Performance Analysis of Underground Power Cables Configuration with Different Backfill Materials

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ABSTRACT

The fundamental constructions of power cables get more complex as transmission power range and voltage increase because they must be built to withstand higher strength and heat buildup. A dependable electrical system with a long operating lifetime will be made possible by adequately installing underground cables. This paper investigates the performance analysis of cable laying configuration in the duct. The temperature distribution of underground cables based on the finite element method (FEM) in the Heat Transfer in Solids (ht) module was analysed using COMSOL Multiphysics software. This study investigated the relationship between different types of cable backfill material and the cable's temperature distribution. Besides, this study analysed the influence of different cable cross-sectional areas and duct types on temperature distribution based on different backfill materials. The proposed materials for cable backfill were Air, Sand, and Fluidized Thermal Backfill (FTB). Each material has a different value of thermal conductivity. The investigation was conducted with constant boundaries such as cable depth, type of cables, and cable laying position. The simulation results indicate that the temperature distribution within the underground cable is influenced by the type of backfill material used and its thermal conductivity. Using air backfill material as the reference, it is found that sand and FTB provide a temperature reduction of 80.5% and 82.53% respectively. The use of HDPE ducts provides a 3 to 4°C temperature reduction compared to PVC ducts, while smaller cable size increases the temperature significantly. The results also indicate that sand is a good alternative to FTB, having comparable performance with cheaper cost.

Keywords: Power cable temperature, Power cable configuration, Backfill material

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1. INTRODUCTION

Underground power cables are increasingly preferred for expanding power supply networks, particularly in urban environments, where safety, reliability, and space constraints make them more advantageous than overhead lines. These cables offer several benefits, including improved safety, reduced risk of damage from environmental factors, and enhanced aesthetic appeal. However, ensuring their long-term and efficient performance requires careful consideration during installation, particularly regarding thermal management [1]. Improper heat dissipation is one of the most common causes of cable degradation and failure, as excessive temperatures can lead to insulation breakdown, reduced ampacity, and eventual system failure.

In many urban areas or regions prone to ground movement, flooding, or rodent activity, cables are often installed in protective ducts to safeguard them against external damage. However, this protective approach can also hinder heat dissipation, leading to higher temperatures around the cable [2]. The thermal performance of underground cables, particularly those installed in non-metallic ducts like PVC, is therefore a critical factor in determining their efficiency and reliability [3]. Backfill materials surrounding these ducts play a vital role in managing heat dissipation, as they help conduct heat away from the cable and into the surrounding soil.

The selection of appropriate backfill materials is essential for preventing overheating and potential thermal degradation of the cables. The thermal conductivity of these materials directly influences the operating temperature of the cables and, consequently, their lifespan and performance. Research has shown that improving the thermal properties of the backfill materials can significantly enhance the cable's ability to dissipate heat, ensuring stable operation even under high electrical loads [4].

Therefore, this study aims to explore the thermal performance of underground power cables installed with different backfill materials. By comparing the thermal properties of various materials, the research seeks to identify those that provide optimal heat dissipation and reduce the likelihood of cable overheating. The findings from this research will contribute to the development of best practices for underground cable installations, particularly in urban areas, resulting in improved reliability, reduced maintenance costs, and extended cable lifespan. Understanding the relationship between backfill material selection and thermal performance is crucial for optimizing underground power systems and ensuring their long-term efficiency.

2. BACKGROUND CONCEPTS

In power transmission and distribution systems, underground power cables are essential for ensuring a stable and reliable supply of electricity. These cables, buried beneath the surface, are often installed with backfill materials that play a crucial role in their thermal performance. Backfill materials are primarily responsible for dissipating the heat generated during cable operation, thereby maintaining the cables' operating temperature within safe limits and preventing thermal degradation. The efficiency of this heat dissipation is influenced by several factors, including the electrical load of the cable, ambient temperature, thermal conductivity of the surrounding soil, and the properties of the chosen backfill materials [5].

When underground power cables are installed in protective ducts, particularly in urban areas or locations prone to external stresses, the issue of thermal management becomes more pronounced. Ducts, often made of non-metallic materials like PVC or HDPE, tend to have higher thermal resistivity, which limits the dissipation of heat and can cause the cable temperature to rise significantly [6]. This increase in temperature affects the cables' current-carrying capacity, or ampacity, leading to reduced performance and reliability. Consequently, the thermal behavior of underground cables is heavily dependent on the thermal conductivity of both the duct material and the surrounding backfill.

