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A research on high voltage cables consisting of different conductors having the same rated voltages

Aynı anma gerilimlerine sahip farklı iletkenlerden oluşan yüksek gerilim kabloları üzerine bir araştırma

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Abstract

Aluminum and copper conductors are commonly used in the transport of energy. In this work, high-voltage cables occurring aluminum and copper conductors exposed to the same rated voltage values are analyzed. In order to obtain the same current carrying capacity for copper and aluminum conductors, the relationship between the cross-sections has been determined and then the most appropriate cross-sectional values for each conductor are identified. Three different cross-sectional values have been selected for each conductor type and the calculations for the cables are carried out by using the Cable Ampacity Calculations Program (CYMCAP) within the framework of the International Electrotechnical Commission (IEC) standards. The performance of the cables has been compared in terms of material losses, cable structures and the cable costs. It is seen from the simulation results that aluminum conductor cables have lower cost and higher electrical loses than the copper conductor cables.

Keywords: Aluminum and copper conductors, Current carrying capacity, CYMCAP, Electrical power losses, High voltage underground cables

Öz

Alüminyum ve bakır, enerjinin taşınmasında yaygın olarak kullanılan iletkenlerdir. Bu çalışmada, aynı anma gerilim değerlerine maruz bırakılan alüminyum ve bakır iletkenlerden meydana gelen yüksek gerilim kabloları analiz edilmiştir. Bakır ve alüminyum iletkenlerinin aynı akım taşıma kapasitesine sahip olabilmesi için kesitleri arasındaki ilişki tespit edilerek her bir iletken için en uygun kesit değerleri tanımlanmıştır. Her iletken tipi için üç adet farklı kesit değeri seçilmiş ve kablolara ait hesaplamalar International Electrotechnical Commission (IEC) standartları çerçevesinde Cable Ampacity Calculations (CYMCAP) programı kullanılarak gerçekleştirilmiştir. Kabloların aynı şartlar altındaki performansları malzemeden kaynaklı kayıplar, kabloları oluşturan yapılar ve kablo maliyetleri açısından mukayese edilmiştir. Alüminyum iletkenli kabloların bakır iletkenli kablolara göre toplam elektriksel kayıpları daha fazla iken maliyetlerinin daha az olduğu görülmüştür.

Anahtar kelimeler: *Alüminyum ve bakır iletkenler, Akım taşıma kapasitesi, CYMCAP, Elektriksel güç kayıpları, Yüksek gerilim yeraltı kabloları*

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1. Introduction

The need for electrical energy in daily life has considerably been increased with the population growth, urbanization and industrialization (Casarino et al., 2018; Huang et al., 2019). Electricity generation sources can be classified into two groups as non-renewable energy sources and renewable energy sources. The most preferred energy sources in last decades are the fossil fuels, nuclear energy and hydraulic energy. On the other hand, hydraulic power plants, thermal power plants, natural gas cycle power plants, wind and solar power plants can be expressed as the most preferred power generation methods.

Energy transmission and distribution is as important as energy production (Casarino et al., 2018). The electrical energy generated in the power plants is delivered to the end-user through electricity transmission and distribution lines. Nowadays, electrical energy transmission is realized by different systems above or below the ground (Alanne & Cao, 2018). While the electricity transmission above ground is carried out by the electric poles, underground electricity transmission is being performed by the buried cables.

Power lines are divided into two groups as low and high voltage lines. Voltage values equal to or lower than 1000 volts are called as low voltage while the values higher than 1000 volts are high voltage. High-voltage lines are being used between the power generation plants and final downloader transformer. The transfer of high voltage directly to the end user is not suitable in terms of insulation and safety (Mueller et al., 2019). Therefore, low-voltage lines are preferred between the last downstream transformer and end user.

In electrical transmission and distribution lines, for open areas while the overhead conductors are used, in cities the underground cables are being preferred (Mueller et al., 2019). The underground cables are more expensive than overhead conductors in terms of installation, material and maintenance costs. However, the underground cables are mostly preferred in residential areas since they are safer and not cause visual pollution (Mueller et al., 2019).

Underground cables may be in single-core or multi-core according to their intended use. Three-phase systems can be designed by using only one cable with multi-core or numerous cables with single-core. These cables may also be armored or unarmored depending on their aim of use (IEC 60502-2, 2015) Underground cables are preferred according to their current carrying capacity, losses, cost and also by considering line route and geographical conditions. Within the framework of all these parameters, the electrical cables can be designed by using conductors consisting of different materials. Nowadays, conductors made of copper or aluminum are used in electrical transmission (IEC 60502-2, 2015; TS EN 60228, 2007) The physical properties of copper and aluminum conductors are given in Table 1.

