Optimization of the Direct Buried Characteristics for 11kV Underground Cable Installation

Shangari K. Raveendran
College of Engineering, Universiti Tenaga Nasional, Malaysia
shangari@uniten.edu.my

Daniel Arokiam a/l Michael Thevadass
College of Engineering, Universiti Tenaga Nasional, Malaysia
danielam93@gmail.com

***Abstract*— Direct buried is the most common and widely used installation method for underground power cable system. However, the installation characteristics that have been used in recent times do not have an optimum level of cable ampacity which could not support the increasing demand of electrical energy utilization. Besides, the existing installation characteristics have deteriorated the operational lifetime of the cables and in many cases have led to cable failure. Therefore, this projects aims to optimize the installation characteristics for underground cable system. The new optimized installation characteristics will ensure that the 11kV underground cable system is able to transmit electricity with an optimum cable ampacity. Throughout this project, CYMCAP software have been used to model and simulate the installation configuration based on the entered parameters in order to calculate the cable ampacity. The objective of this project have been achieved by recommending two new installation characteristics for the 11kV underground cable that can deliver an optimum cable ampacity. The two new optimized installation characteristics are firstly in changing the insulation material and secondly in changing the backfilling material. Hence, by using these two new optimized installation characteristics, the 11kV underground cable will be able to transmit electricity at higher ampacity and also increase the operational lifetime of the power cable whilst minimizing the occurrence of cable fault.**

Keywords—*Direct Buried; Underground Cable; Cable Ampacity.*

I. INTRODUCTION

Underground cable installations are widely being implemented in all over the world because of its reliability and less environmental concerns. The massive economic development in a country also demands for more underground cable network rather than overhead cable lines. Rapid urbanization is also another key factor for the implementation of underground cable network. In Malaysia, the underground cable installation mainly involves medium voltage network. The main advantage of underground cable installation is reducing outages that are usually caused by climate condition. Besides, underground cable installation also preserves the aesthetics value of the particular area. However, the high cost for installation and repair works in case of damage for underground cables is the main disadvantage. The difficulty to locate fault which usually time consuming is one of the reason for utility companies not to consider underground cable installation.

There is various method of installation being practiced worldwide. The most widely used method of cable installation is direct buried. The direct buried method requires digging up trenches in order to lay the cable underground. The planning and designing stage of underground cable installation using direct buried method are greatly influenced by its cable configuration, depth of installation, soil thermal resistivity, and ambient temperature. These characteristics are known as the influential parameters that affects the cable ampacity.

Hence, optimizing the installation characteristics to deliver an optimum level of cable ampacity is essential in order to provide a better heat transfer process for the installed underground cable. The optimized installation characteristics can help to ease the heat dissipation process from the cables and thus increase the operation lifespan of the cable itself.

Currently, the cable ampacity obtained from the existing installation characteristics of direct buried method could not cater the increasing demand for electrical energy utilization. Therefore, this project is deemed necessary to ensure that the installation characteristics for the 11kV direct buried underground cable are optimized in order to meet the electrical current demand caused by the increasing population in Malaysia.

II. DIRECT BURIED METHOD OF INSTALLATION

This is the most common and preferred method of installation for underground cable system. Practically, the cables that are buried in trenches are excavated at site in accordance with the standard dimension being set by the utility company. The trenches are sized by taking into consideration about the number of cables to be laid underground. Besides, the maximum current loading that a cable can carry will also be considered during the designing stage of trench dimension. One main aspect that needs to be taken care off during the installation process is that the trenches should be free from any foreign materials such as stones or glasses that may harm the buried cables.

Choosing direct buried method as an option for underground cable installation is definitely because of its advantages. One of the main advantages of this method is that the installation process is way simpler compared to any other alternate methods. Secondly, direct buried method possesses a lower cost of installation and gives the higher cable ampacity.

