a broad range of uses in the modern world, and its value contribution to our way of life cannot be underestimated, particularly in power reticulation and communications. The significant increase in its commodity price has forced designers and engineers to look at economical solutions and methods of reducing the amount of copper used in installations and switch boards. Whilst this is a necessity, it is essential that we abide by the Australian and International Standards to ensure that we do not compromise the integrity of a system design, and that the safety and longevity of an installation is maintained.

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NHP Electrical Engineering Products Pty Ltd
A.B.N. 84 004 304 812

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1300 NHP NHP

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