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Aluminum versus Copper Conductors

Application of Aluminum conductors in Bus Way systems for more sustainable Data Centers

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Two main conductor materials are used in high current applications: Copper (Cu) and Aluminum (Al). Copper is, and has been, used traditionally. While Aluminum has a large (almost exclusive) market share in the High Voltage overhead line area; Copper still dominates the Low Voltage high current market.

Both Copper and Aluminum conductors are used in Data Center applications: Copper is the material of choice for cabling and for some Bus Way systems; Aluminum is a strong competitor in Bus Way applications.

Data Centers are mainly driven by reliability and sustainability: downtime is not acceptable. A stable power supply is one of the essentials to meet these prime requirements.

In this white paper Aluminum and Copper are compared as conductor materials. This will support the value of the Siemens SIVACON 8PS busbar trunking systems in Data Centers applications.

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The common beliefs

Both Aluminum and Copper have been be effectively used as high current conductors. Aluminum conductors have been around in the electrical industry since the early 1900's. The use of Copper conductors dates back even further to the dawn of the electrical age.

By many Copper is considered to be a superior conductor material to Aluminum. And despite being significantly more expensive, its usage is wide spread and hardly challenged. While - justified or not - especially the issues that plagued the domestic use of Aluminum conductors in the US during the 60 and 70's of the previous century, have damaged the reputation of Aluminum as a Low Voltage conductor material.

Nonetheless, Aluminum is widely spread and successfully used as conductor material in bus bar and Bus Way systems. The advantages of Aluminum over Copper for these applications are obvious:

- Significantly lower material costs (up to 6 times lower than Copper per Ampere),
- About half the weight of Copper per Ampere.

While Copper is not argued against as a conductor material, the application of Aluminum continues being questioned. There are many arguments brought up against the use of Aluminum, which for a significant part can be traced back to historic belief, inadequate or superseded information, gut feeling or even plain ignorance.

With the preoccupied questions filtered out, the main concerns to the application of Aluminum conductors are:

- *The malleability of Aluminum versus Copper: Aluminum is softer than Copper and will flow or creep under pressure and over time.*

  This comment probably relates to the early and now obsolete Aluminum conductor alloys that were used after WOII until into the 70's. A fairly soft alloy (1350 Al) was used then, especially in the US market. The combination of this soft alloy and the applied connector materials has been generating the well known failures.

  Nowadays, the industry uses harder Aluminum alloys that have tensile strengths comparable to that of Copper. Furthermore, the optimization of the connection surface dimension to the connection pressure, ensures that flow or creep issues do not longer exist.

  Illustrative for the strength and durability of Aluminum is its wide spread application in the aeronautic industry: Over 80% of the structural material in modern commercial airplanes consists of Aluminum alloys.

- *Aluminum oxidizes quite rapidly when exposed to the air, and Aluminum-oxide is a good insulator. Therefore, upon installation contact surfaces have to be specially treated to allow for reliable connections.*

  To eliminate the risk of oxidation, the Aluminum bus bar material used in Siemens Bus Way systems, is Tin plated over the full length. This process eliminates Aluminum to Aluminum contact surfaces.

  Seemingly contradictory, it is this specific property of Aluminum that actually helps to ensure a reliable connection, when pieces of the contact surface become scratched during equipment installation: The bare metal on the location of the scratch will oxidize directly preventing it from further oxidation. The remaining contact surface will ensure the required conductance.

- *Aluminum and Copper cannot be interconnected without additional measures being taken.*

  This statement is essentially correct, but resolved by the conductor plating as described above. The Tin plating prevents direct physical contact between the bus bar conductor metals and allows for direct connection between Copper and plated Aluminum bus bars.

  The thermal expansion difference between Aluminum and Copper is compensated by the use of spring (or 'Belleville') washers at the bolted connections. In torqued condition these washers act as a spring, maintaining the proper contact pressure when the metal is expanding as a result from temperature increase. As the metal cools and contracts, the spring follows this movement. Therefore, the use of these spring type washers provides maintenance free connections, regardless the applied bus bar material: Copper or Aluminum.