Table 1. Physical properties of the materials

Properties	Unit	Copper (Cu)	Aluminum (Al)
Density	g/cm^3	8.96	2.71
Specific conductivity at 20 °C	Ω/m	58.14	35.46
Resistivity at 20 °C	Ω mm^2/m	1.72×10^{-8}	2.82×10^{-8}

The electrical conductivity of copper conductor is higher than the aluminum conductor. The purpose of these conductors used in cables is to carry the highest amount of current without disturbing the cable structure. Current carrying capacity also depends on multiple parameters (TS IEC 60287-1-1, 2003; TS IEC 60287-2-1, 2015; TS IEC 60287-3-1+A1, 2015; TS IEC 60287-3-2, 2012). Among the conductors on the earth, silver offers the highest electrical conductivity and it is followed by copper, gold and aluminum. However, copper is the most preferred conductor in cables since gold and silver are too expensive. For the same cross-section of copper and aluminum, the copper conductor is approximately 3.3 times heavier than the aluminum. In this case, the cost of the conductor increases considerably. Since the copper conductor cables are more expensive, aluminum conductor cables can sometimes be preferred in order to decrease the investment cost.

The selection of cables to be used in energy transfer is theoretically determined based on the IEC 60502-2 standards. The parameters of current-carrying capacity, electrical losses and cost have to be taken into account while determining the optimal cable type. Especially, parameters of conductor type, insulation type and the installation conditions have direct effect on current-carrying capacity. CYMCAP offers an effective alternative to eliminate all these uncertainties, choose the most suitable cable and verify the theoretical calculations. In this work, the current carrying capacity of high voltage underground cables are analyzed depending on the conductor type and possible electrical losses, which are difficult to detect in the laboratory environment, are characterized by using the CYMCAP program.

In order for copper and aluminum conductors to carry the same current in a line with the same voltage value, the conductor resistances must be equal as shown in Equation 1.

$$R_{Al} = R_{Cu} \,, \quad \left(R = \left(U/I\right)\right) \tag{1}$$

where U, I and R represents the line voltage, line current and resistance of the line, respectively. As seen from Equation 1, conductor cross-sections can be modified using Equation 2 in order to equalize the line resistances of two different conductors made of copper and aluminum.

The direct current (DC) resistance value on the line can be calculated by using Equation 2.

$$R = p\left(L/S\right) \tag{2}$$

where, p and S represents the resistivity and conductor cross-section, respectively. Furthermore, when the line lengths represented by L are considered as equal, it is seen that the ratio of the resistances of different conductors to each other becomes equal to the ratio of the cross-sections of the conductors.

If the resistivity values given in Table 1 for copper and aluminum conductors are written in Equation 2, the ratio of aluminum cross-sectional area (S_{Al}) to copper cross-sectional area (S_{Cu}) is approximately obtained as $S_{Al} / S_{Cu} = 1.6$. At first step, the two underground cables with copper and aluminum conductors that are exposed to the same voltage and desired to carry the same amount of current are dealt. The relationship between the cross-sections of the conductors of these two underground cables has been determined using Equation 2. According to the results obtained, different groups are formed so that the cables with the same current carrying capacity are in the same group. The groups formed are represented in Table 2.

Table 2. The groups according to current carrying capacity

	Cross section (mm^2)	
Groups	**Copper conductor**	**Aluminum conductor**
Group 1	95	95
Group 2	150	150
Group 3	240	240

In literature, there are few studies in which the copper or aluminum conductors are analyzed in different areas. In (Olivares et al., 2010), the physical properties of these two materials in the construction of transformer windings have been compared by Olivares and his friends. The physical properties compared in this work are the conductivity, the bulk density, the cost, the bonding, the oxidation, the workability and the behavior of these two materials under short circuit. It has been obtained from the analysis realized according to the prices for unit cost of copper and aluminum in November 2009 that for the transformers with nominal power lower than 190 kVA, aluminum is the best choice in the design of transformer windings. On the other hand, for 190 kVA and above power values copper has been stated to be better than the aluminum.

In this work, the performances of copper and aluminum conductor cables used in high voltage underground cables have been compared in terms of electrical losses and conductor costs. The CYMCAP (Version 7.0 rev.1) program has been used to analyze the performances of copper and aluminum conductors in varying cross-sections. By using CYMCAP program, cables with desired voltage values can be designed and also by changing many parameters, the effects of these parameters on the design can be examined.

