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Computer Aided Design for Underground Cable System

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ABSTRACT

This paper proposes computer aided design for the distribution system of underground cable. Program computer can be help for searching the suitable size of cable which bases on many parameters such as voltage level, electrical load, the length of installation, temperature, power factor, the height of man hole, co-efficiency of ground resistance, type of duct bank and etc. Moreover characteristic of surge voltage and surge current wave form which take place both direct over head wire and neighbor over head wire influencing underground cable are studied. This is advantage for the designer to select the capacity of lightning arrester. This program is found to be useful significantly for engineers who design distribution system of underground wire because the program can mainly reduce the error which either make longevity of system shorter or cause losses of components higher. Developed time used for installation planing is also declined by the program.

I. INTRODUCTION

Conventional design and calculation are only estimated value and are mainly added skills. At the working area, the installations usually have error which cause the losses of materials, instruments, time, and even extended expenditure. Conventional plan, furthermore, usually have no energy analysis and possess no any parameters determination taken place in system. Hence, designers and users will not know authentic boundary and limitation of the underground distribution system effecting the damage and the decreasing lifetime of cable. On account of many databases and many equations such as voltage level, load capacity, characteristics of cable, configuration of installation, working area and etc, the design and analysis of underground cable system is very intricate. Computer and program Delphi, thus, are used as a tool to solve those problems. Simultaneously, lightning surge both on overhead wire and beside overhead wire are determined because these must relate to standard recommendation. Also, two types of sheath to ground connection effecting the underground system design are taken into account. This program can be utilized as a program software package in order to raise life span of underground cable.

II. THEORY

In the design for underground cable system, the rated current flowing in the cable is the first parameter to determine. However, there are different methodologies and standards to compute that. In this paper, the calculation of rated current is based on IEC 287 standard used worldwide and is rooted in Metropolitan Electricity Authority (MEA) of Thailand[2]. The computation of that is limited at steady state and possesses 100% load factor. The volume of current can be changed by three factors:

- ❒ The characteristics of cable such as thermal resistance
- ❒ Environment of the installed cable
- ❒ Information receiving from the meeting between manufacturer and user to save people from the utilization

From equivalent circuit of 3 cores cable in Figure 1, the rated current of underground cable can be calculated by Equation (1)

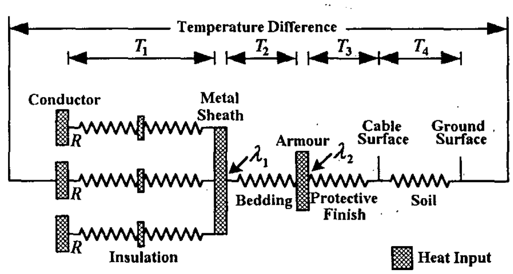

Figure 1: Equivalent circuit of 3 cores underground cable

$$I_{AC} = \left\{ \frac{\Delta\theta - W_d\left[0.5T_1 + n(T_2 + T_3 + T_4)\right]}{RT_1 + nR(1+\lambda_1)T_2 + nR(1+\lambda_1+\lambda_2)(T_3+T_4)} \right\}^{1/2} \quad (1)$$

when:

- I_{AC} = Rated current of underground cable
- $\Delta\theta$ = Maximum temperature (°C)
- R = AC resistance of conductor (Ω/m)
- W_d = Total power dissipated (W/m)
- T_1 = Thermal resistance between conductor and metal sheath (km/W)
- T_2 = Thermal resistance between sheath and armour (km/W)
- T_3 = Thermal resistance of outer covering or external serving (km/W)
- T_4 = External thermal resistance (km/W)
- n = Number of core
- λ_1 = Loss factor of armour or reinforcement
- λ_2 = Loss factor of sheath or screen

Value of the parameters in Equation (1) depend on

- ❍ Type of conductor, single core or three cores
- ❍ Characteristic of cable layout in duct bank
- ❍ Size of conductor
- ❍ Kind of material insulation

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❍ Position of duct bank
❍ Type of duct bank
❍ Type of cable, screen or belted

Thus, if only one parameter in Equation (1) is altered, output data of Equation (1), rated current, will be varied.

