Underground cable laying – proposal to lay power cable and OFC in one trench

Matam Manjunath  
Department of Electrical and Electronics Engineering  
National Institute of Technology  
Goa, India–403401  
Email: manjunath@nitgoa.ac.in

Ankita Singh Gaur  
Department of Electrical and Electronics Engineering  
National Institute of Technology  
Goa, India–403401  
Email: asgaur93@gmail.com

Soumik Pissurlenkar  
Department of Electrical and Electronics Engineering  
National Institute of Technology  
Goa, India–403401  
Email: soumikpissurlenkar@yahoo.com

Abstract—The Objective of this paper is to workout and highlight the possibilities to operate an AC Power cable and Optical Fibre Cable (OFC) by laying both in one trench. This paper has studied the electrostatic, magnetic and thermal parameters associated with the above proposal. Mathematical equations, derivations supporting the claim have been presented. At the end, simulation tests were conducted by incorporating the obtained mathematical parameters into simulated environment. Beneficiaries of this proposal range from industry consumer(s), service providing companies, smart grids and the general public. Benefits could include distribution automation, economic aspect, reduced space requirement, reduced manpower and reduced road digging work. However, experimental tests to conform the proposal claims, developing standards for installation and operational purpose etc., all inspire us to work further on this proposal.

Index Terms—Power cable, OFC cable, underground cable laying.

I. INTRODUCTION

DEVELOPMENT in the field of technology has led us to progress in daily life and the levels of communication as well. Electricity has become the fundamental necessity of all the sections of the society and so is communication. In earlier days the transmission of electricity was done over small distances. But now, the transmission lines run for miles together. Same is the case with communication system. Underground transmission lines are preferred over overhead transmission lines for low power ratings because underground cables are less prone to damage and the transmission of power is done very efficiently.

Many departments, organizations and companies exist that produce, promote, finally install and look after consumer power cable and OFC operations. In this supplier-consumer chain, interestingly, it is the end consumer who suffers in the form of huge investments due to these service providers. It is a loss-loss situation for both supplier and receiver if better solutions to reduce expenditure are not discovered. The following example will prove this point. An academic institution, in this case consumer, was served with a demand notice by an under ground power cable and OFC laying organizations individually to install respective cables for a length of 250 m and 1.2 km. Cable laying work components like digging, trench forming, cable laying etc., all were same for both organizations. Only the cables differ with respect to each other. It has been found that 30% of consumer investment, in both cable works, goes towards labour work and trench formation. On other hand, for a length of about 250 m near the premises of the consumer, trench belonging to power cable and OFC travel side by side. This is how it was planned and ready to be executed to match consumer requirements followed by standard installation procedures of installing organizations. At this stage, a question was put up to both organizations if they could lay both cables in one trench instead of two for a length of 250 m from the consumer end. This would save the consumer from investing an amount equivalent to a 250 m length trench digging work and associated manpower and labour work. In the end, the service providing organizations refused to oblige stating that neither of the organizations have procedural standards that allow the installation of another cable in its trench. This has inspired the current authors to work on a solution that would help future consumers.

The organizations involved in these installations have not looked at the merit of such a proposal because of administrative issues and the organizational difficulties they possess. Service providing organizations belonging to Govt. or Private institutions have grown in size and structure tremendously in such a manner that chances for inter mutual cooperation at ground level is low. These organizations have not put any effort to come together and co-ordinate with other serving organizations to benefit the consumer. This paper is an attempt to overcome the barrier and develop a standard benefiting the end consumer. At end, this has inspired the authors to present this proposal.

Technically a possibility exists to operate both cables in one trench but no provisions could be found for laying the power cable and the communication cable together. Given a new cable installation task, both the departments have their separate specifications of laying the cables in the underground trench [3], [6]– [9]. After a study of the specifications and the expenses that occur while laying the cables at any loca-
tion, it was observed that most of the expenditure was due to the labour work in digging, trench formation and cable installation. Both the departments create similar trenches to lay their cables. For any new complex, the electricity department and the communication department, do their work separately though a possibility may exist to cooperate. Trenching is not a quick process and is most effective for short distance applications. The depth of the cable may vary with application, intended user and construction [7]. The depth of laying the power cable is about 0.5 meters and for communication cable is about 1.65 meters [8].