In response to these challenges, concrete duct banks have been widely used in cable installations to reduce thermal resistance and enhance heat conductivity. These duct banks, typically constructed in stages with spacers to accommodate multiple cables, are often filled with concrete as the primary backfill material. This practice is common in North American communities, where medium voltage (MV) and low voltage (LV) cable systems are frequently laid in duct banks to fit multiple circuits in a single trench. By compacting each layer of backfill, the heat dissipation is further optimized, allowing for safer and more reliable cable operation.

Research has also shown that certain locations where cables are buried, such as beneath roadways or near railway crossings, are more susceptible to overheating due to external forces like vibrations or heavy traffic. In such cases, casing pipes or protective ducts are implemented to prevent mechanical damage and penetration [2]. These ducts, which are often used during the transition between buried cables and other infrastructure, provide an additional layer of protection while also influencing the thermal performance of the cable system.

Given these complexities, it is crucial to ensure that trenches are properly prepared, with enough space to prevent mutual heating effects between adjacent cables. The selection of appropriate backfill materials, combined with strategic duct design, can significantly impact the thermal performance of underground power cables, reducing the risk of overheating and improving their operational longevity.

2.1 Thermal Analysis

Thermal considerations dominate the design of a cable system. The generated heat must be dispersed into the surrounding ground or air. The thermal conductivity of each insulation layer, as well as the surrounding environment (earth, air), have a significant impact on cable cooling during operation, affecting the ampacity of the cables. Cable temperatures typically vary depending on the conditions [7].

Thermal distribution of underground power cables is critical when designing underground cable systems. Depending on the portion of the load supplied, buried lines produce varying amounts of radiating heat. This heat may reduce moisture levels in the backfill material surrounding the cable. This behaviour may cause dry and band formations around the cable, making the soil thermally unstable and potentially causing the cable's polymeric insulation to fail due to overheating [8].

Researchers have recently conducted extensive studies on thermal heat analysis in underground cables. According to research [2], the heat generated by electrical cables must be distributed by their surroundings in order to prevent the insulation from melting and keep the cable's operating temperature within acceptable limits. It was discovered that heat production causes moisture to leave the cable's immediate surroundings, reducing the cable's ability to conduct heat and causing it to warm up even faster.

The discharge of heat energy in the cable raises the temperature and increases cable resistance. As a result, the amount of electricity that can be delivered through a specific cable line is limited [5]. The use of a suitable cable backfill material is required for efficient heat dissipation from the wire [9]. Underground cable heat transfer works by transferring heat from hot areas (the conductor) to cold areas (the surrounding soil and environment). The cable's ampacity allows for the maximum amount of electric current to be delivered while maintaining the cable within optimum temperature limits. The temperature distribution of cables laid in ducts is strongly influenced by duct thickness and cable laying procedure [3].

According to Ossama, Adel, and Ghada's [10] hypothesis, a cable's longitudinal dimension is always significantly more extensive than its depth, turning the issue into a two-dimensional heat conduction problem. Conduction is thus the primary system of heat transport in an underground system.

The conductor at the cable's centre produces heat, but the dielectric material in the power cable restricts heat transfer. The power cables were cooled, and the heat flow surrounding them was controlled by using thermal backfill material, which assisted in dissipating the heat around the cable. The backfill material also disperse the heat produced by the cable conductor [11].

2.2 Cable Backfill Materials

Francisco de Leon [12] investigated whether using backfill material is more efficient when the mother ground has a low thermal conductivity. Some soils have low thermal conductivity by nature, such as dry sands, but low thermal conductivity can also occur when moisture migrates or the soil dries out. IEEE Standard 442 defines thermal resistivity measurement methodologies and assigns values to specific soils based on moisture content. Backfilling can be an effective way to prevent soil from drying out near a cable.

According to a study by [4], thermal backfill materials are frequently used to improve heat transfer from underground cables to surrounding soil. Backfill materials exceed native ground in terms of thermal conductivity and hydraulic conditions. To provide appropriate implementation, the thermal backfill material must have the following characteristics: lower critical moisture content, high temperature consistency limits, ease of installation without the presence of void spaces in the backfill composition, reasonable operation and material costs, and a backfill structure based on materials widely available at the site location. High thermal conductivity across a broad range of operating conditions [5].

