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The Case for Aluminium Cable Usage in 1-kV Networks in Nigeria with Emphasis on Public Awareness

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Abstract

This paper presents the needed analysis for the use of Aluminium conductors as an alternative to the use of copper in 1-kV armoured and non-armoured cable network applications in Nigeria. The study revealed that over the years, copper cables have dominated the Nigeria cable market, except for bare Aluminium conductors (AOHL) and service cables (NAY and NAYY). The use of Aluminium as a conductor material has reached a great development due to its mechanical and electrical characteristics, in addition to the economic advantage over other metals used as conductors. The specification of its properties is expressed in the same units employed for other materials in order to appreciate its application as compared to other conductors. This paper carried out a rigorous comparison analysis on the price, weight and conductor's minimum cross section to sustain the permissible current carrying capacity, allowable voltage drop and short circuit current for 4-cores armoured mains cables.

Keywords: *1-kV armoured cable, Aluminium, Copper, Current Carrying Capacity*

1. Introduction

Africa knew nothing about cable technology until the late 19th century. The development of cable industry in Nigeria has been influenced by the western world especially Britain, Canada and Germany in the Sixties and by Indians, to a lesser extent, as a result of indigenisation decrees in the late seventies. An Electrical cable consists principally of two parts: an active part termed "conductor" that conducts electricity and the other that has one or several layers of material termed "thermoplastic" to provide electrical insulation and physical mechanical protection. The commonest conductor materials in cable technology are copper and aluminium. But over the years, copper cables have dominated the Nigeria cable market, except for bare aluminium conductors and service cables. Nigeria cable users are yet to know more about the advantages of alternative to copper such as aluminium cables in 1-kV, three-phase and neutral network applications. Our intended purpose is to provide the user with information necessary to make an informed decision on the selection of copper or aluminium conductor within electrical conductors and the need to replace 60-80% of copper mains cable with aluminium of minimum cross section with the same current carrying capacity.

The debate over the pros and cons of aluminium versus copper conductors has been discussed for many years. Many of the conclusions are based on old information and also misinformation which are addressed in section 3. These conclusions centre on the very different properties of the two materials and their suitability for application within electrical power cable standard specifications as set out by the Cable Manufacturer Associations of Nigeria (CAMAN).

2. Parameters of Aluminium versus Copper as Conductor for Electrical Purposes

Copper as a metal is superior to Aluminium in the table of electro-chemical voltage series, that is, it has better electrical as well as heat conductivity characteristics. That is, it offers less resistance to the flow of electricity than aluminium of the same cross section area under the same condition. The conductivity of copper is $58 m/\Omega mm^2$ while that of aluminium is $35.4 m/\Omega mm^2$. This means that the latter has 39% lower conductivity than Copper. (see table 1: Electrical and mechanical characteristics comparison between copper and aluminium). In addition, the density of copper is $8.89 g/cm^3$ while that of aluminium is $2.7 g/cm^3$. The weight of aluminium is about 30% of copper for the same volume. This indicates that an aluminium conductor of the same volume with a copper conductor will be about one-third of the weight of copper. This provides ease of handling of aluminium armoured cables and the transportation of aluminium cable of the same current rating with copper is therefore easier and more convenient to handle. On the other hand, the ultimate tensile strength of aluminium is 160N/mm^2 compared with that of copper of 250N/mm^2. That is, aluminium is 30% weaker in mechanical strength than copper. If Aluminium has this disadvantage over Copper, what are we then talking about?

However, this disadvantage is resolved and reviewed as contained in the result analysis shows in table 3 and the graphical representation of permissible short-circuit current for PVC insulated cables of figure 3 which results in larger Aluminium conductor size or more quantity of Aluminium conductors. Detailed analysis is carried out in the next section.

