

# Comprehensive PSCAD-Based Analysis of Sheath Overvoltage in 33 kV XLPE Cables Considering Grounding and Segmentation Effects

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**ABSTRACT-** The performance reliability of underground medium voltage (MV) networks is largely dependent on how metallic sheaths behave both in a normal operating mode as well as during transients. One critical form of stress applied to the insulation is that of excessive sheath voltage which can rapidly degrade the insulation material used on underground conductors and endanger operators. This paper details a thorough examination of overvoltage mechanisms affecting sheaths of 33kV XLPE single-core underground cable through a simulation approach. By establishing a PSCAD/EMTDC model, it was analyzed how the variables of sheath grounding resistance, cable length, load current, and grounding location affect the segmented cable systems. The analyses identify cable length and load current as the two most significant contributors to the increase of overvoltage due to inductively and capacitively coupled behavior between the cable conductor and sheath. Grounding resistance is only noticeable due to its secondary contribution to overvoltage and is most pronounced at extended cable lengths for many circuit configurations. Further, the grounding configuration for segmented cable system directly affects the distribution of potentials, as evidenced by the ability of poor grounding methods to produce sheath overvoltage on a very large scale. Based on these results, best practices can be established for identifying suitable grounding locations and segmenting strategies as a means of ensuring the system reliability and safety of MV cable networks in urban distribution applications.

**Keywords:** Underground Cable, Metal Sheath, Overvoltage, Grounding Resistance, Segmentation, PSCAD, XLPE Cable.

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## 1. INTRODUCTION

Power distribution networks, particularly in dense urban areas, use underground cable systems as the primary means of conveying power. Underground cable systems have a number of advantages, with added safety, less exposure to the elements and reduced effects on the overall urban environment. However, underground cable systems have many disadvantages as well; the most serious disadvantage is the potential for induced voltage on the shield caused by the coupling of the conductor to the shield through electromagnetic fields. High levels of induced voltage on the shield cause a number of problems; these problems include stress on the insulating material, premature thermal degradation, breakdown of the dielectric material, and increased maintenance requirements [1-5].

Many studies have recently shown how standard monitoring/fault location methods are inadequate for use within today's Modern Power systems, where Inverter based Resources (IBR) are prevalent. The complexity of control and the introduction of distorted/non sinusoidal fault currents by IBRs have reduced the efficacy of older methods. Some techniques have used sheath currents to achieve increased accuracy in fault detection, but the practical applications for this type of approach have limitations due to the added cost of any extra sensors needed and the difficulty in maintaining those sensors once installed [1]. Many research examinations regarding high-voltage cables include the effect that the method of how grounding configurations of cable sheath conductors has on the high-frequency resonance and transitory overvoltage created in a cable to transformer environment. However, most research does not take into consideration the relationship between a surge voltage limiter (SVL) and transformer(s) at the time of transient events [2]. Additionally, similar to what has been found regarding SVL's & transformers, some techniques (both practical & modeled) have also been developed to manage the common maintenance issues associated with mixed burial-tunnel cable installation within an urban electricity distribution system [3], however, many age-related issues such as degradation of cable sheaths are yet to be properly addressed. In an effort to provide a deeper understanding of transient stress mechanisms, researchers simulated numerous conditions associated with the operation of cables such as steady-state, short circuit, and lightning strike in order to

provide minimum SVL dimensioning requirements. Grounding the cable sheath at the transformer terminal is the best way to minimize the impact of high frequency resonances; however, it leaves the ungrounded source side of the cable sheath subject to extreme overvoltage surges, creating a critical design compromise with regard to grounding systems [4]. As cable grounding systems continue to increase in complexity, researchers are investigating innovative data-driven methods of fault detection. One such study utilizes a combination of physical relationships integrated into a Graph Attention Network (GAT) to detect grounding faults occurring in buried cable systems. However, the model assumes that the cables will be arranged horizontally and that there will only be two circuits which share a grounding grid; therefore, its application is limited to specific types of installations throughout most parts of the world [5]. Secondly, the authors proposed a fault detection technique based on the absolute phase-angle difference between the beginning and ending of the same sheath loop for cross-bonded high voltage cable grounding systems along with the effective value of the sheath current; however, although accurate at diagnosing faults, it fails to address the overall expense of installing and maintaining the monitoring equipment on existing networks as well as its complexity of installation [6]. Some studies have compared different modeling methods of lightning-induced transients in underground cables and have shown that simplified formulations substantially overestimated the overvoltage produced by lightning-induced transients. However, these studies were limited in practical relevance due to the simplified representation of the studied cable system and the lack of experimental validation; so that it is necessary to consider more realistic grounding models and insulation stress analysis associated with different cable bonding arrangements [7]. In addition, a three-dimensional panoramic digital tunnel model and associated cable sheath current simulation tool have been created to improve the ability to monitor high-voltage cable systems in urban settings, although the accuracy of the simulations is compromised by the use of measured cable lengths [8-9]. A new analytical model has been created to increase accuracy in the analysis of sheath current characteristics. The new model divides sheath current characteristics into three separate categories: current resulting from unequal section length, circulating current between circuits, and current flowing to ground. While this new model provides solutions for the issues presented in previous research, it mainly focuses on dual circuit operation and does not address the characteristics of greater than 2 circuit/phase configurations [9]. An additional fault detection technique combining amplitude and phase has been designed and tested, using both simulation and field testing, for the purpose of identifying the faults in submarine cable grounding systems. This technique will work in high load and stable conditions; however, it relies heavily on historical/current data and, therefore, the threshold settings for each fail to provide an absolute level of accuracy and may lead to false alarms or non-detections [10].