CYMCAP based cable design processes has become an important area of research in recent years. (Ratkowski et al., 2022) have analyzed the effect of burying the cables in the channels, instead of burying them directly in the ground, on the current carrying capacity by using the CYMCAP program. Xiao et al. calculated the cyclic load carrying capacities of cables directly buried to the ground by considering heat transfer conditions and then compared the results to that of CYMCAP calculation results (Xiao et al., 2022). In addition, Fu et al. have combined the CYMCAP program and the genetic algorithm in order to examine the transient temperature increases in the power cables buried in the channels (Fu et al., 2021). Matuszak et al. developed a novel CYMCAP based cross-bonding method in order to optimize current carrying capacity and power losses in medium voltage cable lines (Matuszak et al., 2019). Finally, the effects of ambient temperature, connection pattern, channel size and installation depth parameters on the current carrying capacity have examined by Leon via CYMCAP (Leon 2006).

2. Material and method

2.1. Identification of the cables used in simulations

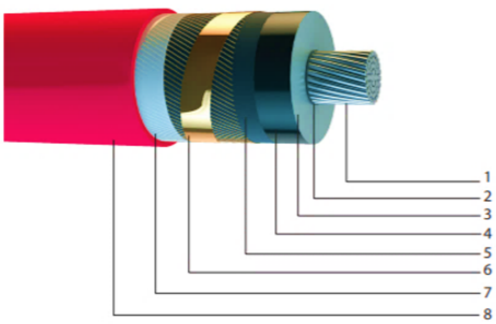
In this section, detailed information has been given for the cables used in the simulations.

The rated voltages of high voltage underground cables can be defined as U_0/U_m. In this expression, U_0 is the voltage value at the rated mains frequency. This voltage occurs between the conductor and the ground or between the conductor and the metal shield on which the cable is designed. U represents the voltage value at the rated mains frequency between the conductors on which the cable is designed. Finally, U_m can be defined as the highest system voltage at which the device can be used (IEC 60502-2, 2015). In this work, the simulations have been realized by using the cables with rated voltage value of $18/30(36)\,\mathrm{kV}$.

The cables are coded using some standard symbols for international convenience, the symbols of the cables used in this work are N2XSY and NA2XSY. According to the Verein Deutscher Elektrotechniker (VDE) standards the symbols are being defined as the following,

N: Cables resistant to extreme conditions.
A: The conductor material is aluminum. But if not specified, the conductor is copper.
2X: Insulation material, Cross-linked polyethylene (XLPE).
S: Single core and copper screen.
Y: PVC outer sheath.

The underground cables used in this work consists of eight layers as shown in Figure 1, the conductors are at the center of the cables. These conductors made of copper or aluminum can be produced as twisted-braided (TS EN 60228, 2007).



1.Copper or Aluminum Conductor Compacted - Class 2
2. Inner Semi Conductive Layer
3. XLPE Insulation
4. Outer Semi Conductive Layer
5. Semi Conductive Swelling Tape
6. Copper Wire and Tape Screen
7. Seperating Tape
8. PVC Jacket

Figure 1. Structure of the N2XSY or NA2XSY, copper or aluminum conductor, single core, high voltage power cables

Cross-linked polyethylene (XLPE) has been used as the insulation material. For XLPE insulated cables the maximum conductor temperature is about 90 ° C and short circuit temperature is about 250 ° C (Huang et al., 2016; Alanne & Cao, 2019; Mueller et al., 2019; IEC 60502-2, 2015). XLPE insulated cables are more preferred than PVC due to their temperature features because for PVC the conductor temperature is about 70 ° C in normal operation and short circuit temperature is about 140-160 ° C (IEC 60502-2, 2015). However, the outer sheath can be made of PVC or polyethylene (PE).

2.2. Layers forming the cables

Three different load groups are created in the simulations. In the first group 1*95/16 mm^2 (Copper conductor) N2XSY and 1*150/25 mm^2 (Aluminum conductor) NA2XSY; in the second group 1*150/25 mm^2 (Copper conductor) N2XSY and 1*240/25mm^2 (Aluminum conductor) NA2XSY; and in the last group 1*240/25 mm^2 (Copper conductor) N2XSY and 1*400/35mm^2 (Aluminum conductor) NA2XSY energy cables have been used. The voltage values of the cables in all groups are selected as 18/30 kV. Table 2 is taken as reference in determining the conductor cross-sections of the cables in the groups.

In this work, three cables with copper and aluminum conductors consisting of the same layers in different sections are used for each group as in Table 2. The design parameters such as conductor type used in the cable, its twist shape and diameter, conductor insulation thickness, XLPE insulation thickness, outer semiconductor thickness, copper screen wire diameter and PVC sheath diameter have been included to CYMCAP program as default values before the simulations. For the cables used in the simulations, the cable designs realized in the CYMCAP program are represented in Figure 2. All parameters given for cable layers are defined by IEC 60502-2 standard. The dimensions of the layers forming the cables are given below in Table 3. By using the values given in Table 3, the designs have been realized separately for each of the 6 cables.