3. Aluminium Problems and Breakthrough as Electrical Conductor

Although, aluminium found its application as cable conductor in Europe, Asia and Canada since 1900, it took a relatively longer time before it made a break through

3.1 Connections and Terminations

Great difficulties were encountered in the joining of aluminium conductors. For a long time, welding was the best known joining method. Only very few jointers could master this technique. As a result of these difficulties, many electricity supply organisations in Germany resorted to the use of copper after 1945 and remained so in spite of high copper prices in the sixties and the beginning of seventies. This attitude has changed because the constructions of Aluminium wire and terminals have both been revised from past strength and thermal expansions of the conductors. A particular concern is the ability of the conductor to because they are dissimilar metals, galvanic corrosion may occur in the presence of an electrolyte and these connections can become unstable over years. At one time, the conductors were nearly pure aluminium, now they are all much stronger 8000 series alloys, with physical characteristics such as conductivity, creep resistance and strength similar to copper resulting in reliable long-term connectors when installed. One of the most compelling arguments using AA-8000 series is that the National Electric Code (NEC) has approved on its use; section 310.14 states that aluminium conductors "Shall be made of an AA-8000 series electrical grade aluminium alloy conductor material" [1]. Thus, the problem of joining Aluminium conductor is solved.

There is a common misconception that only compression (crimp) lugs should be used with aluminium cables, but this is not true. In the past with the use of the softer aluminium conductors only, compression connectors were suitable. However, with the aluminium conductors used today and modern design and plating of mechanical pressure connectors, compression connectors are no longer required [2]. Though physically larger, the Aluminium wire is lighter and in most cases the same lug can accommodate either Aluminium (equivalent Copper size as in table...) or copper and has adequate wire range. Any lug marked "ALCU" is suitable for use with either conductor.

3.2 Oxidation

Both aluminium and Copper will oxidize when exposed to the atmospheric. Concern over the aluminium oxidation away from the joint is not an issue and will act to protect the conductor from further corrosion in most environments.

* Bolted connection of un-plated aluminium to copper conductor is not allowed. This cannot be joined together Breakthrough as Electrical Conductor

Although, aluminium found its application as cable conductor in Europe, Asia and Canada since 1900, it took a relatively longer time before it made a break through. The properties that need to be of concern to cable end users are the tensile time.

3.3 Conduit Size

Another factor with the use of aluminium wiring for supply or load from a piece of the electrical equipment is the size of the conduits. As mentioned previously, the use of Aluminium conductors will result in either larger conductor size or more quantity of conductors. Either way, more or larger conduits will be utilized. A design trend is always toward equipment with smaller footprints [2].

3.4 Density and Conductivity of Aluminium

The conductivity and density of aluminium were previously reported as a disadvantage when compared with copper. However, Electrical conductor (EC) grade aluminium is rated at 63% international Annealed copper standard (IACS). Combining this conductivity measure, which is on a volume basis, with the densities of the two metals yields the result that 0.22kg of aluminium has the same conductive capability as 0.45kg of copper [3]. This means that aluminium conductor must have a larger cross sectional area for the same ampere rating.

4. Major Advantages of Aluminium over Copper

The two major advantages of aluminium over copper are light weight and price advantage. As earlier mentioned, the weight of aluminium is about 30% of copper for the same volume. This provides ease of handling for aluminium cable. Also the transportation of 4-cores aluminium armoured cable of the same current rating with copper is cheaper, easier and more convenient to handle. This is of a great important commercial advantage. For applications where weight is a concerned, aluminium may be the better choice as it is the case in high voltage (HV) cable applications.

4.1 Price Comparison Analysis

The only valid reason for choosing a material is that it performs required function at the lowest overall cost. The cost difference between copper and aluminium varies with the fluctuating cost of the base metals in the commodities market. However, this price difference is a big deciding factor when a customer is considering aluminium conductors. Figure 1 presents the trend in the aluminium and copper price in 1year as reported by London Metal Exchange (LME).