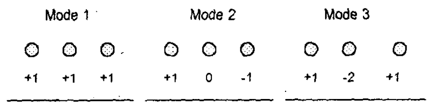


Figure 2: Mode of propagation

The study of lightning surge characteristic in underground cable has to determine the lightning surge both on[4] and near overhead wire that affect underground cable[5]. As a result surge characteristic analysis bases on complicated travelling wave, mode of propagation is used as a tool to separate voltage and current independently. Mode of propagation comprises of 3 mode, zero mode, alpha mode, and beta mode which are indicated in Figure 2. Three-phase conductors have the same behavior and have the same polarity in zero mode ([1 1 1]). On account of the turning back of current to ground, zero mode is generally called line-to- ground mode or homopolar mode. Alpha mode ([1 0 –1]), recognized as the first kind of line-to-line mode or phase-phase mode, merely has external propagation. Beta mode ([1 –2 1]) possesses external phase to consign current to load. Thus, the third mode of propagation is known as the second kind of line-to-line mode or interface mode.

From the lightning analysis by mode of propagation method, current injected into each mode can be calculated as follow:

$$[i_{o\alpha\beta}] = [T]^{-1}[i_{abc}] = \begin{bmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{2}} & 0 & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & \frac{-2}{\sqrt{6}} & \frac{1}{\sqrt{6}} \end{bmatrix} \begin{bmatrix} \frac{I_o}{2}\left(e^{-\alpha t} - e^{-\beta t}\right)U(t) \\ 0 \\ 0 \end{bmatrix} \quad (2)$$

i_{abc} = Current in three phase cable (A)
$i_{o\alpha\beta}$ = Current in mode of propagation (A)
I_o = Maximum current (A)
$v_{o\alpha\beta}$ = Voltage in mode of propagation (V)
$z_{o\alpha\beta}$ = Impedance in mode of propagation (Ω)
T^{-1} = Invert of transformation matrix (T)
t = Time (sec)
α = Increase rate of surge current
β = Ratio between velocity of lighting surge and electromagnetic wave in air
$U(t)$ = Unit Step Function, $U(t) = 0$ when $t < 0$ and $U(t) = 1$ when $t < 0$

The relationship between voltage surge and current surge at lightning point is described following this:

$$[v_{o\alpha\beta}] = [z_{o\alpha\beta}][i_{o\alpha\beta}] \quad (3)$$

and

$$[i_{abc}] = [T][i_{o\alpha\beta}]$$
$$[v_{abc}] = [T][v_{o\alpha\beta}] \quad (4)$$

III. FLOW CHART AND PROCEDURE

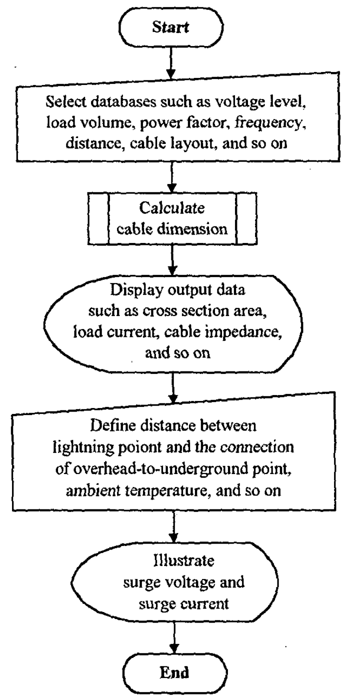


Figure 2: Main flow chart of the program

Figure 2 is the main flow chart of the design underground cable system. The first step supplies databases to the program. For example, Figure 3 is shown for selecting sheath-to-ground connection, size of duct bank, and cable layout. After that, cable dimension and cable properties are calculated and displayed. Figure 3 is shown only part of cable output. Then, those data of cable will be transferred to lightning analysis before user defines some parameters influencing surge characteristic. Program will separate and display output information of lightning surge both on and near over head wire in graphic mode as indicated in Figure 5 as well as Figure 6 respectively.

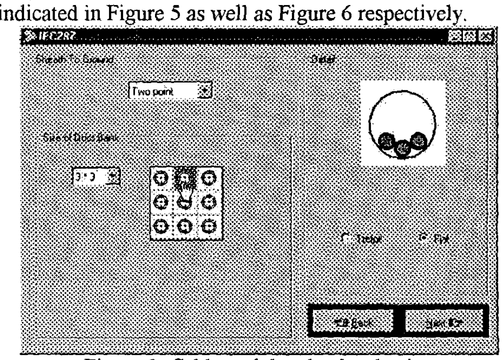
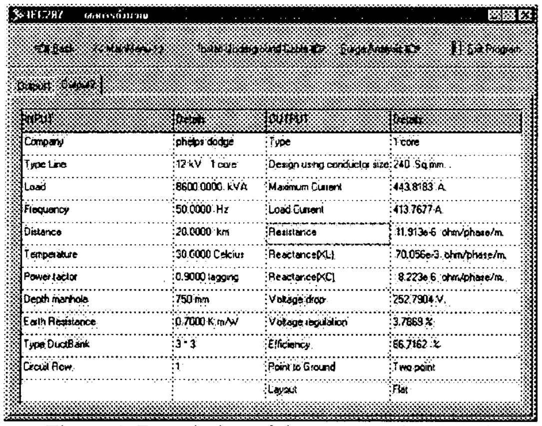