Nevertheless, direct buried method also possesses some disadvantages. This type of installation is the main contributor for cable breakdown since it is likely prone for third party digging [1]. Apart from that, direct buried method of installation would cause poor eyesore for the road user during the installation process whereby the trench will

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remain opened until the cable laying process is performed [1].

Direct buried underground cable is proved to be the second cheapest technology after overhead lines. Looking at the lifetime operation cost, buried method is the least expensive technology used for underground installation [1]. Hence, it can be said that direct buried is the most favorable method for underground cable installation.

III. Cable Ampacity

Cable ampacity or known as the current carrying capacity is defined as the maximum electric current that a conductor can safely carry without exceeding the insulation rated limit. Emphasizing cable ampacity during the planning stage of underground cable installation is utmost important in order to meet the continuous increase in demand of energy utilization in the electrical power system. The ampacity of the underground cable heavily rely on the rate of heat generated within the cable as well as the rate of heat dissipated from the cable itself to the outer environment.

The ampacity of the cables is greatly influenced by a multitude of factors. The ampacity of the cables heavily rely on the dominant of limiting factor. The limiting factor for cable ampacity is referred as the withstanding temperature of insulating material. For each insulating material, the maximum operating temperature will be taken into consideration to determine the maximum electric current that the cable can safely carry. For this project, two insulation materials will be considered which are XLPE and EPR insulation.

Besides, the prominent factor that will affect the cable ampacity is the thermal characteristics possess by the backfilling material that is installed to cover the direct buried underground cable. The capacity of the backfilling material to extract heat from the cable and dissipate them to the outer environment such as the surrounding soil or atmosphere will determine the ampacity of the installed underground cable.

IV. Cable Insulation

The insulating material provides insulation between the conductor and earth to avoid dielectric failure. Cable insulation helps to relieve electric stress and ensures that the conductors do not come in contact with other metal substances. Typically insulating material should possess a high electrical resistance in order to prevent the flow or leakage current between conductor and the earth. There are many type of insulating material used for underground electrical cable. Howver, as far as this project is concerned, only two insulating material which are cross-linked polyethylene insulation and ethylene propylene rubber insulation shall be reviewed. In general, both of this insulation is the most predominant materials used for cable construction.

XLPE was introduced since the year 1960's as an insulating material for low, medium and high voltage power cables. This XLPE insulation used for the underground cable system is able to operate in both wet and dry environments. In Malaysia, XLPE cables are widely being used in the distribution and transmission lines because of its high reliability intended for transmitting electrical power.

EPR is the most common insulating material used in many countries to insulate power cables. However, in Malaysia, this insulating material is still under consideration to replace the widely used insulating material which is XLPE. This is because EPR insulation is known for its good physical and electrical properties. Generally, EPR is known as an alternative insulating material for polyethylene compound. EPR is a result from the polymerization of ethylene monomer with propylene [2]. An added filler compound is cross-linked with copolymers in order to produce the EPR insulating material. The added filler or called as inorganic fillers is used to improve the mechanical properties of the insulating material. The Table 1 below shows the comparison of XLPE and EPR insulating material.

Table 1: Comparison between XLPE and EPR

Feature	XLPE	EPR
Thermal Performance	Operating: 90°C Overload: 140°C	Operating: 105°C Overload: 140°C
Dielectric Strength	Good	Good
Resistance to Partial Discharge	Weak	Excellent
Insensitiveness to Water Treeing	Weak	Excellent
Dielectric Losses	Very Moderate	Moderate

V. Backfilling Material

Backfilling material is used to increase the current carrying capacity of the installed underground cable. The presence of backfilling material can increase the rate of heat dissipation from the cable to the outer surrounding and in return increases the maximum allowable conductor current.

Practically, the cables that are buried underground will be covered with the native soil. This native soil is the least expensive backfilling material that can be used for an underground cable trench. The thermal resistivity of the native soil is 2.0 °C-m/W and is considered as very high [3]. So, it is often impractical to use the native soil as the backfilling material as well as generally being undesirable for optimizing the heat transfer process away from the cables [4]. Therefore, it is necessary to install a new backfilling material layer.