Siemens uses and guaranties bolted Copper to Aluminum bus bar connections in all of its SIVACON distribution panels and Bus Way systems.

User Case

Although Aluminum has been used as a conductor material in Low Voltage high current applications for many years, there are always questions regarding its suitability.

The primary reason for the application of Aluminum over Copper is initial investment. When looking to the first decade of the 21st century, Copper is still three times more expensive than Aluminum. In parallel, the worldwide Copper demand has been rising. With the ranging of Copper prices since the recession of 2009, in excess of 7000 $ per metric ton, it is obvious that significant cost savings can be obtained when using Aluminum as conductor material.

On the other hand, especially in the US, a lot of industries have broad spread reluctance to the usage of Aluminum as a conductor material in Low Voltage applications. Retrospectively, the sentiments that fed this reticence are intelligible. Particularly, as the usage of Aluminum conductors in building wiring in the early 60's and 70's has lead to failures and even building fires.

Although the incidents can be directly related to wiring devices as well as craftsmanship, Aluminum's image as a conductor has suffered significantly. For instance, in the US the Aluminum building wiring market value, which was reaching 31% in 1974, had declined to 8% in 1991[1].

When evaluating Aluminum conductor applications in the historical perspective of the 60 and 70's, two main issues need to be considered:

- First of all, the majority of the incidents were related to building wiring applications,
- Secondly, they occurred 3 to 4 decades ago with materials that date back even further.

In parallel, technology has improved significantly since the early 60's. These developments make Aluminum conductors the economic, lightweight and equally reliable alternative to Copper in Bus Way applications.

[1] Source Eaton – Aluminum the other conductor - 2006

Aluminum versus Copper conductors

Material Properties of Aluminum and Copper

In order to compare the Aluminum and Copper for Bus Way applications, we need to address the physical properties of each of these two materials.

When using materials as a conductor, the following material properties are to be considered:

- conductivity,
- tensile strength,
- coefficient of expansion / creep,
- weight.

Table 1
Material properties of pure Copper and Aluminum

Material property	Dimension	Copper	Aluminum
Density (@20°C)	$g \cdot cm^{-3}$	8.94	2.70
Electrical resistivity (@20°C)	$n\Omega \cdot m$	16.78	28.2
Thermal expansion (@25°C)	$\mu m \cdot m^{-1} \cdot K^{-1}$	16.5	23.1
Ultimate tensile strength	MPa	380	200

Table 1 gives some of the material properties for both Aluminum and Copper. Please note that the material properties in this table refer to the pure elements and can differ per alloy.

Feasibility

Review of the physical material properties in the light of conductor use reveals the following characteristics:

- The Electrical resistivity ratio per volume of Copper compared to Aluminum is 3 to 5. Consequently, a Aluminum conductor volume is to be increased by 68% in order to obtain equal resistivity to Copper. Therefore, Aluminum conductors have larger cross sections for equal current carrying capacity.

- Copper and Aluminum's density relate as 3:1, implying that Copper is about three times heavier than the equal volume of Aluminum. However, when the weight ratio is related to the electrical resistivity, the balance tips in favor of Aluminum: the resistivity ratio per mass of Copper compared to Aluminum is 2 to 1. This implies that per kg, Aluminum is a two times better conductor than Copper.

- When considering the 2014 raw material prices - Copper vs. Aluminum ratio roughly 3 to 1 - combined with above physical material characteristics, result in a cost per amperage relation between Copper and Aluminum of about 6 to 1.

  Furthermore, as Copper prices tend to increase with respect to Aluminum, this ratio will continue to increase.

  Due to the huge and increasing cost difference between both materials as well as their equal applicability, Aluminum conductors will find more and more applications within the industry, especially within Data Centers.