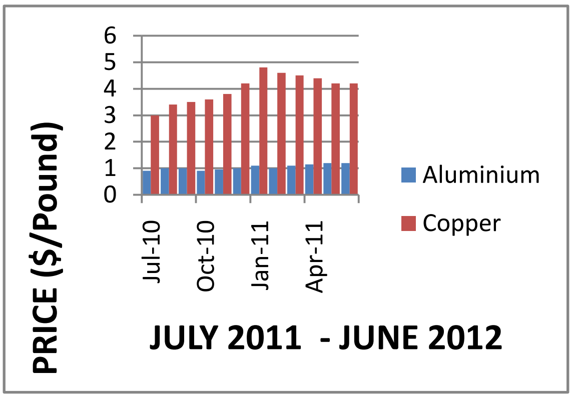

Figure 1: LME Aluminium / Copper Prices for 1year (July 2010-June 2012)

From Figure 1 above, the copper price reached an all-time high of $4.8 per pound in January 2012 while the highest price of aluminium is $1.2 per pound. At the time of this study, one can expect to spend approximately 30 – 40% more for copper than its aluminium counterpart.Copper raw material price has been on the rise and it is impacting badly on every Nigerian cable manufacturer with respect to the cost of cables, in particular the heavy duty cable (3- or 4 core armoured/non-armoured). Between July 2010 and June 2011, CAMAN has reviewed price more than four times due to high price of copper. Table 2 shows the price comparison between aluminium and copper conductor in armoured cables.

Table 2: Price Comparison between Aluminium and Copper in1-kV Armoured Cable

S/no	Aluminium Cable Type	Current in Air (Amps)	Price per m (#)	Copper Cable Type	Current in Air (Amps)	Price per m(#)	Comments
1	NAYFY 4X16	61	880	NCYFY 4X16	80	3250	AL is 73% cheaper than CU
2	NAYFY 4X25	78	1180	NCYFY 4X25	101	4830	AL is 75.6% cheaper than CU
3	NAYFY 4X35	96	1290	NCYFY 4X35	126	6380	AL is 79.8% cheaper
4	NAYFY 4X50	117	1480	NCYFY 4X50	153	8790	AL is 83.2% cheaper than CU
5	NAYFY 4X70	150	1880	NCYFY 4X70	196	12170	AL is 90 cheaper than CU
6	NAYFY 4X95	183	2360	NCYFY 4X95	238	16740	AL is 84.55% cheaper

I invite you at this point, to have a closer look at our 'table of comparison' between copper and aluminium as conductor for electrical purposes.

From the above table of comparison, copper is found to be three or four times the price of aluminium for the same current rating in air. With this analysis, one can expect to spend approximately 30-40% more on 4-core armoured copper cable than on aluminium.

The lower price of aluminium compared with copper can further be analysed for clarity using the graph of price of copper and aluminium against current in air as presented in Figure 2.

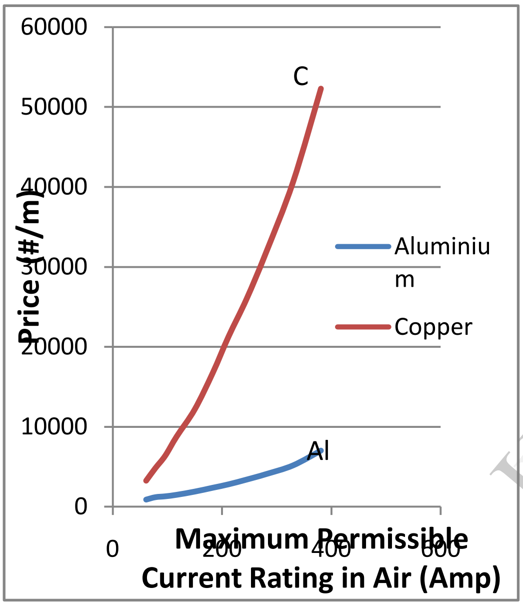

Figure 2: Graph of Price against Current in Air for 1-kV 4-core Copper and Aluminium Armoured cables.