The new backfilling material should have better heat transfer characteristics. For a material to be considered a good thermal backfill, it must have thermal resistivity of 1.0 °C-m/Watt or less measured at dry condition. Dry condition is assumed to be the worst case scenario for heat transfer characteristics. The typical values of backfilling material used would be in the range of 0.50 to 0.75 °C-m/W [4].

Apparently, in Malaysia, washed river sand is used as the new layer of backfilling material for the direct buried underground cable. The disadvantage of washed river sand is that it has poor thermal properties during dry condition compared to any other backfilling material. The thermal resistivity of the washed river sand is 1.2°Cm/W [3]. This indicates that the washed river sand dries quickly if the surrounding soil does not have high moisture content with relatively low rate of heat dissipated from cables.

There is another backfilling material which is currently being used worldwide for underground cable system. This backfilling material is known as fluidized thermal backfill (FTB). FTB is made up of "high slump" material that is engineered by the soil specialist to have low thermal resistivity based on a prepared mix design. The mix design varies based on application but generally comprises, sand, aggregate, cement, fluidizers and water and is supplied by a ready-mix concrete supplier [5]. The thermal resistivity of FTB material is measured to be 0.65°Cm/W which is considered to possess good thermal characteristics [5].

VI. SIMULATION RESULTS

The installation configuration involving one, two and three circuits of 11kV direct buried underground cable was modelled and simulated using the CYMCAP software. CYMCAP software is dedicated in performing ampacity calculation for power cable installation. Trefoil formation is being adopted as the cable laying arrangement for this project. Figure 1 to 3 shows the sample arrangement for one, two and three circuit respectively.