This paper would like to search, propose and investigate the possibilities of laying both the cables simultaneously in a single trench. It presents its findings in order of describing mathematical equations, necessary assumptions in Section II, simulating the practical environment, incorporating mathematical parameters and operational analysis in Section III and conclusions in Section IV.

![Image](image_url)

Fig. 1: In a domestic locality, (a) OFC and (b). Power cable are installed in trench dedicated to each separately.

II. MATHEMATICAL EQUATIONS

This proposal would like to investigate the electrostatic, magnetic and heat parameters affecting the smooth functioning of both OFC and power cable if lying in one trench. However, studying the consequences of operating a power cable near an OFC matters most and not vice versa. It is because the power cable supersedes OFC in terms of physical size, weight, electric potential and more importantly handling power capacity. Hence, in this study, power cable is treated as a cause and OFC is the consequence. It is understood that OFC is immune to Electro Magnetic Interference (EMI) and its operational performance is not affected [1], [2]. Now, the focus would go to other operational parameters that are likely to interrupt OFC functioning.

Power cable and OFC working together could create three operational possibilities where former would certainly affect or damage the latter. They are, first, electrostatic potential created at OFC location caused due to insulation failure of unloaded power cable. This is no load case where cable conductor carries negligible or no current. In this case, finding the electrostatic potential or electric field intensity (E), charge formed at the OFC location due to un loaded power cable voltage form the first step. Second, magnetic potential created at OFC location due to loaded power cable. In this case, finding the magnetic field intensity(B) due to current carrying conductor forms a part of this task. Third, find the heat or temperature rise at OFC due to a rise in power cable temperature. As per British Standard BS:6346:1989, power cable operating temperature shall not exceed 70°C. Finding the OFC temperature when power cable operates at its rated or exceeded temperatures form final part of this study.

Let E be the electric field intensity at the position of OFC operated in vicinity of a power cable carrying per phase voltage V. Let power cable be charged and it carry no or low current. It causes the electric field intensity to develop around the space of power cable in form of voltage gradient. It is given, as in [4], by

$$E = -\nabla \cdot V$$  \hspace{1cm} (1)

Expanding above (1) in cartesian system of coordinates gives

$$E = -(\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + \frac{\partial V_z}{\partial z})$$

Assume that power cable is layed along z-axis and the x, y coordinates remain same at all positions of power cable and that of OFC. This sets V_x, V_y both to zero and V_z to be the supply voltage given by V_m sinωt. In order to find the charge formed at OFC location due to E (V gradient), it is required to find the charge density given by

$$\rho = \nabla \cdot D$$  \hspace{1cm} (2)

where ρ is the quantity of charge developed at OFC location, D is the displacement charge density. D is a derived quantity given by

$$D = \epsilon E$$  \hspace{1cm} (3)

where ε is the dielectric coefficient of the medium lying in between power cable and OFC. It shall consider all material types and their dielectric coefficients that come in between these two cables.

Proceeding to the next step i.e. the task of finding the magnetic potential or flux enclosing the OFC due to loaded power cable. Maxwell equations which could help in this task are Ampere Circutal law and Gauss law for magnetic field as given by,

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$  \hspace{1cm} (4)

$$\nabla . B = 0$$  \hspace{1cm} (5)

where H is the magnetic filed intensity around the OFC perimeter, J is current density enclosed by OFC and D is the displacement current density enclosed and B is magnetic flux density at it. These H, J and B are recipient parameters measured in the medium present in between and at the OFC location in particular. It is to be noted here that this study considers steady state analysis but not time variant. This sets D as in (4) to zero. Further, expressing the magnetic flux density B in cartesian system of coordinate gives \(B_x(x,y,z,t) + B_y(x,y,z,t) + B_z(x,y,z,t)\) where x,y,z represents OFC location and t represents time (t is neglected.
as it deals with steady state parameters). Any vector said to be called as magnetic flux density only if its gradient as in (5) results null. This analysis assumes B at OFC location as a known quantity. However, relating the magnetic flux density (B) with source the power cable current is given by