According to [13], initiatives in North America have primarily focused on the use of special backfill mixtures with high thermal conductivity that remain balanced in the naturally occurring temperature difference around buried cables. Generally, it has been argued that special backfill materials with improved thermal properties are available and can be manufactured using a specific amount of water, sand (also known as fine aggregate), and cement to achieve low thermal resistivity (TR) values with little or no compaction. They also have simple installation procedures [14].

For identical cable interface temperatures, using backfill material can increase the heat transfer rate from a cable installation by 50% compared to the alternative. Because the backfill resistivity is greater than one-fifth of the value of the native soil resistivity, changes in the backfill thermal resistivity have a significant hypersensitivity [15].

Details on the backfill material specification used in this work is provided in Section 3.1 and Table 5.

3. METHODOLOGY

The proposed geometry for modelling is an 11kV single core cable with a cross-sectional area of 500 mm^2, Cu conductor, and XLPE insulation power cable. The parameters for this cable construction model are derived from the IEC 60502-2 standard and the manufacturing specification. The cable system's electric distribution determines the duct configuration.

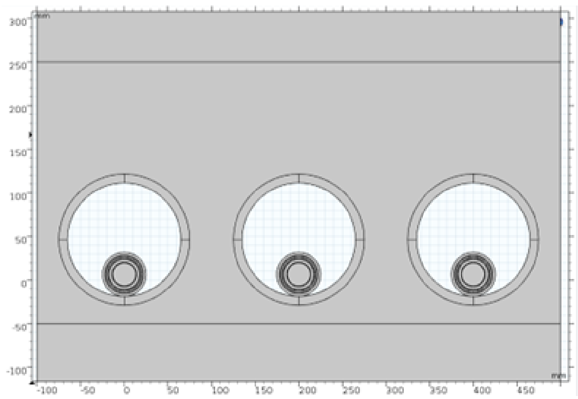

Fig. 1: *2D steady state of 11kV underground cable model.*

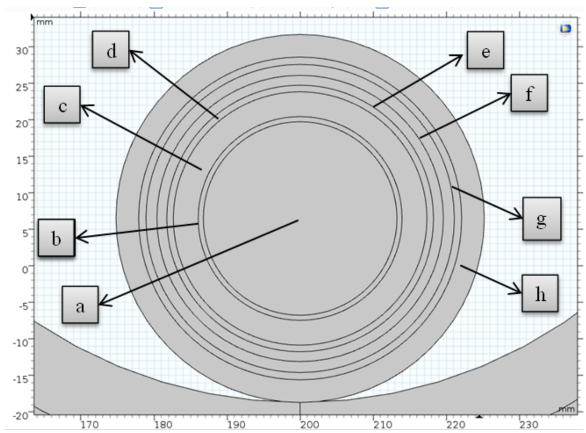

Fig. 2: *Schematic diagram of single core 11kV XLPE cable construction from COMSOL.*

This method generated a 2D model wizard for the XLPE underground cable in the ducts. This model was created to examine the relationship between the thermal conductivity of the cable backfill material and the temperature distribution within the cable.

Following the IEC 60502 standard, the single core underground cable used is the medium voltage 11kV cable system consisting of three power cables cross-linked polyethylene (XLPE) insulated with a cross-sectional area of 500 mm^2 and 70 mm^2. Both types of cable are laid in similar positions as shown in Fig.1.

The designed cables contain a solid cable core, cross-linked polyethylene (XLPE) insulation, metallic sheath, and non-metallic outer covering. The copper cable conductor is additionally segmented to reduce current losses. The design and instrumentation of the cable-layers in the suggested power cable are shown in Fig.2. The configuration and measurements used are not only correlated to IEC standards but also consider the manufacturer's specifications. The specifications of the unarmored single-core cables with copper wire screens as mechanical protection structure are tabulated in Table 1 and 2.

***Table 1**: Specifications of construction elements of 11kV cables presented in Fig.2.*

Pt	Constr. elements	Diameter (mm)		Material	Therm. Cond. (W/(m/K))
		$500mm^2$	$70mm^2$		
a	Conductor, d_c	26.5	9.7	Copper	400
b	Conductor Screen, d_{cs}	27.2	10.4	Copper screen	400
c	Insulation, d_{ins}	30.6	13.8	XLPE	0.3232
d	Insulation Screen, d_{inss}	31.6	14.8	Semi-conducting XLPE	3.0
e	Copper Wire Screen, d_{cw}	31.7	14.9	Copper	400
f	Inner Sheath, d_{ish}	35.7	18.9	MDPE	0.3
g	Separation Tape, d_{st}	37.2	20.4	Polyethylene	0.155
h	Outer Sheath, d_{osh}	41.2	24.4	MDPE	0.3