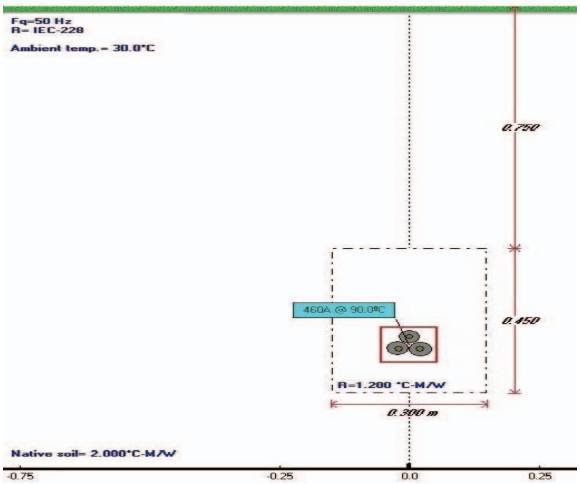

Figure 1: Sample arrangement for one circuit

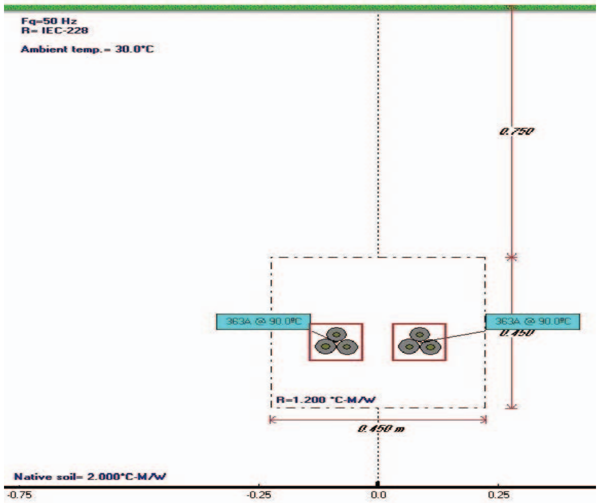

Figure 2: Sample arrangement for two circuits

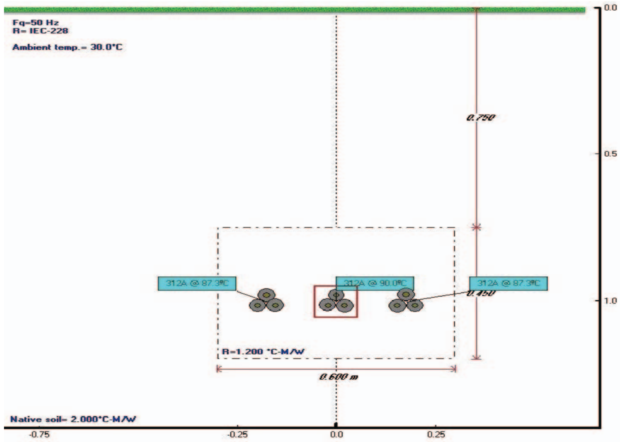

Figure 3: Sample arrangement for three circuits

When more than one circuit is being buried in the same trench, then a minimum distance of two cable diameter should be maintained. For this project especially when two and three circuits are being simulated, the distance between the circuits is maintained based on the minimum distance required.

On the other hand, some important parameters need to be set in the CYMCAP software in order to carry out the required simulation. Table 2 below summarizes the simulation parameters value.

Table 2: Simulation Parameters

Parameters	Value
Native Soil Thermal Resistivity	2.0 º C .m/W
Ambient Temperature	30^0C
Conductor Temperature	90^0C
Bonding Arrangement	Cross Bonded
Duct Type	Cable not in Duct

Having in mind that the installation characteristics of the direct buried underground cable need to be optimized, it is preferable first to study on the ampacity obtained for the existing practice of installation characteristic for direct buried underground cable. The existing practice of installation characteristics uses XLPE as its insulating medium and aluminium as the conductor type with the cross sectional area of the single core cable is 500mm^2. Figure 4 below shows the cross sectional model of the existing installation characteristics.

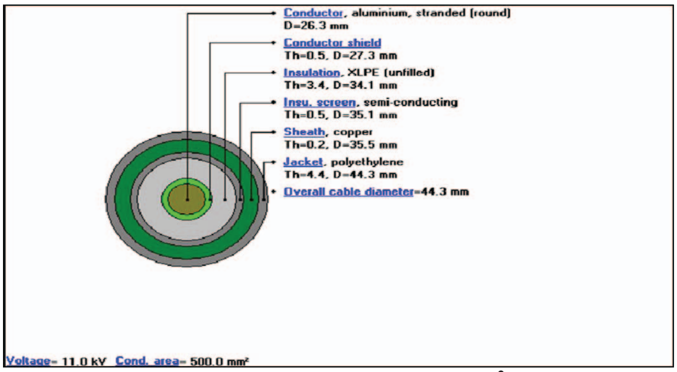

Figure 4: Cross sectional model of 11kV 500mm^2 XLPE 1C AL underground cable

The depth of installation is set in CYMCAP with respect to the existing guideline that is being practice by TNB during the cable laying process. The depth is fixed at 1.05 m.
Table 3 below shows the ampacity result obtained through simulation for the existing TNB direct buried cable laying practice.

Table 3: Ampacity result for typical TNB cable laying practice

Number of Circuit	Cable Ampacity (A)
One Circuit	460
Two Circuit	361
Three Circuit	311

Four alternate characteristics are being proposed to be simulated to obtain the ampacity result and in which then will be compared with the ampacity result obtained from typical TNB cable laying practice. In order to optimize the installation characteristics, the ampacity of the alternate characteristics should be higher than the typical TNB cable laying practice. The proposed alternate characteristics are changing the conductor type, changing the design of cable, changing the insulation material and changing the backfilling material

A. Changing the conductor type.

Figure 5 below shows the cross sectional model of the 11kV underground cable when the conductor type is changed from aluminium to copper.