$$B(r, \theta, \phi) = \frac{\mu I}{2\pi r} a_r$$  \hspace{1cm} (6)

where $B(r, \theta, \phi)$ is magnetic flux density(in Wb/sq.m) at OFC location expressed in spherical coordinates, $\mu$ is magnetic permeability of the medium expressed as $\mu_0 \mu_r$, $\mu_0$ is permeability of the free space, $\mu_r$ is relative permeability of the medium, $r$ is radial distance(in m) from power cable to OFC and $I$ is power cable current(in Amps). It has presence of various parameters representing the relative permeability of cable conductor insulation is $\mu_{ins.}$, cable sheath is $\mu_{sheath}$ and soil is $\mu_{soil}$. The third and final task is to find the heat transfer related parameters. Heat transfer between two bodies possessing different temperatures set the heat to flow from high temperature body to low temperature body given, as in (possessing different temperatures set the heat to flow from high temperature body to low temperature body). Heat transfer between two bodies and soil is

$$\mu = (\frac{1}{\mu_{ins.}} + \frac{1}{\mu_{sheath}} + \frac{1}{\mu_{soil}})(7)$$

where $\mu$ is permeability of PVC cladding roughly the resistance of cable 0.457, magnetic relative permeability of OFC. The power cable, it has a cable jacket to match OFC environment operating conditions. In this case, single core Fibre cable having net dia. of 0.025 sq.mm is considered for purpose of simulation.

By theoretical analysis and from point of OFC immunity to EMI, [1], [2], technically it is understood that optical fibre cables can be laid in the vicinity of power cables. This will help to save the expenditure and time for completion of work. This study has identified all the possibilities of laying the two cables together and two such possibilities were identified. The first problem identified was that if the strand of the power cable snaps, then there will be contact between the optical fibre cable and the power cable resulting in short circuit and live contact among the two, which is unsafe. Second possibility, is that it will create a problem while maintenance as the power cable lies, as shown in Fig. 3, above the optical fibre cable and access to the OFC will be a challenging task. However, this gives installation and operational possibilities to realize the proposal. As per Power cable installation procedures followed by installation organizations, it was installed at 0.5 m deep from surface. Similarly, as per OFC installation procedures followed, it was installed at 0.9 m or 1.65 m deep in to earth. Proposal considers a distance of 0.5 m, chosen in relation to trench width, lateral distance to be maintained among two cables shown as in Fig. 3.

Finally, placing both cables diagonally opposite to each other was found to be the best arrangement. This reduces the probability for both to come in live contact. The power cable was placed at a certain distance from the optical fibre cable. This way of laying helps to sort out maintenance problems which has been pointed in the above text. The power cable will not come in contact with optical fibre cable even if there is a fault and maintenance of both is easier. Adding to this, only a section of few meters requires maintenance or repair at any point of time.

Laying the two cables, some mechanical support must be there in between so that they don’t come in contact with each other. Also, the space between the two cables must be filled with sand so that the cables are geographically stable in their installed positions. In addition, non-conducting material’s like wood may be provided between the two to provide mechanical support. But, this method invites disadvantage. The power cables are robust and can be bent or twisted. This will cause no hindrance in transmission of power. But it is not the same with the communication cable. Unlike power cables, the OFCs are weak and can be damaged easily. They cannot be bent or twisted. If this is done then the transmission of the communication signal is not possible.

For purpose of simulation, typical ratings were chosen to simulate practical environment. Operating voltage 11kV, roughly the resistance of cable 0.457 , magnetic relative permeability of PVC cladding $\mu_{sheath}$ of power cable is 0.045, and that of free space is 1 and for soil also it is 1 [10].
Horizontal spacing between OFC and power cable is 0.5 m, diagonal spacing is 0.64 m. From point of damage the power cable may cause to the OFC, three possibilities of failures as discussed above were simulated and response of parameters was recorded. OFC is immune to EMI interference but however higher and continuous exposure may have negative effects [1], [2]. Understanding both cables operations from this aspect is vital to the proposal.