***Table 2**: Parameters of cable structure.*

Physical Quantity	Values (mm)
Nominal conductor diameter, d_c	26.5
Conductor screen thickness, δ_{cs}	0.7
Insulation thickness, δ_{ins}	3.4
Semi-conducive insulation screen thickness, $\delta_{ins,s}$	1.0
Copper screen wire thickness, δ_{cw}	0.1
MDPE inner sheath thickness, δ_{ish}	4.0
Separator tape thickness, δ_{st}	1.5
MDPE inner sheath thickness, δ_{osh}	4.0

Based on Table 1, the thermal conductivity of the cable core is 400 W/(m/K). As far as the research is conducted, the value of thermal conductivity for the XLPE insulation is 0.3232 W/(m/K) [16], the lapped copper screen and copper wire screen are 400 W/(m/K), the semi-conducting XLPE insulation screen is 3 W/(m/K), the polyethylene separator tape is 0.155 W/(m/K) and MDPE inner and outer sheath are 0.3 W/(m/K) [17].

Three case studies on temperature distribution were examined in this work, summarized in Table 3. The steady-state heat conduction equation in Eq. 1 is used to model the temperature distribution in the cable and surrounding materials (i.e. insulation, duct, backfill, and soil).

$$\nabla.(k\nabla T) + q = 0 \quad (1)$$

This equation is solved for each material layer (cable core, insulation, duct, backfill, etc.) with appropriate boundary conditions. The first case study is to analysed the effect of different cable backfill materials on temperature distribution in underground cable model. Next, the second case study is to analyse the influence of duct type on temperature distribution based on different backfill material. Last but not least, the third case study is to analysed the influence of cable sizing on temperature distribution based on different backfill material.

***Table 3**: Case study categories on temperature distribution.*

	Case Study 1	Case Study 2	Case Study 3
Title	Effect of different cable backfill materials	The influence of duct type on different backfill materials	The influence of cable sizing on different backfill material
Cable	11kV, single core, Copper conductor, XLPE insulation		
Nominal cross-sectional area (mm^2)	500		70
Current Carrying Capacity (A)	675		283
Duct	HDPE	PVC	HDPE
Backfill Material	Air, Sand, Fluidized Thermal Backfill (FTB)		

3.1 Duct and Backfill Model

The cables were laid in the ducts in a flat formation for simplicity. The geometry measurements of the underground cable laid in the ducts based on cable installation is shown in Fig. 3. The native soil was assumed to be a homogeneous medium with constant thermal conductivity. The boundaries of native soil have been accepted as a constant temperature of 20°C [18].

The cables were laid in HDPE (High-Density Polyethylene) ducts for Case Study 1 and 3 while for Case Study 2, the cables were laid in PVC (Polyvinyl Chloride). Both types of ducts use the same configurations, 150 mm in outside diameter with 10mm thickness [19]. The duct

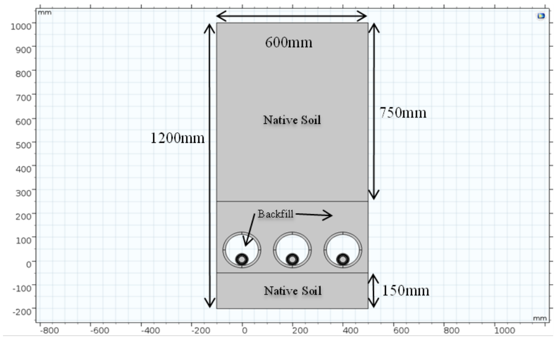

Fig. 3: Configuration diagram of 11kV underground cable in the duct.

Table 4: Specifications of HDPE and PVC duct.

Duct Configuration		
Material	HDPE (High-Density Polyethylene)	PVC (Polyvinyl Chloride)
Diameter (mm), d_D	150	
Distance between Ducts (mm), D_D	200	
Thermal Conductivity (W/(m/K), λ_D	0.48	0.16
Formation	Flat (in line)	

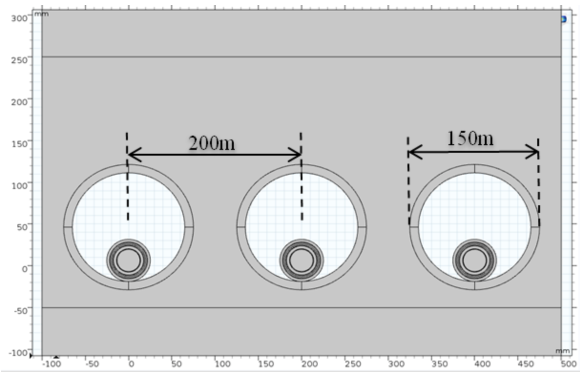

Fig. 4: Duct configuration.