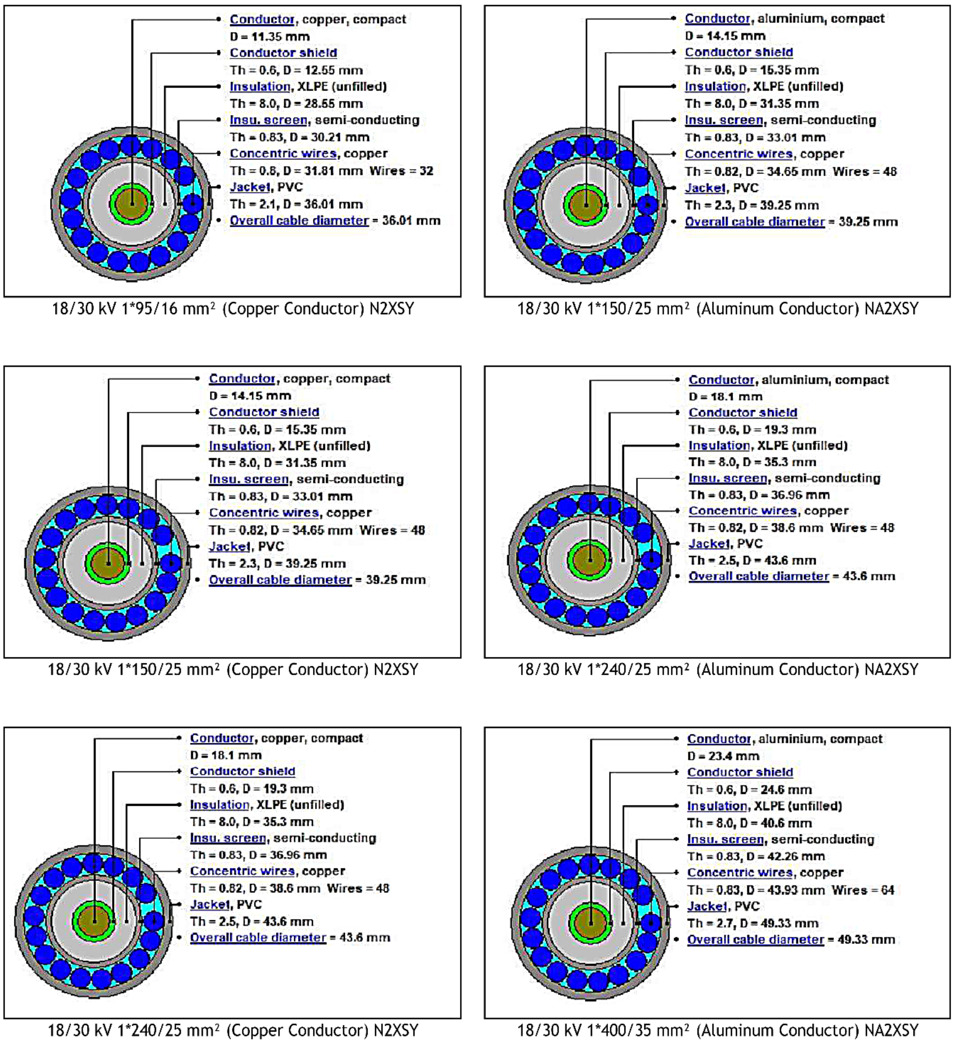


Figure 2. The design of the cables with CYMCAP

Table 3. Layers and quantities of the cables

Comparison groups (each group is compared with 2 cables in itself)	Cables	Conductor cross- section (mm^2)	Conductor diameter (mm)	Inner semi conductive layer thickness (mm)	Insulation (XLPE) thickness (mm)	Outer semi conductive layer (mm)	Copper screen (mm^2)
Group 1	18/30 kV 1*95/16 mm^2 (Copper conductor) N2XSY	95	11.35	0.6	8	0.83	16
	18/30 kV 1*150/25 mm^2 (Aluminum conductor) NA2XSY	150	14.15	0.6	8	0.83	25
Group 2	18/30 kV 1*150/25 mm^2 (Copper conductor) N2XSY	150	14.15	0.6	8	0.83	25
	18/30 kV 1*240/25 mm^2 (Aluminum conductor) NA2XSY	240	18.1	0.6	8	0.83	25
Group 3	18/30 kV 1*240/25 mm^2 (Copper conductor) N2XSY	240	18.1	0.6	8	0.83	25
	18/30 kV 1*400/35 mm^2 (Aluminum conductor) NA2XSY	400	23.4	0.6	8	0.83	35

2.3. Laying conditions of underground cables

The performances of the underground cables may also vary according to laying conditions. In (Bustamante et al., 2019), the effects of ground resistance and cable depth on the current carrying capacity in high voltage underground cables has been investigated by Bustamante and friends. In their studies for cable depths ranging from 0.5 m to 3 m, they obtained the result that the maximum temperature of the cable will increase with an increase in the installation depth (Bustamante et al., 2019).