Figure 3: Cable and duct bank selection



INPUT	Details	OUTPUT	Details
Company	phelps dodge	Type	1 core
Type Line	12 kV 1 core	Design using conductor size	240 Sq.mm.
Load	8600.0000. kVA	Maximum Current	443.8183 A.
Frequency	50.0000 Hz	Load Current	413.7677 A.
Distance	20.0000 km	Resistance	11.913e-6 ohm/phase/m.
Temperature	30.0000 Celcius	Reactance(XL)	70.056e-3. ohm/phase/m.
Power factor	0.9000 lagging	Reactance(XC)	8.223e-6 ohm/phase/m.
Depth manhole	750 mm	Voltage drop	252.7904 V.
Earth Resistance	0.7000 K.m/W	Voltage regulation	3.7869 %
Type DuctBank	3 * 3	Efficiency	86.7162 %
Circuit Row	1	Point to Ground	Two point
		Layout	Flat

Figure 4: Description of the computed output data

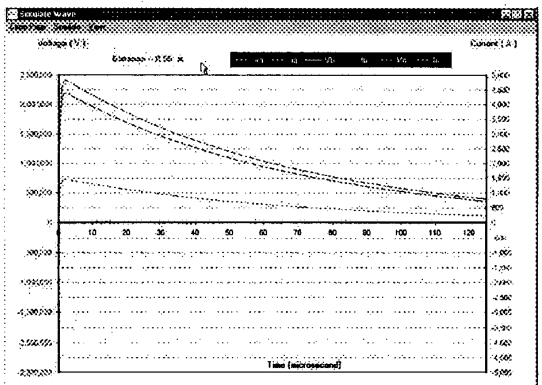


Figure 5: Surge configuration happening on overhead wire

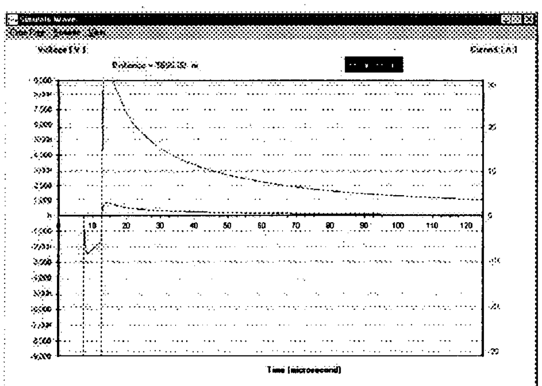


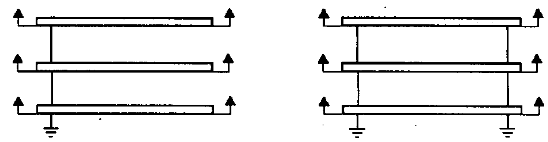
Figure 6: Surge property happening near overhead wire

IV. RESULT AND DISCUSSION

When some parameters comprising of voltage level 24 kV, XLPE one core with one conductor, electrical load 15,000 kVA, frequency 50 Hz, 0.75 power factor, distance of wiring 10 km, and size of cable 500 mm^2 are fixed, the changing another parameters which influence maximum flowing current in underground cable following IEEE 287 standard is studied. The characteristics of cable layout of underground wire and sheath to ground connection is indicated in Figure 7 and Figure 8, respectively.

(a) Cradle (b) Trefoil

Figure 7 : Characteristics of underground cable layout



(a) Single point (b) Two points

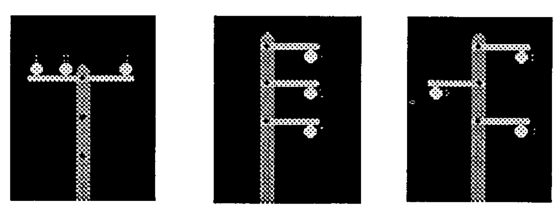
Figure 8: Characteristics of sheath to ground connection

From the analysis by program computer, the maximum flowing current changed in various conditions is shown in Table 1. From the table, we can conclude that:

- The higher ambient temperature of soil, the less maximum current in the cable.
- If the depth of duct bank increases, the flowing current in cable will decrease.
- Flat type of cable layout allows current flow more than trefoil type.
- Single point of sheath to ground connection can conduct current higher than two points of that connection.