5. Analysis for Selecting Aluminium of Copper Equivalent Size (4-cores Armoured Cable)

Generally, selection of power cables must consider electrical parameters and environmental conditions such as

- Operating Voltage
- Load Current
- Condition of installation
- Allowable Voltage Drop
- Short Circuit Current

Operating Voltage**:** Voltage rating of the cable is the voltage for which the cable is designed to operate and according to which the insulation of the cable core is determined. The standard rated voltage of cables is designated as U_o / U. U_o is the voltage between phase and a neutral while U is the voltage between phases. The maximum permissible continuous operating voltage for which the cable may be used is designated as U_m. Note that $U_m = 2U_o$

The standard values of these voltages defined in International Electrical Commission (IEC) standards are given below:

Table 3: IEC Voltage Standards

Rated Voltage (U_o / U)	Maximum Permissible Operating Voltage (U_m)
600 / 1000V	1200V
1800 / 3000V	3600V
3600 / 6000V	7200V
6000 / 10000V	12000V

For example, for a cable to be installed in a low voltage three-phase network with operating voltage of 415V, selection should be made for a cable with rated voltage of 600 / 1000V [4]. Similarly, for a cable to be installed in a medium voltage three-phase network with operating voltage of 11000V, selection should be made for a cable with rated voltage of 6000 / 10000V.

Load Current: The current carrying capacity of a cable is determined by the maximum allowable conductor temperature and the ambient conditions of installation, which influence the dissipation of heat occurring in the conductor.

The power required to be carried by the cable is used to calculate the load current, I. The cross section of the cable must be selected such that the current carrying capacity of the cable is equal to or higher than the load current of the cable. For a given operating voltage U_m (volts) and real power KW at a power factor of cosθ or apparent power KVA to be transmitted, the load current I, in amperes, is calculated as [4]:

$$I = \frac{P*1000}{\sqrt{3}U_m \cos\theta} \ or \ \frac{KVA*1000}{\sqrt{3}U_m} \quad for\ three-phase\ AC \qquad (1)$$

Condition of Installation: Cables may be buried inside the ground or installed in air.

Current ratings for cables buried in ground are based on standard service parameters, as described below:

Thermal resistivity of soil 100°Ccm/W
Ground temperature 20°C
Laying Depth 70cm
No of cables / system 1
Load factor 0.7
Spacing between cables approximately twice the overall diameter of cable

Current ratings for cables installed in air on perforated cable trays are based on service conditions most often encountered in plants as stated below:

Ambient temperature 30°C
No of cables / system 1
Load factor 1
Spacing between cables approximately twice the overall diameter of cable

Voltage Drop**:** There is a voltage drop between the ends of a conductor when current flows in a cable conductor. This is the product of the current and resistance of the cable. After choosing a cable size to take account of the load current to be carried, the voltage drop should then be checked such that it is below the maximum voltage drop allowed for the application [4]. The line voltage drop of the cable used must be less than the maximum permissible voltage drop for different applications as described below:

- 3% in cables used for lighting
- 5% in cables used in general power distribution, including standard motor loads.

Taking the above factors into considerations, we designed 1kV armoured/non-armoured aluminium conductor cables, equivalent of copper conductor armoured/non-armoured cables to have the same identical performance for the same volume of copper conductor. In addition, the values of the maximum permissible current rating, allowable voltage drop and the weight for different cable sizes for aluminium and copper are determined. This is presented in Table 4 for easy comparison and it serves as a guide for selection of aluminium equivalent size of copper.