In this work, in order to ensure that all cables to operate under the same conditions, the parameters given in Table 4 has been kept constant for all cables. Also, the parameters directly affecting the working performance of the cable such as soil thermal resistance, soil temperature, distance between cables and laying depth of the cable have also been taken as with fixed value for all cables. Due to the use of XLPE as an insulation material, the operating temperature is limited to a maximum of 90 °C because chemical deterioration may occur in XLPE materials at temperatures higher than 90 °C. Among the cables laid side by side in Figure 3, the cable in the middle is partially exposed to the temperature of the cables on its right and left. For this reason, the maximum operating temperature of the middle cable is 90 °C while the others are 85 °C.

Table 4. Conditions for laying cables under the ground

Description	Unit	Value
Thermal resistivity of native soil	°C.m/W	1.5
Ambient soil temperature at buried depth	°C	20
Maximum conductor temperature	°C	90
Frequency	Hz	50
Distance between cables (center-center)	m	0.2
Depth of laying	m	0.8
Load factor (*p.u*)	-	1

The cables can be laid to underground in ducts or they can directly be buried in the ground (IEC 60502-2, 2015). In this work, it is assumed that the cables are directly buried on the ground, and the way the burying of cables in the CYMCAP program has been shown in Figure 3. Due to 3-phase systems are considered in applications, three single-core cables have been used.

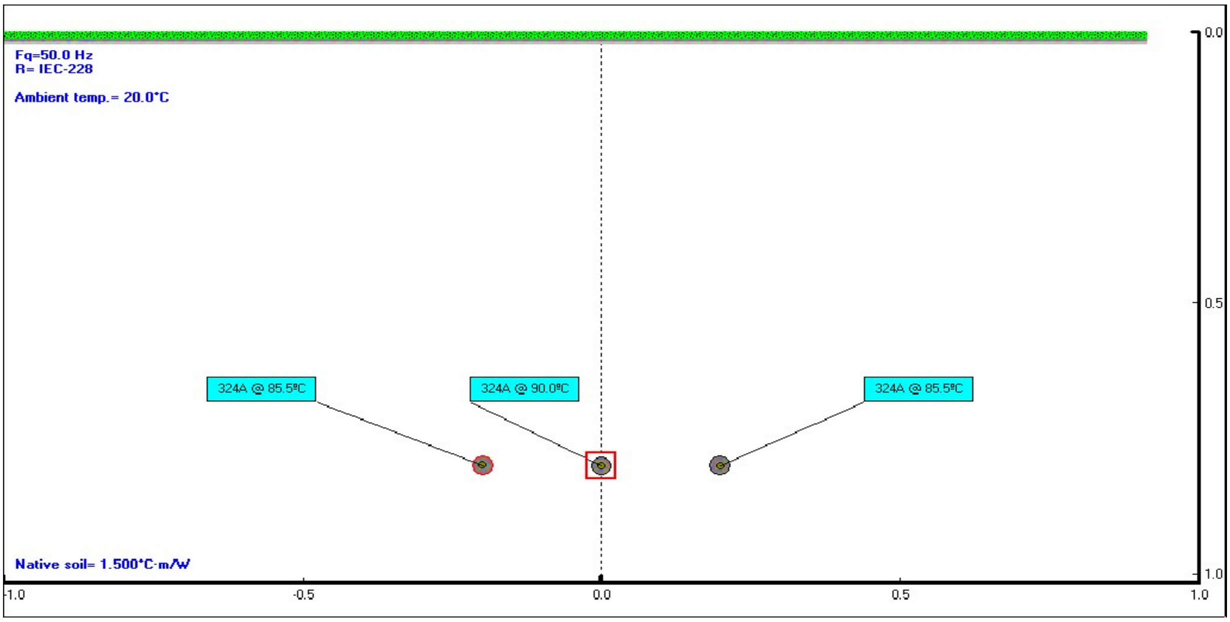


Figure 3. Laying of cables in CYMCAP

2.4. Obtaining of the electrical parameters

Since the cables analyzed are in 3-phase AC structure, the AC resistance values at operating temperature should be calculated by the following steps.