Normal functioning power cable is as shown in Fig. 2, has voltage gradient curves distributed around conductor insulation and in the outer sheath also. This shows the importance of insulation and shielding in limiting the voltage gradient distribution. However, highly concentrated voltage gradients are a point of concern to the cable health. They increase stress on insulation leading to a physical damage like treeing phenomenon. In addition to this, voltage harmonics are found to be another source of stress causing phenomenon results in treeing and damage to the cable insulation [5]. The proposed laying of trench power cable and OFC, as shown in Fig. 3, has satisfied all standards put up by respective installation procedural standards. This proposal works well as long as no interruptions were put by either of them throughout length of operation. In this regard, to study the parameters discussed as above, the power cable failures have been introduced and response was simulated respectively. First, response of an unloaded and punctured power cable operating at 11 kV, as shown in Fig. 4, was simulated to report voltage gradients, electric field vectors respectively. Voltage gradients were shown in contours surrounding the punctured cable, surrounding space and OFC premises. Its continued operation would result a charge to accumulate on OFC outer surface. However, the surrounding soil is at ground potential resulting in accumulation of charge if any on OFC surface to discharge at same rate. Adding to this, low voltage gradients at OFC make it less prone to the danger even during worse power cable failure. Unlike normal operating condition as shown in Fig. 2, cable voltage gradients as shown in Fig. 4 are less concentrated and radially occupy more space. This is a possible reason to explain less voltage gradient at OFC location despite the fact that live power cable has punctured. Note, the electric filed vector arrows point radially outward with power cable at centre and at this stage power cable was mere an infinite length charged line placed at a distance from OFC. Second, loaded and punctured power cable operating at 11kV, current density of 1 A/sq.mm was simulated to report, as shown in Fig. 5, the magnetic filed gradients, potential vectors respectively. Comparing to Electrostatic potential gradients as in Fig. 4, Magnetic potential contours as shown in Fig. 5 appear similar to electric contours and where magnetic flux density vector’s are radial, clockwise directed arrows which appear dissimilar to electric field vectors. Magnetic potential gradient appear more than half at places near to power cable and low at places far away from power cable and at the location of OFC in particular. This confirms low presence of flux at OFC location during event of cable failure that was exposed to surroundings completely. The OFC functioning is immune to EMI and hence low quantity magnetic flux presence would have negligible effects on its performance [1], [2]. Third, temperature failure of power cable where its operating temperature exceeds 70°C was simulated and
then, heat transfer related parameters response was recorded. Heat transfer parameters like coefficient of heat conduction(k), convective heat transfer coefficient are set at 0.3 W/m.K and 1 W/(sq.mm K) for insulation, filling around insulation, sheath layer and at 1 W/m.K and 1 W/(sq.mm K) for soil and $T_{final}$ at 35°C, the surrounding normal temperature respectively. In this case, cable temperature was set to 90°C, higher than normal operating voltage and simulation response was recorded here with as shown in Fig. 6. Unlike power cable components, the high heat conductivity of the soil helps improve heat conduction from soil and is faster than cable components. This could be a possible reason for low temperatures at OFC location influenced mostly by ground temperature and less by cable operating temperature. Soil heat conductivity results in evaporation of heat from the cable into atmosphere before it reaches the OFC. Adding to this, radial heat transfer of the heat produced is an added advantage. Though OFC, as shown in Fig. 6, possess heat gradient contours, they are low value heat curves and hence they have less influence in causing damaging to the OFC.

IV. CONCLUSION

The operational possibilities of laying power cable and OFC in one trench have been discussed. Operating conditions which could affect OFC performance were simulated and respective electrostatic, magnetic and heat parameters were analysed. Simulation results, influencing parameters response during power cable failures were recorded and they found to have less or negligible affect on OFC performance. This proposal has found a solution for reducing the investment cost of the consumer. However, field tests conforming the proposal claims, development of a standard etc. inspire to work on this proposal further.

ACKNOWLEDGMENT

The authors would like to thank Mr. Saini Singh, A.E., Mr. Nishant, J.E., Central Public Works Department-Goa, Mr. Kerker and Mr. Anshul Kumar, Bharat Sanchar Nigam Limited- Panaji and Mr. ND Roy, GM Electrical, M/s. Finolex Cables Pvt. Limited, Verna-Goa for rendering help during course of study.

REFERENCES