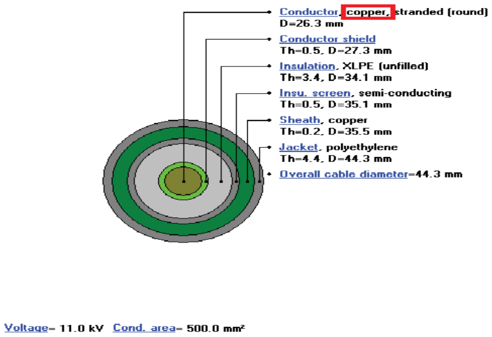

Figure 5: Cable design for copper conductor

Table 4 below shows the ampacity comparison between aluminium conductor and copper conductor.

Table 4: Ampacity comparison between aluminium conductor and copper conductor

TYPE OF CONDUCTOR	NUMBER OF CIRCUIT		
	One Circuit	Two Circuit	Three Circuit
	CABLE AMPACITY (A)		
ALUMINIUM	460	361	311
COPPER	577	453	390
PERCENTAGE DIFFERENCE	**+25.43 %**	**+25.48 %**	**+25.4 %**

As can be observed from the table, copper conductor gives a higher cable ampacity as compared to the aluminium conductor. The percentage difference calculated for the cable ampacity is huge with an average of 25%. Hence, with no any doubt it can be said that by choosing the copper conductor as a design for direct buried underground cable can optimize the cable ampacity with huge margin difference.

But however, copper conductor does exhibit some drawbacks. Copper conductor weights heavier than aluminium conductor. The copper conductor weights three times more than aluminium conductor. Besides, the price for copper conductor is very expensive as compared to aluminium conductor. Therefore, looking at the cost effectiveness criteria, aluminium conductor is the better choice compared to copper conductor. In other words, the 11kV 500mm2 1C XLPE AL cable could not be optimized by changing the type of conductor used.

B. Changing the design of the cable

Figure 6 below shows the cross sectional model of the 11kV underground cable when the design of cable is changed from single core to three core.

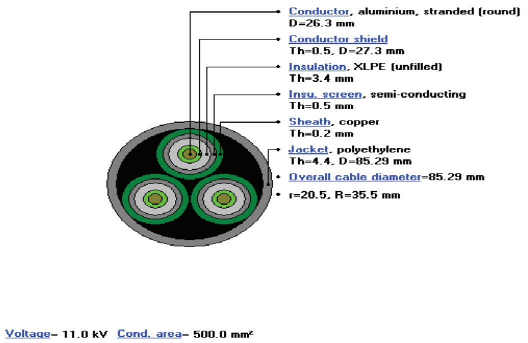

Figure 6: Cable design for three core cable

Table 5 below shows the ampacity comparison between single core and three core of 11kV 500mm^2 XLPE aluminium underground cables.

Table 5: Ampacity comparison between single core and three core cable

TYPE OF DESIGN	NUMBER OF CIRCUIT		
	One Circuit	Two Circuit	Three Circuit
	CABLE AMPACITY (A)		
SINGLE CORE	460	361	311
THREE CORE	447	356	307
PERCENTAGE DIFFERENCE	**-2.82 %**	**-1.39 %**	**-1.29 %**

It can be seen that the three core cable design has lower cable ampacity as compared to the single core cable design. This is due to that fact that single core has lower mutual inductance has compared to three core cable. Three core cables are normally designed such that each core in the cable is compressed and compacted. This causes less space factor between each core in the design of three core cable and eventually creates a higher mutual inductance.

Thus, the ampacity is lower for three core cable. The average percentage difference for the cable ampacity is calculated to be -1.83 %. Therefore, considering the declination of cable ampacity, the 11kV 500mm2 1C XLPE AL cable could not be optimized by changing the cable design by three core.

C. Changing the insulation material

Figure 7 shows the cross sectional model of the 11kV underground cable when the insulation material is changed from XLPE to EPR.