Table 4: Four-Core Armoured /Non-Armoured Copper and Aluminium Main Cables 0.6/1kV

Nominal Cross Section for **Copper** (mm^2)	Equivalent Cross Section for **Aluminium** (mm^2)	Maximum Permissible Current Rating (Amp)	Allowable Voltage Drop (mV/(A/ m)	Weight per 1000m Delivery Length of Copper (Kg)	Weight per 1000m Delivery Length of Aluminium (Kg)
4 x 16	4 x 25	95	2.5	1430	888
4 x 25	4 x 50*	130	1.5	1992	1620
4 x 35	4 x 70*	150	1.0	2243	2072
4 x 50	4 x 95 *	186	0.72	2869	2612
4 x 70	4 x 120*	220	0.55	3858	3072
4 x 95	4 x 150	255	0.43	5074	3692
4 x 120	4 x 185	288	0.36	6330	4453
4 x 150	4 x 240	329	0.29	7460	5595
4 x 185	4 x 300	370	0.25	9263	6784

***** Current rating of the selected equivalent aluminium cross section is slightly higher than the maximum permissible current rating.

Table 4 shows 50% increase in the selected aluminium cross section for the same current carrying capacity. This results in an increase in conductor size for aluminium conductor versus the copper conductors for the same current capacity but with a lesser weight.

From the above table, the difference in weight between 4 x 150mm^2 of copper and 4 x 240mm^2 of aluminium armoured cable is 1865Kg. Similarly, the difference in weight between 4 x 185mm^2 of copper 4 x 300mm^2 of aluminium armoured cable is 2479Kg. This indicates that for applications where weight is a concern, aluminium may be the better choice as it is the case in high voltage (HV) applications.

Short-Circuit Current**:** The cross section of conductor necessary for a cable is dictated by its ability to carry short circuit current besides the continuous load current. Cable must be protected against sustained overload and short-circuit current by adequately dimensioned device such as circuit breaker or fuses. But conversely, the cable has to be selected so that it is effectively protected by the devices chosen for the network.

To assist selection of conductors' cross section, the graph of figure 3 provides minimum cross section of conductor required to sustain various levels of short-circuit currents for PVC insulated copper and aluminium conductors.

6. Results and Discussion

From the comparison tables 2 and 3; it is revealed in table 3 that aluminium has a cross sectional area larger than that of copper for the same current capacity for armoured/non armoured cable types but copper is found to be three to four times more expensive than the price of aluminium for the same current rating as presented in table 2.

From table 2 for example, the cost of an application that requires 4 x 70mm^2 copper main cable is #12,170, while the cost of aluminium equivalent, 4 x 120mm^2 is #2790. Therefore, with the reviewed information in table 3, aluminium is still three to four times cheaper than copper.

Many cable end users appreciate this price difference between the two, but they don't have personal experience with 1-kV armoured/non armoured cable with aluminium conductor and therefore they are hesitant to change. Despite the fact that copper price has been on the rise (details in figure 1) and are impacting negatively on every Nigerian cable industry in the cost of cables, Nigerians are still reluctant to switch to aluminium. The variance in cost between copper versus aluminium cables is now affecting the customer's buying decision and consequently slowing down capital projects at both state and federal levels.

Again, many consultant specifications and end user specifications require copper only conductors throughout their projects. Some of these specifications could be relics from the time when aluminium was not the best choice due to difficulty encountered in the joining of aluminium conductors and this had been addressed in section 3.1.

Since copper has become probably the most watched of the commodities for those with a macroeconomic bent like Nigeria, there should be a lot of public awareness and development activity as to how to replace copper with aluminium in 1-kV network applications. As earlier mentioned, majority of the civilized countries in Europe, Asia and America have over the years taken advantage of aluminium over copper by making extensive use of aluminium conductors in mains cables.

7. Conclusion

From the analysis carried out in the use of aluminium conductor in 1-kv armoured and non-armoured cables, it has been seen that aluminium is the alternative material in cable industry now, especially as copper prices continue to increase while the aluminium market remains steady. This and other advantages enumerated in this discussion are worthy of consideration to make a change into aluminium conductor mains cable in Nigeria a necessary objective.

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