Step 1. The DC resistance (R^l) value at the operating temperature is measured according to the following statement.

$$R^l = R_0[1+\alpha_{2\alpha}(\theta - 20^\circ)] \tag{3}$$

where R^l is the DC resistance value measured at 90 °C, R_0 is the DC resistance value measured at 20 °C, $\alpha_{2\alpha}$ represents the temperature coefficient of the conductor and can be determined as

0.00393 for copper and 0.00403 for aluminum (TS EN 60228, 2007). Finally, the operating temperature (θ) is taken as 90 °C because of using XLPE insulation material (Huang et al., 2016; Alanne & Cao, 2019; Mueller at al., 2019; IEC 60502-2, 2015). Thus, the DC resistance value occurring at 90 °C can be found by using Equation 3.

Step 2. The AC resistance value R at working temperature is calculated by using Equation 4,

$$R = R^{l}\,[1+\gamma_s+\gamma_p] \tag{4}$$

Skin Effect (γ_s) and Proximity (γ_p) parameters also should be taken into account when calculating the AC resistance. In this work, the coefficients of these parameters are chosen as 1 for all cables in order to make a fair comparison. As a result of calculations, it is seen that the DC and AC resistance values at operating temperature found as equal.

The ratio of the electric charge of a conductor cable to its potential is defined as the capacity value of that conductor cable and is calculated by Equation 5 which is used to calculate the dielectric losses.

$$C = \frac{\varepsilon}{18\,In(\frac{D_e}{D_i})} \tag{5}$$

In this equation, ε is the dielectric constant of the insulator and it is taken as 2.5 for XLPE 18/30 kV voltage values (Karaca, 2016), D_e represents the outer diameter of the insulated conductor and D_i can be defined as the conductor diameter.

Conductive losses due to the current flowing through the cable are associated with the conductor resistance and the square of the current (Osman et al., 2014) and can be calculated using Equation 6,

$$W_c = I^2 R \tag{6}$$

where, W_c represents the conductor losses; I is the line current and R is the AC resistance at operating temperature. Conductor losses for single phase can be obtained by using Equation 6. The results obtained by using Equation 6 and given in Table 5 are the loss values in single phase and these values should be multiplied by 3 for 3 phases.

Dielectric constant and loss factor are the most important factors determining the capacity value of an insulator. The value of loss factor should ideally be zero, but if the insulator is not ideal, a leakage current (I_l) occurs and this current causes dielectric losses. At high voltage or frequency an important amount of heat occurs as a result of dielectric losses. Therefore, the loss factor of the selected insulation material should be as small as possible. The loss factor is expressed by $\tan(\delta)$ and can be defined as the ratio of the leakage current to the capacitor current (I_c) as shown below (Taslak, 2014).

$$W_d = \omega C U_0^2 \tan(\delta) \tag{7}$$

In Equation 7 which is used to calculate the dielectric losses, ω represents the angular frequency and can be defined as $2\pi f$. $f = 50\,Hz$ is the operating frequency of the system and the capacity value C can be calculated by using Equation 5. U_0 is the voltage between phase and neutral and is taken as 18 kV. Also, $\tan(\delta)$ is taken as 0.004 for the XLPE insulation material (Karaca, 2016).

Table 5. Performance results of cables

Comparison groups (each group is compared with 2 cables in itself)	Cables	DC resistance of conductor at 20 °C (ohm/km)	AC resistance of conductor at operating temperature °C (ohm/km)	Capacitance (µF/km)	Ampacity (A)	Conductor losses (W/m)
Group 1	18/30 kV 1*95/16 mm^2 (Copper conductor) N2XSY	0.193	0.242	0.168	324	25.52
	18/30 kV 1*150/25 mm^2 (Aluminum conductor) NA2XSY	0.20	0.261	0.194	318	26.42
Group 2	18/30 kV 1*150/25 mm^2 (Copper conductor) N2XSY	0.124	0.156	0.194	411	26.42
	18/30 kV 1*240/25 mm^2 (Aluminum conductor) NA2XSY	0.125	0.158	0.231	416	27.47
Group 3	18/30 kV 1*240/25 mm^2 (Copper conductor) N2XSY	0.075	0.095	0.231	536	27.48
	18/30 kV 1*400/35 mm^2 (Aluminum conductor) NA2XSY	0.077	0.991	0.277	538	28.63

3. Results

In the simulations, electrical and cost analyzes are obtained by adhering to the parameter values defined in the international standards.

3.1. Performances of the cables under the specified conditions

A performance comparison has been made for the cables with different cross-sections with copper and aluminum conductors and having the same current carrying capacity in theory. For this purpose, cables with different conductors and theoretically equal current carrying capacities are compared in pairs under the names of groups 1, 2 and 3 in Table 5.

For the cables within each group the DC resistors at 20 °C, alternative current resistances at working temperature, capacitance, current carrying capacity, conductor losses and dielectric losses has been compared.