The research community has conducted considerable investigations into cable overvoltage issues in addition to identifying the sources of faulted cables. There have been many

investigations undertaken to simulate the effects of the overvoltage created by faults on cables of various types and various cable configurations, in addition to identifying what various factors contribute to cable overvoltage, such as cable geometry, grounding resistance, and soil resistivity [11-14]. There has also been considerable investigation into long-term studies that indicate that the presence of a cumulative effect of the cable's lead sheath current on its lead sheath will significantly decrease the lifetime of the cable [13]. As a result, proper selection of cable sheath voltages as well as optimizing grounding systems, have become established practices in mitigating overvoltage hazards associated with cable networks [15].

Cable segmentation is another practical challenge, generally owing to obstacles that are either natural or manmade. Changes in segmentation also change the ground configuration and the effective voltage distribution over the sheath. Grounding behavior related to segmentation is poorly addressed in the existing literature, despite its significant impact on cable transmission [8].

Although factors including cable length, grounding resistance and load current were investigated individually in the literature there is limited reporting of multi-parameter interaction analysis in a segmented cable system, which this work provides. It details the uniquely integration of grounding location effects in halved units, exhibits super-linear voltage escalation due to synergistic inductive and capacitive coupling, and guides engineering design insight on placement of groundings in urban networks.

## 2. SIMULATION MODEL AND GOVERNING EQUATIONS

### 2.1. Cable Structure and Parameters

A 33 kV single-core XLPE insulated copper conductor cable with a cross-sectional area of 1625 mm<sup>2</sup> was simulated using PSCAD/EMTDC [16]. As shown in *table 1*, all physical and electrical parameters (e.g. radii, permittivity, resistivity, etc.) of the cable have been defined and its structural arrangement has been illustrated in *figure 1*. Cable lengths of 1, 5, 10, and 15 km are examined.

**Table 1. Geometrical and Physical Parameters of 33 kV XLPE Cable**

| Parameter                   | Value  |
|-----------------------------|--|
| rc conductor (copper)       | 11.9 mm  |
| rXLPE insulation (XLPE)     | 18.55 mm   |
| rsh sheath (copper)         | 19.75 mm   |
| rPVC jacket (PVC)           | 22.75 mm   |
| Permeability ( $\mu$ )      | $\mu_{r,e}=1, \mu_{r,c}=1, \mu_{r,XLPE}=1,$<br>$\mu_{r,sh}=1, \mu_{r,PVC}=1$                 |
|                             | $\rho_c=100 \Omega.m$<br>$\rho_c=2.09.10^{-8} \Omega.m$<br>$\rho_{sh}=3.26.10^{-8} \Omega.m$ |
| Permittivity ( $\epsilon$ ) | $\epsilon_{r,e}=1, \epsilon_{r,XLPE}=2.72, \epsilon_{r,PVC}=6$                               |

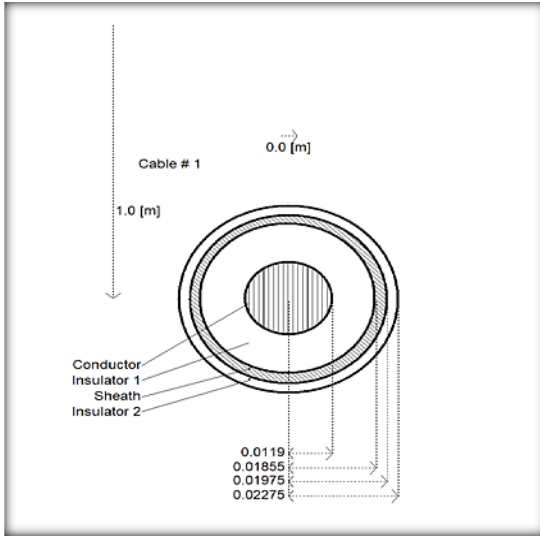


Figure 1. Structure of XLPE cable [17]