Table 2
Characteristic ratios between Copper and Aluminum

Material property	Copper	Aluminum
Market price raw materials (2014)	3	1
Weight	3	1
Resistivity per volume	3	5
Resistivity per mass	2	1
Cost per Ampere	6	1

Table 2 sums the different ratios between Copper and Aluminum elaborated upon above.

Tensile strength

As stated above, from an investment perspective Aluminum conductors provide significant advantages comparing to Copper. However, for Aluminum to be a long term equivalent, it must be ensured that this initial advantage is not undone by any long term quality degradation effects.

The tensile strength of the pure metals Copper and Aluminum relates as about 2:1 (ref: table 1). For electrical grade Aluminum alloys this ratio is almost 1:1. This indicates that the tensile strength of Aluminum conductors approaches that of Copper conductors.

Aside from the influence of connection components, it is mainly the increased tensile strength of the currently available Aluminum conductor alloys that defines Aluminum as a competitive alternative to Copper. The 5 to 10% resistivity rise that results from the alloy's increased tensile strength, is compensated by with increased conductor volume.

Oxidation

Both Copper and Aluminum will oxidize when exposed to outside air. There are however two distinct differences.

First of all, the oxidation process of Aluminum is much quicker than that of Copper: it will oxidize directly when the bare metal is brought in contact with air.

Furthermore, there is a big difference in the material properties of the oxide layer that forms when the metals oxidize. The Aluminum-oxide layer is impregnable to oxygen, which will stop the oxidation process as soon as a very thin (µm's) thick layer has formed. Copper-oxide is permeable to oxygen. As a consequence, the oxidation process will continue until all the Copper is consumed. Aluminum-oxide is a very good insulator (volume resistivity $>1.10^{17}$ Ω.m). Therefore, in Bus Way applications where contact surfaces are bolted together, oxidation of the contact surface is not an option.

To prevent oxidation, for Siemens SIVACON 8PS Bus Way systems the Aluminum conductors are Tin (Sn) plated over the full length. The sole purpose of this plating is to ensure a durable low resistant surface at the contact points.

The Aluminum galvanizing process is optimized for the specific alloy:

- Cyanide free Zincate treatment ensures high bonding of the Nickel-layer,
- Sulfamate Nickel plating prevents Aluminum oxidation and allows for a ductile, pore free sealing layer with high hardness properties,
- Pure Tin plating ensures long term low resistance connections.

As the conductors are Tin plated over the full length, there are no direct Aluminum to Aluminum contact surfaces. In case the contact surface is damaged or scratched exposing the bare metal, the rapid Aluminum oxidation prevents the damage from growing over time. As the contact surface's area is over dimensioned, the remaining contact surface will ensure the required conductive capabilities.

Connection

Plated Aluminum conductors allow direct connection between Copper and plated Aluminum bus bars. The plating ensures there is no direct physical contact between the two metals.

When standard nut and bolt connection materials are used, the difference in thermal expansion between the two metals can however cause issues.

To guarantee maintenance free connections, Siemens uses disk spring washers (or *Belleville* washers) for all bolted current baring connections (Aluminum to Aluminum, Aluminum to Copper and Copper to Copper), in both distribution panels and Bus Way systems. Upon installation, these bolted connections are set at a specific torque to compress the washer. In its compressed state, the washer acts as a spring, compensating expansion and contraction whist maintaining proper contact pressure.

Use of these spring washers annihilates the effects of temperature expansion. The difference in expansion coefficient between Aluminum and Copper is not an issue when these spring type washers are used.

With the use of spring washers, fatigue due to thermal cycling will not occur. This type of fatigue is caused by the plastic deformation of the conductor as a result of the difference in thermal expansion ratio of the conductor material and the clamp/bolt/connector material. In the case of bolted connections, the spring-type washers will follow the expansion and contraction of the metals, preventing the contact pressure from entering in the plastic deformation zone.

The spring washers ensure maintenance free connections, whether the bus bar material is Aluminum or Copper based.