3.2. Analysis of current carrying capacities

According to the results obtained with Equations 1 and 2 the cross-section of aluminum conductors which are expected to have the same current carrying capacity with copper conductors should be 1.6 times to that of copper conductors' cross-section. The results obtained in analysis can be given as the following.

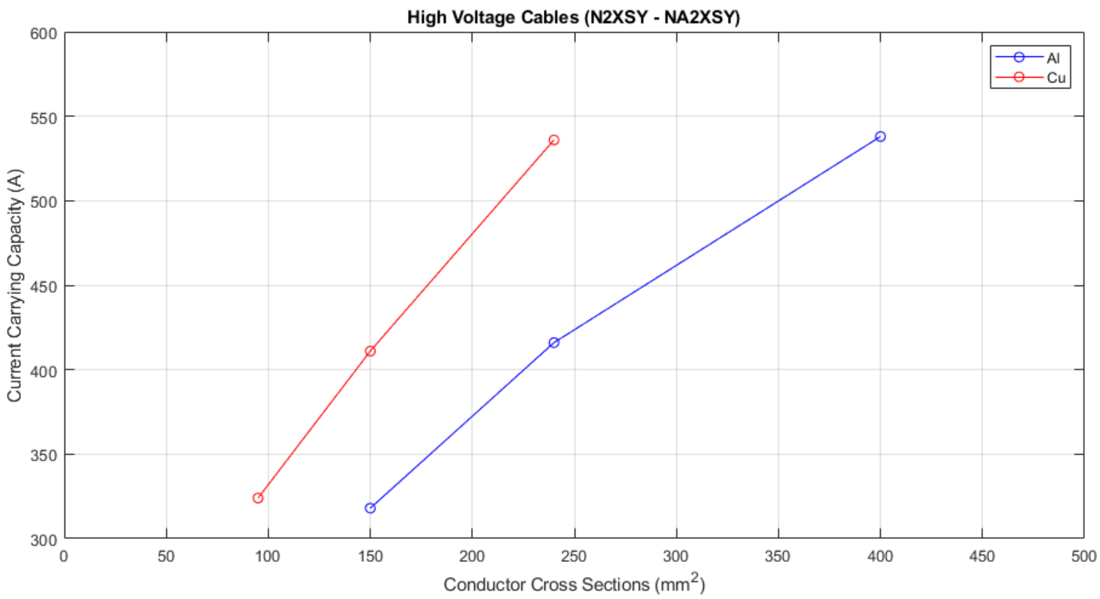


Figure 4. Variation of current carrying capacity versus conductor cross section

As seen from the figure in Group 1, copper conductor carries 324 A and aluminum conductor carries 318 A, in Group 2, copper conductor carries 411 A and aluminum conductor carries 416 A and in Group 3, copper conductor carries 536 A and aluminum conductor carries 538 A.

While the current carrying capacities in the groups should be equal in theory, it has been observed that there are deviations in the range of % 1-2 according to the simulation results.

3.3. Analysis of the losses

In this work, losses in underground cables are analysed in two groups including conductor losses and dielectric losses. The resistances of copper and aluminum materials have been effective in conductor losses. The difference between the conductor losses for single phase given in Figure 5 has been found as 0.9 W/m in Group 1, 1.05 W/m in Group 2 and 1.15 W / m in Group 3. In addition, as the conductor cross-sections grow it is seen that the difference between these losses has been increasing. Although the insulation material and insulation thickness are the same, different dielectric losses has been obtained due to the different capacity values in Equation 7. It is seen that the ratio of D_e/D_i for aluminum conductors has been obtained as different to that of copper conductor in the same group. Since the ratio of D_e/D_i among these cables in the same group is lower in copper conductor cables, it can be stated that dielectric losses will be lower in copper conductor cables. Moreover, it is seen that the difference between dielectric losses increases while the conductor cross-sections increase. For single phase, the difference between dielectric losses has been obtained as 0.010 W/m in Group 1, 0.013 W/m in Group 2 and 0.018 W/m in Group 3. Also, the total losses for each group have been shown in Figure 5.