In the proposed simulation, a conventional single-point grounding configuration (see figure 2) is employed [18-19], whereby one terminal of the metal sheath is connected to earth across grounding resistance (known as "sending-end grounding"), and the receiving end is left open. The grounding resistors used are 0.1, 0.5, 5 and 10 Ω, respectively.

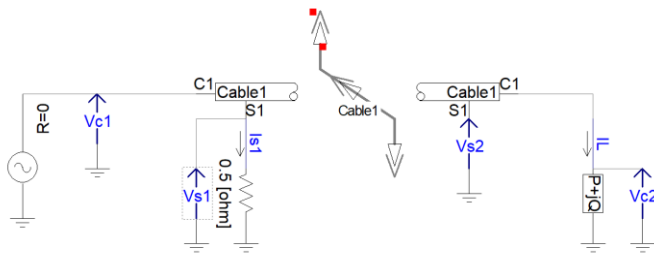


Figure 2. Simulation model of 33KV cable system

## 2.2. Sheath Voltage Rise in Medium Voltage and mutual Coupling Model

In single-core medium voltage (MV) and high voltage (HV) power cables, it is a well-established fact that a potential difference (voltage rise) develops between the metallic sheath (or screen) and the ground [22-23]. This voltage is induced via electromagnetic coupling between the current-carrying conductor and the metal sheath. The mutual coupling is two-fold: inductive and capacitive. The inductive component resulting from mutual induction between the conductor and the metal sheath, while the capacitive component results from the voltage difference across the core-sheath insulation. In single-point bonding, these sheath-coupled voltages do not fully eliminate and can present significant standing voltages at the ungrounded end point, exposing safety and insulation risk [19-27].

## 2.3. Mathematical Model of Mutual Coupling

For a cable of length, the per-unit length parameters governing this interaction are: the mutual inductance,  $M$ , the core-to-sheath capacitance,  $C_{CS}$ , and the sheath-to-ground capacitance,

$C_{sg}$ . A fundamental relationship exists for the coaxial geometry where the product of the mutual inductive and capacitive coupling terms is constant for a specific assumption [27].

$$[C] = \begin{bmatrix} C_{CS} & C_m \\ C_m & C_{CS} \end{bmatrix} \quad (1)$$

$$C_{CS} = \frac{2\pi\epsilon_0\epsilon_r}{\ln\left(\frac{r_s}{r_c}\right)} \quad (2)$$

$$C_{CS} = -C_m \quad (3)$$

$$M = \frac{\mu_0\mu_r}{2\pi} \ln\left(\frac{r_c}{r_s}\right) \quad (4)$$

In symmetric case, the mutual inductance between core and sheath equal;

$$M.C_{CS} = \mu_0\epsilon_0\epsilon_r \quad (5)$$

So, 
$$M = \frac{\epsilon_r}{c^2} \quad (6)$$

Where:

$\mu_0 =$  permeability of free space =  $4\pi \times 10^{-7}$  H/m

$r_c =$  conductor radius

$r_s =$  sheath radius

$\epsilon_0 =$  is the relative permittivity of air  $8.85 \times 10^{-12}$  F/m

$\epsilon_r =$  is the relative permittivity of cable insulation

and  $c$  is the speed of light

In medium-voltage single-core underground cables, the metallic sheath exhibits distributed electrical behavior due to its longitudinal geometry and electromagnetic interaction with the current-carrying conductor. Accordingly, the sheath can be accurately represented using distributed parameter model, where electrical quantities are defined per unit length. The series impedance of the sheath is expressed as:

$$Z_s = R_s + j\omega L_s \quad (7)$$

while the shunt admittance to ground is given by

$$Y_s = G_s + j\omega C_s \quad (8)$$

Where,  $R_s$  is the sheath resistance,  $L_s$  is the inductance,  $C_s$  is the capacitance between sheath and ground, and  $G_s$  represents the leakage conductance. The angular frequency is defined as  $\omega = 2\pi f$ .