was arranged in a flat formation with an axial separation diameter of ducts 200 mm at a thermal conductivity of 0.48 W/(m/K) for HDPE and 0.16 W/(m/K) for PVC. A minimum distance between circuits is set to be at least two (2) cable diameters. Details are provided in Table 4 while the graphical illustration can be found in Fig. 4.

Table 5 shows the material and thermal conductivity of the native soil and three different types of backfill material. IEC Standards [20] mention the thermal conductivity of λns = 1.0 W/(m/K) for the native soil [4]. This study proposes three types of backfill material: Air, Sand,

Table 5: Thermal conductivity of each material.

Material	Thermal Conductivity (W/(m/K)
Native Soil, λ_{ns}	1
Air, λ_{air}	0.025
Sand, λ_{sand}	0.8
Fluidized Thermal Backfill, λ_{FTB}	1.54

and Fluidized Thermal Backfill (FTB). FTB is composed of Portland cement, blast furnace slag, sand, and fly ash. Thermal conductivity for air is 0.025 W/(m/K) [21], while for the sand material is 0.8 W/(m/K). Besides, the thermal conductivity of the suggested backfill material, FTB, is significantly higher than 1.0 W/(m/K), which is 1.54 W/(m/K) [5].

In addition, for the simulation, the ambient soil temperature, T_{soil}, ambient air temperature, T_{air}, and maximum conductor temperature, $T_{c,max}$ is assumed to be 20°C, 45°C and 90°C respectively. The reference ambient temperatures for underground cables, either directly in the soil or in ducts in the ground is set to 20°C, based on IEC 60287-1-3 [21]. For the XLPE insulated-power cables, the maximum allowable temperature is equal to 90°C, based on IEC 60853-2. Above this limit, the underground power cables should not operate to avoid the XLPE material from melting. The simulation assumed steady-state conditions with no external cooling mechanisms. For the ambient air temperature, the value of 45°C is based on the industry best practices for underground installations.

4. RESULTS AND DISCUSSION

The 2D steady-state model of 11kV underground cable laying in flat formation in the ducts was established in COMSOL Multiphysics software. The study employs thermal modeling based on IEC 60287-1-3 and IEC 60853-2 standards to analyze the steady-state loading conditions of cables. The thermal analysis of underground cable was computed using the finite element method (FEM) in the Heat Transfer in Solids (ht) module. The electromagnetic heating interface was added by coupling the Magnetic Field (mf) and Heat Transfer in Solids (ht) to model the temperature distribution produced by heat generated from the cable conductor. The configuration and specifications of 11kV, XLPE insulated underground cable, three types of cable backfill material, and ducts were simulated based on standards, design manuals, literature reviews, and cable manufacturing data sheet. The study analysed different backfill materials (Air, Sand, and Fluidized Thermal Backfill), duct types (High-Density Polyethylene, Polyvinyl Chloride), and cross-sectional area (500mm^2 and 70mm^2). The temperature cable conductor values were recorded, and temperature

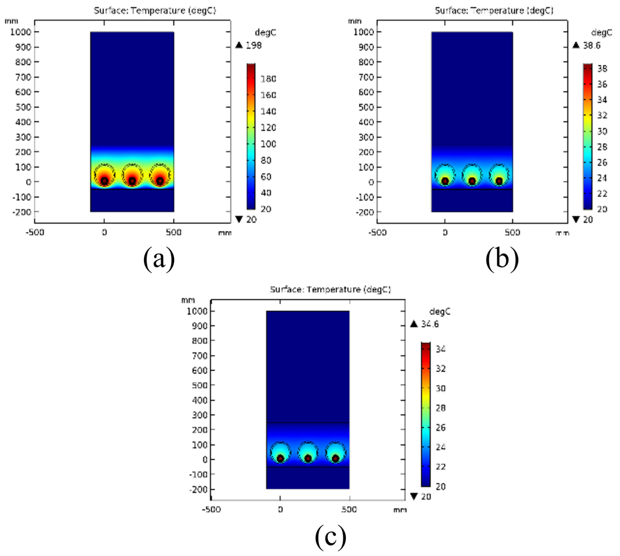

Fig. 5: Simulation result for Case Study 1: Backfill material (a) Air (b) Sand (c) FTB.