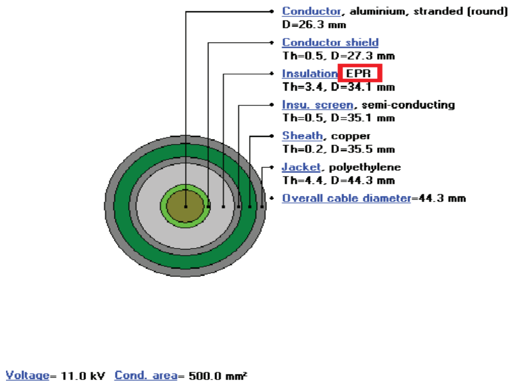

Figure 7: Cable design for EPR insulation

Table 6 below shows the ampacity comparison between XLPE and EPR insulation.

Table 6: Ampacity comparison between XLPE and EPR insulation

TYPE OF INSULATION	NUMBER OF CIRCUIT		
	One Circuit	Two Circuit	Three Circuit
	CABLE AMPACITY (A)		
XLPE	460	361	311
EPR	499	393	339
PERCENTAGE DIFFERENCE	**+8.48 %**	**+8.86 %**	**+9.0 %**

The ampacity result shows that the EPR insulation has higher ampacity compared to the XLPE insulation. The average percentage difference calculated is 8.78%. The inclination of cable ampacity is purely because EPR insulation has a higher maximum operating temperature which is 105°C as compared to XLPE insulation which is only at 90°C. The excellence thermal performance of EPR has cause the cable ampacity to be higher.

Apart from that, EPR insulation has an excellence dielectric strength, high resistance to partial discharge and insensitive to water treeing activities. This indicates that EPR is also able to increase the lifespan of the underground cable. Therefore, it is arguably agreed that 11kV 500mm2 1C XLPE AL cable can be optimized by changing the insulation material from XLPE to EPR.

D. Changing the backfilling material

The backfilling material is changed from the washed river sand to fluidized thermal backfill material (FTB). Table 7 shows the ampacity comparison between the washed river sand and FTB backfilling material.

Table 7: Ampacity comparison between washed river sand and FTB

TYPE OF BACKFILLING MATERIAL	**NUMBER OF CIRCUIT**		
	One Circuit	Two Circuit	Three Circuit
	CABLE AMPACITY (A)		
WASHED RIVER SAND	460	361	311
FTB	494	385	330
PERCENTAGE DIFFERENCE	**+7.39 %**	**+6.65 %**	**+6.11 %**

As can be seen from the table, the FTB backfilling material has a higher cable ampacity compared to wash river sand material. The average percentage difference between the two backfilling materials is 6.72%. It is a common known fact that the lower the thermal resistivity of backfilling material, the higher the cable ampacity. In view of that, FTB has a lower thermal resistivity which is at 0.65°Cm/W as compared to washed river sand which has resistivity of 1.2°Cm/W. Thus, FTB is able to deliver a higher cable ampacity.

Apart from its thermal characteristics, FTB possess a long term strength gain and high reliability for underground cable system. Therefore, it is highly noted that the 11kV 500mm2 1C XLPE AL cable can be optimized by changing the backfilling material from washed river sand to FTB.

VII. Conclusion

Therefore, the proposed optimization tool for the installation characteristics is changing the insulating material of the cable from XLPE to EPR and also changing the backfilling material from washed river sand to FTB. This project has proven that by changing those two installation characteristics, the cable ampacity is at the optimum level. This means that the cable ampacity delivered by the proposed new installation characteristics is higher when compared to the ampacity obtained from the existing guideline of installation characteristics which is being implemented by TNB in Malaysia.

Apart from optimizing the cable ampacity of the direct buried method of 11kV underground cable, the proposed optimization tool is also able to increase the lifespan of the cable and hence reduces the occurrence of cable fault. Besides, this proposed optimization tool can also reduce the total power loss in distribution system network. This is achievable by making sure that the cable insulation is operating at the maximum allowable temperature and the network is loaded based on the ampacity rating of the cable conductor.

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