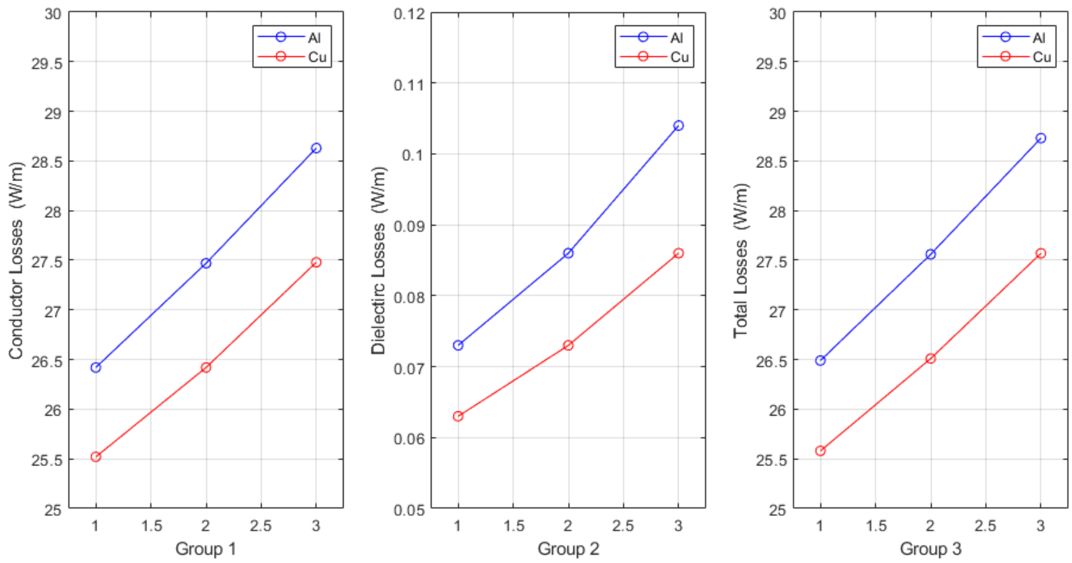


Figure 5. Total losses occurring for each group

3.4. Cost analysis

For the copper and aluminum conductor cables which are thought to have the same current carrying capacity in theory within each group, only the amount of conductor used for power transmission has been calculated. Prices have been determined according to London Metal Exchange (LME) values dated 02.10.2023. It is seen at the relevant date that copper raw material prices are approximately 3.56 times more expensive than aluminum. When the investment costs of the conductors exposed only to phase-to-phase voltage are compared, it has been identified that the cost of copper is approximately 7.28 times higher than the aluminum, as shown in Table 6. However, it can be expressed when all the components of the underground cable are taken into account that this cost difference will be reduced. In addition, the amount of all other materials used will also increase due to the larger cross-section of the aluminum cables.

Table 6. Comparison of conductor costs without copper screen

Comparison groups (each group is compared with 2 cables in itself)	Cables	Quantity (kg/km)	Amount ($/km)
Group 1	18/30 kV 1***95**/16 mm^2 (Copper conductor) N2XSY	845.5	6.958
	18/30 kV 1***150**/25 mm^2 (Aluminum conductor) NA2XSY	405	934
Group 2	18/30 kV 1***150**/25 mm^2 (Copper conductor) N2XSY	1.335	10.987
	18/30 kV 1***240**/25 mm^2 (Aluminum conductor) NA2XSY	648	1.495
Group 3	18/30 kV 1***240**/25 mm^2 (Copper conductor) N2XSY	2.136	17.579
	18/30 kV 1***400**/35 mm^2 (Aluminum conductor) NA2XSY	1.080	2.492

Al: 2.307 $/Kg - Cu: 8.230 $/Kg (LME 02.10.2023)

4. Discussion and conclusions

In this work, the performances of high voltage underground cables with aluminum or copper conductors has been analyzed and compared via CYMCAP software. In order to obtain the same current carrying capacity in theory, cross-section ratios between conductors has been found by equalizing the resistance values. Since the aluminum conductor has larger cross-section than the copper conductor, it is seen that these two conductors have different performances in terms of cable performance and cost. In the simulations, these cables has been analyzed in terms of the current carrying capacities, the electrical losses and the costs. From the results obtained it can be concluded that current carrying capacities of aluminum and copper conductors are close to each other. It is also seen that aluminum conductor cables are more disadvantageous than copper conductor cables in terms of electrical losses and dielectric losses. However, it has been identified that the cost of aluminum conductor cables is lower due to the fact that both the raw material costs are less expensive and the unit weight of aluminum is lower.

The CYMCAP based performance analyzes have been realized for the cables of different cross-sections of two different conductors which are expected to carry the same current in theory. Since the change of the insulation material will affect the nominal operating temperature of the cables, the current carrying capacity will also be directly affected. Similarly, it is known that the distances between the cables and the laying conditions of the cables are directly affecting the transmission quality. Therefore, in future works new analyzes can be carried out by changing parameters such as type of insulation material, laying type of cables, laying depth of cables and soil thermal resistance. Moreover, the performances of the cables of different conductors in the same cross-section may also be compared.

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Author contribution

The authors contributed equally to the research.

Declaration of ethical code

The author of this article declares that the materials and methods used in this work do not require ethical committee approval and/or legal-specific permission.

Conflicts of interest

The author declares that there is no conflict of interest.

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