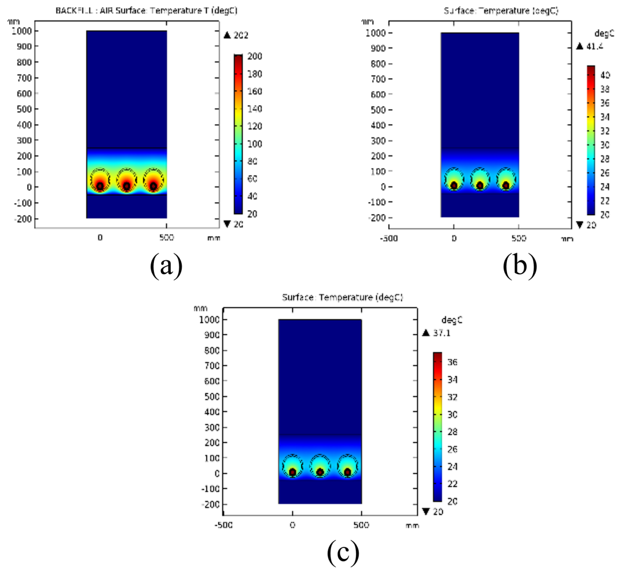

Fig. 6: Simulation result for Case Study 2: Duct type (a) Air (b) Sand (c) FTB.

distribution in underground cables was discussed.

4.1 Case Study 1 (Backfill Material)

The effect of cable backfills materials on temperature distributions of the flat buried cable in HDPE (High-Density Polyethylene) ducts when the 675A current carrying capacity flows through the conductor was shown in Fig.5.

The scope of this research is limited to assessing the thermal performance of underground cables under specific conditions without the inclusion of any additional cooling mechanisms. This method enables a direct comparison of the thermal properties of various backfill materials under the same set of assumptions.

As air has comparatively low thermal conductivity which is 0.025 W/(m*K) as stated in Table 5, it causes the highest possible temperature of the cable conductor to be 198°C. The thermal conductivity of sand is assumed to be 0.8 W/(m*K). Fig. 5(b) reveals that the maximum temperature of conductor cable in sand backfill is 38.6°C, considerably lower than in air backfill. Based on Fig. 5(c), the applied thermal backfill is FTB has a lower thermal conductivity than sand which is 1.54 W/(m*K). The result indicates that the maximum temperature of the cable conductor is 34.6°C.

4.2 Case Study 2 (Duct Type)

Fig. 6 illustrates the influence of duct type on temperature distribution based on different backfill material. In this case, the type of duct was changed to PVC (Polyvinyl Chloride) duct and effect of this changes on cable conductor temperature has been investigated.

The results depict the maximum conductor temperature when air is used as the backfill material is 202°C. This result indicates that if the cable backfill is not applied,

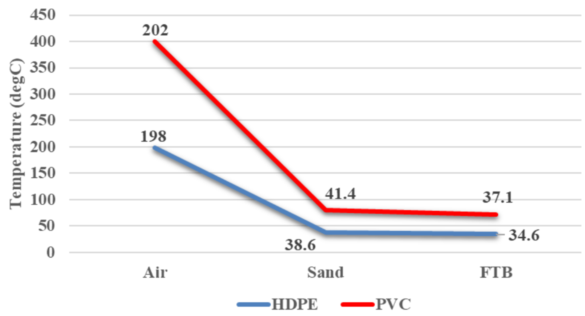

Fig. 7: The comparisons of temperature distribution between HDPE duct and PVC duct.

the cable conductor will attain a temperature of 202°C, significantly higher than the cable specification maximum temperature of 90°C. Meanwhile, the temperature of the cable conductor with sand backfill differs by 41.4°C from that of the cable core with air backfill. Finally, the maximum temperature of the cable conductor affixed to FTB backfill is 37.1°C, which is lower than sand backfill.

The temperature distribution of cables laid underground in a duct made of PVC is marginally higher than those laid in the HDPE duct as shown in Fig.7. PVC has a lower thermal conductivity than HDPE. The thermal conductivity of PVC is 0.16W/(m*K), while HDPE's is 0.48 W/(m*K), which is lower than HDPE. Thermal conductivity is a characteristic that determines the capacity of a material to conduct heat. A more excellent thermal conductivity permits a more efficient transfer of heat from the cable to the surrounding environment. In an HDPE duct, the heat generated by the cable can be dissipated more effectively, resulting in a lower cable temperature than in a PVC duct.