SIVACON 8PS Busbar trunking systems

Data Centers are critical facilities, looking for ways to increase sustainability while continuing to push more and more data through their servers. Power distribution is directly correlated to the rising computing demand, and needs to be adapted whenever there are changes within the Data Center configuration.

Supplying power to Data Centers requires optimum reliability and consistent high transparency. Data Center facility operators have to manage power capacity fluctuations and ensure power stability by eliminating peaks in power demand linked to computing server demands. They may even have to face some limitations in the power distribution systems, because of the Data Center power design itself. This makes an adaptable power infrastructure highly appreciated, if not a necessity.

There are many factors that support the usage of Bus Way systems in a Data Center environment, regardless whether Aluminum or Copper conductors are selected.

For industrial plants as well as in the infrastructure of a Data Center, a reliable supply of electrical energy is a basic necessity.

Safety, flexibility, easy cost-effective planning and rapid installation are some of the important attributes needed to meet the complex requirements of this type of power distribution.

Living up to complex requirements at all times

Siemens offers a total of five different types of Bus Way systems, all belonging to the SIVACON 8PS busbar trunking product group. The busbar trunking systems for power transportation and distribution match Data Center facility requirements. With the SIVACON 8PS busbar trunking systems, Data Center facility operators benefit from a transparent and flexible solution for controlling the increasingly complex area of the Data Center whilst considerably improving on safe and reliable power supply.

Reliable and safe power transportation

Reliability by eliminating power interruptions is absolutely critical for Data Center facilities. Power distribution in a Data Center requires optimum reliability and consistently high transparency. Further requirements are a low fire load and low susceptibility to electromagnetic fields. The SIVACON 8PS busbar trunking systems offer optimum safety thanks to the verified design in accordance to IEC/EN 61439-1 and -6 (formerly known as TTA). The high short-circuit strength and low fire load due to the metal enclosure of the systems, increase safety for people and facility.

Bus Way based power distribution is characterized by full transparency. In addition, the racks enjoy high power supply reliability. The demand-oriented expandability keeps all options open.

Easy planning and flexible modification of power distribution

High calculation expenditures, laborious installation and high power losses are a thing of the past. With SIVACON 8PS busbar trunking systems, facility operators can easily plan and quickly assemble the power distribution within Data Centers. Modifications and expansions are possible at any time when the usage of the data space changes. In contrast to conventional cable installations, which allow power tap off only at the pre-defined points, tap-offs can be individually varied with the SIVACON 8PS thanks to flexible deployable tap-off units.

Siemens SIVACON 8PS busbar trunking system Highlights

- Full range from 40 A to 6'300 A for industrial applications and infrastructure
- Safety through full verified design in accordance with IEC/EN 61439-1/6.
- Easy planning and quick assembly of the power distribution system

Conclusion

Aluminum conductors are a viable alternative to Copper conductors for bus bar applications in distribution panels and Bus Way systems. Using Aluminum as conductor doubles the conductivity per mass in comparison to Copper and saves more than 30% of the costs.

For Data Center applications, Aluminum based Bus Way systems are the perfect alternative to traditional Copper systems, as they offer reduced cost whilst maintaining the mandatory reliability and sustainability criteria.

SIVACON 8PS Bus bar trunking systems are available with both Aluminum and Copper conductors. Both types of conductor materials are Tin plated over the entire length for oxidation prevention, durable low resistance connections and interchangeability. All bolted connections are made using disk spring washers, ensuring a maintenance free connection for life.

Siemens SIVACON 8PS Busbar trunking systems ensure the safe and cost-efficient flow of power in all kinds of applications, especially Data Centers. Altogether, five different systems offer everything for optimal power transportation and distribution: from simple planning, fast installation and safe operation to flexible modification and expandability.

Literature

A comparison of Aluminum vs. Copper as used in electrical equipment (General Electric)

Aluminum - The other Conductor (Eaton - 2006) – ref IA08703001E/Z4488

Aluminum vs. Copper: Conductors in Low Voltage Dry type Transformers (Square D, SE - 1996) – ref 7400PD9601

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