In order to study the effect of lightning surge voltage and lightning surge current that impact the over head wire to underground wire connection in case of having no lightning arrester, maximum surge voltage and maximum surge current of both direct surge and beside surge of over head wire at about 100 m. from the connection between over head and underground wire, are investigated. The 3 characteristics of cable layout of overhead wire are illustrated in Figure 9. From the calculation by program, Table 2 represents those of studying which limit that direct surge is taken place on phase A of over head wire. So, the computed data in Table 2 can be summarized following this :

- The third type of over head cable layout has the lest lightning surge voltage and lightning surge current.
- In the same phase of direct lightning, both flat and trefoil type have similar surge voltage and surge current. However, when lighting happens near overhead wire, trefoil layout is markedly higher than flat layout.
- Surge voltage value of direct lightning on overhead wire mainly depends on size of cable. The bigger size of cable, the lower surge voltage characteristic.



a) Type 1 b) Type 2 c) Type 3

Figure 9: Characteristics of cable layout of overhead wire

Table 1 : Output data of current flow in cable

Input Data		Size of Cable (mm^2)	Max. Current Flow in Cable (A)
Ambient Temp. of Soil (°C)	25	500	469.3708
	32	500	443.3773
	40	500	411.6655
Depth of Duct Bank (mm.)	750	500	442.0409
	1000	500	443.3773
	1250	500	444.2945
Lay out of Cable	Trefoil	500	443.3773
	Flat	500	452.7661
Characteristic of Sheath to Ground	Single Point	500	444.1139
	Two Point	500	443.3773

V. CONCLUSION

This work has dealt with computer aided design for underground cable system. The calculation and analysis of data based on IEC 287 standard have been performed. The results have proved effective for program capability. It is possible to use proposal program software package for the realistic underground cable system installation.

Nevertheless, the value of appropriate tension to pull the cable, side wall pressure, percent conduit fill, jamming and clearance of underground cable installation are not taken into account in this work. The further work will fully examine these points.

ACKNOWLEDGEMENTS

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REFERENCE

[1] IEC 287 standard "Calculation of the continuous current rating of cable (100% load factor)", 1992.

[2] "Undergroun Construction Standard", Electrical Standard Section, Electrical Engineering Division, MEA.

[3] P. Chowdhuri, "Analysis of Lighting-induced Voltages on Overhead Lines", IEEE Transaction on Power Delivery, Vol. 4, pp. 479-492, 1989.

[4] P. Thiravasin, J. Sinthusonthichat, and S. Potivejkul "Surge Voltage in Underground Cable Analysis" The Nineteenth Electrical Engineering Conference (19th EECON), vol. 2, pp. PW142-PW147, 1996.

[[5] Aallan Greenwood, "Electrical Transients in Power Systems", A Wiley-interscience Publication, John Wiley&Sons Inc., 1991.

Table 2 : Output data of lightning surge analysis at 100 m. from the connection of cable

Input Data		Direct Lightning Surge						Indirect Lightning Surge	
		Surge Voltage (kV)			Surge Current (kA)			Surge Voltage	Surge Current
		1	2	3	1	2	3	in 1, 2 and 3 (kV)	in 1, 2 and 3 (kA)
Lay out of Over Head Wire	Type 1	62.0	0.15	0.05	9.49	0.25	0.134	0.727	0.71
	Type 2	61.6	0.40	0.20	9.45	0.77	0.450	0.688	0.13
	Type 3	60.0	0.17	0.10	9.35	0.285	0.164	0.610	0.092
Distance from Surge Point to the Connection of Cable (m.)	500	61.1	0.09	0.059	9.48	0.096	0.055	0.629	0.095
	1000	62.0	0.15	0.05	9.49	0.25	0.134	0.727	0.71
	1500	61.82	0.96	0.55	9.50	0.29	0.167	0.775	0.11
Lay out of Cable	Trefoil	62.0	0.15	0.05	9.49	0.25	0.134	0.727	0.71
	Flat	60.0	0.105	0.06	9.50	0.22	0.120	0.726	0.11
Size of Underground Cable (mm^2)	240	72.3	0.112	0.064	9.48	0.168	0.095	0.845	0.11
	400	62.0	0.15	0.05	9.49	0.25	0.134	0.727	0.71
	800	50.64	0.06	0.035	9.52	0.19	0.11	0.594	0.11