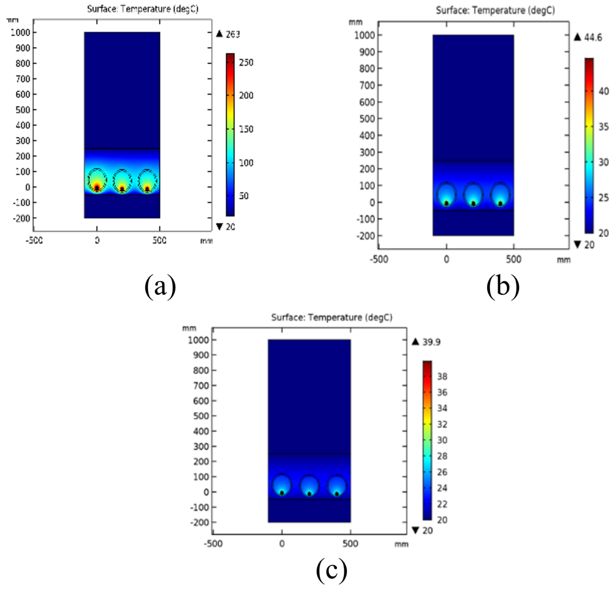

Fig. 8: Simulation result for Case Study 3: Cable sizing (a) Air (b) Sand (c) FTB.

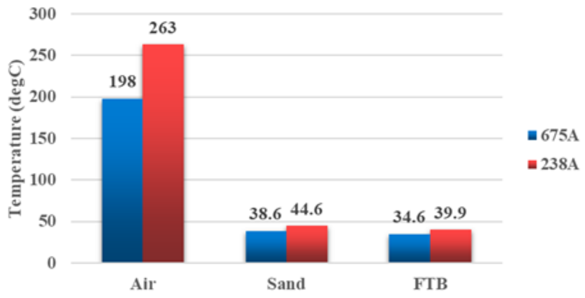

***Fig. 9**: The comparisons of temperature distribution between the cross-sectional area of 500mm^2 and 70mm^2.*

4.3 Case Study 3 (Cable sizing)

In this case study, a smaller cross-sectional area of underground cable was applied which is 70mm^2. This study is to analyze the influence of thermal conductivity backfill material on cable conductor temperature. Fig.8 below depicts the temperature distributions when the current carrying capacity is fixed at 238A.

Fig. 8 indicates that for the backfill material of air, the cable conductor may exceed a maximum temperature of 263°C. Meanwhile, the highest conductor temperature in sand backfill is 44.6°C, far lower than in air backfill. And finally, for FTB, the maximum temperature of the cable conductor is 39.9°C.

The difference in current carrying capacity flows in the conductor will affect the amount of heat the cable generates. Based on the standard, the larger the cable's cross-sectional area, the greater the current it can carry without overheating. A cable with a cross-sectional area of 70mm^2 can carry less current than one with a cross-sectional area of 500mm^2 without overheating.

As can be seen from Fig.9, when the crossing sectional area of the cable is 500mm^2, the current carrying capacity will be greater, which is 675A. The current carrying capacity of a conductor cable is directly related to the temperature resistance of the conductor; thus, the greater the current can flow through the conductor, the temperature resistance of the conductor will be decreased, allowing it to dissipate the heat more effectively. Hence, producing a lower temperature distribution at the conductor.

However, when the cross-sectional area of the cable is 70mm^2, the current carrying capacity will be lower, which is 238A. Therefore, the smaller the current that can flow through the conductor, the conductor's temperature resistance will increase, producing higher temperature distribution at the conductor.

In Case Study 3, the same duct size was used for both cable sizes (500 mm^2 and 70 mm^2) to maintain consistency in the simulation setup and to isolate the influence of cable sizing on temperature distribution. This approach allows for a direct comparison of the thermal performance of the cables under identical external conditions, ensuring that any observed differences in temperature distribution are solely attributable to the change in cable size and not influenced by variations in duct dimensions.

In general, the expected result from this study is the FTB material will provide a better heat dissipation effect on the conductor as this material has higher thermal conductivity than air and sand. With a better heat dissipation effect on the conductor, the performance of the temperature distribution in the cable will enhance. Hence, FTB is the most suitable material to be used as backfill material in the underground line.

Table 6 summarizes the maximum temperature reduction percentage when the maximum temperature of the cable conductor is compared between air material and thermal backfill material of sand and FTB. From the above table, Fluidized Thermal Backfill material showed the highest temperature reduction compared with sand, with an average reduction for each case is 83%. Besides, the average reduction percentage when using sand backfill for each case is 81%. This analysis proves the importance of using thermal backfill material in underground cables. When cable backfill is applied instead of air, the cable conductor temperature can be reduced by more than 80%.

Air has an extremely low thermal conductivity of 0.025 W/(m*K), causing the maximum temperature of the cable conductor in every case to exceed the limit operating temperature for cable conductors, which is 90°C. The heat created in the conductor must be released onto the surrounding area. If the heat cannot be dissipated, the temperature of the conductor will continue to increase until the cable exceeds its temperature rating. At that point, the cable will start to deteriorate. The insulation could melt, resulting in electrocution and fires. The thermal conductivity of FTB is greater than that of sand. Therefore, the effect of the power cable's heat dissipation significantly increases.

The backfill's thermal conductivity variation modifies

***Table 6**: Percent reduction of maximum temperature based on backfill material.*

	Case Study 1		
	Air	Sand	FTB
Max Temp (°C)	198	38.6	34.6
Percentage (%)		80.50	82.53
	Case Study 2		
Max Temp (°C)	202	41.4	37.1
Percentage (%)		79.50	81.63
	Case Study 3		
Max Temp (°C)	263	44.6	39.9
Percentage (%)		83.04	84.83

***Table 7**: Estimated cost comparison of backfill materials.*

Backfill Material	Thermal Conductivity (W/(m/K)	Estimated Cost (USD/m^3)
Air	0.025	Negligible
Sand	0.8	\$50-\$100
FTB	1.54	\$150 - \$300

the electrical cables' heat transfer intensity. The larger the conductivity, the faster the soil receives heat and thus lowers the cable conductor's temperature. When a thermal backfill with high thermal conductivity is applied to the analyzed system, the temperature gradients inside the cable and backfill are lowered. As a result, the heat from the power cable dissipated more efficiently into the surrounding environment.

4.4 Cost Considerations

While it is expected that materials with higher thermal conductivity provide better heat dissipation, the practical implementation must consider cost constraints. Table 7 presents an estimated cost comparison for different backfill materials based on industry prices per cubic meter. The cost values were estimated based on market research, and supplier quotations on construction materials. Fluidized Thermal Backfill (FTB) has the highest cost due to its cementitious composition, while sand is more affordable but less thermally conductive. This analysis suggests that FTB is preferable in high-load applications where thermal management is critical, whereas sand may be a cost-effective choice for lower-power installations.

5. CONCLUSION

The temperature distribution of an 11kV single-core underground cable laid in a ducted model was established in this paper. The COMSOL Multiphysics software was used to build the finite element method of Heat Transfer in the Solids module, which allowed for the analysis of temperature distribution in the underground cable system. The impact of three cable backfill material types on underground cables' temperature distribution was investigated. The thermal conductivity of air was simulated at 0.025 W/(m*K), material Sand at 0.8 W/(m*K), and fluidized thermal backfill (FTB) at 1.54 W/(m*K). The higher the thermal conductivity of the backfill material, according to the analysis, the lower the temperature of the cable conductor. As a result, using FTB as a cable backfill material can reduce cable conductor temperature by an average of 83%. The effect of cable cross-sectional area and duct type on underground cables' temperature distribution was also investigated.

The current carrying capacity that flows through the conductor of the 500mm^2 cross-sectional area cable is greater than that of the 700mm^2. The temperature resistance in the 500mm^2 cable decreases, as the current flows are 675A compared to 238A in the 70mm^2 cable. When the cable's temperature resistance reduces, the maximum temperature on the cable conductor drops, allowing the cable to disperse heat more efficiently to the surrounding environment. Because HDPE ducts have better thermal conductivity than PVC ducts, heat can be transferred from the cable to the surrounding environment. As a result, underground cable in an HDPE duct has a lower temperature distribution than underground cable in a PVC duct. Finally, Fluidized Thermal Backfill (FTB) with a thermal conductivity of 1.54 W/(m*K) is preferable for underground cable backfill. In addition, moisture content in backfill materials plays a crucial role in their thermal properties. Soils with higher moisture content exhibit better thermal conductivity than dry soils. The thermal performance of backfill materials can also vary with time as moisture levels change due to weather conditions and drainage.

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