## 2.4. Mathematical Modeling of Sheath Voltage Using Telegrapher's Equations

The voltage and current distributions along the sheath are governed by the telegrapher's equations, which describe electromagnetic wave propagation in distributed systems [22-23]. For the sheath circuit, these equations can be written as:

$$\frac{dV_s(x)}{dx} = -Z_s I_s(x) - j\omega M I_L \quad (9)$$

$$\frac{dI_s(x)}{dx} = -Y_s V_s(x) \quad (10)$$

where  $V_s(x)$  and  $I_s(x)$  denote the sheath voltage and current along the cable,  $I_L$  is the load current in the conductor, and  $M$  is the mutual inductance per unit length between the conductor and sheath. The term  $j\omega MIL$  represents the induced electromotive force (EMF) resulting from inductive coupling [24-27].

By combining the above equations, a second-order differential equation governing voltage propagation is obtained as:

$$\frac{d^2 V_s(x)}{dx^2} - \gamma^2 V_s(x) = 0 \quad (12)$$

where the propagation constant is defined as:

$$\gamma = \sqrt{Z_S Y_S} \quad (13)$$

This formulation indicates that the sheath behaves as a transmission line supporting wave propagation phenomena.

For practical engineering analysis under steady-state power-frequency conditions, an approximate expression for the sheath voltage can be derived. Considering a cable of length  $L$  with single-point grounding, the sheath voltage at the open end can be approximated as:

$$|V_s| \approx \omega M I_L L \cdot F(\gamma L) \quad (14)$$

where the correction factor  $F(\gamma L)$  accounts for distributed effects and is given by

$$F(\gamma L) = 1 - \frac{1}{\cosh(\gamma L)} \quad (15)$$

For electrically short cables where  $|\gamma L| \ll 1$ , the hyperbolic cosine function approaches unity, and the sheath voltage reduces to

$$|V_s| \approx I_L \omega M L \quad (16)$$

This simplified expression reveals a linear dependence of sheath voltage on both load current and cable length, which is consistent with classical cable theory and recent studies [24].

The mutual inductance  $M$  is primarily determined by the cable geometry and can be approximated for a coaxial structure as:

$$M = \frac{\mu_0}{2\pi} \ln \left( \frac{r_{sh}}{r_c} \right) \quad (17)$$

where  $r_c$  and  $r_{sh}$  are the radii of the conductor and sheath, respectively, and  $\mu_0$  is the permeability of free space. It is important to note that grounding resistance does not directly influence the magnitude of the induced EMF but affects the boundary conditions and voltage distribution along the sheath. The presented formulation is consistent with transmission line theory and widely adopted standards for cable modeling [25-26]. While the model is suitable for power-frequency analysis, it does not capture high-frequency transient effects or frequency-dependent parameters, which may require advanced modeling approaches.

Solving this system for the common case of a sheath grounded at the sending end and ungrounded receiving end  $I_s = 0$ . This equation resembles an approximate  $V_s=0$  formula for the sheath voltage value at the end of a cable section, at  $x = l$  due to inductive and capacitive coupling from the core, under certain simplifying assumptions.

### 3. RESULTS

This section provides a comprehensive analysis of simulation results, explaining not only trends but also the physical mechanisms behind them. The analysis is divided into four key components which are; influence of load current, cable length, grounding resistance, and grounding location in segmented cable on sheath voltage.

Induced sheath voltages at each cable end (per one section) with respect to reverse single-point grounding are compared in *tables 1 & 2*. The inductive voltage effects are defined by the fact that the greatest sheath voltage is always located at the insulated potential (ungrounded) terminal. The location of the grounding point determines the location of greatest voltage stress on the insulating sheath. For example, *table 2* indicates that the greatest induced voltage on the sending end ( $V_{s1}$ ) occurs with the receiving end connected to the ground ( $R_{sh} = 0.1 \Omega$ ) because the sending end has high voltage potential ( $V_{s1}$ ) and a low voltage ( $V_{s2}$ ) potential. Additionally, since only a small sheath current ( $I_{s2}$ ) flows from the sending end to the receiving end, the circulating current is effectively limited. Conversely, *table 3* illustrates that when the sending end is grounded, the high voltage stress ( $V_{s2}$ ) is transferred to the receiving end and a small amount ( $I_{s1}$ ) of sheath current flows from the receiving end to the grounded end.

**Table 2. Sheath Receiving End Grounded  $R_{sh} = 0.1 \Omega$**

| IL (kA) | Vs1 (kV) | Vs2 (kV) | Is2 (kA) |
|---------|----------|----------|----------|
| 0.1     | 0.236    | 0.00015  | 0.0015   |
| 0.2     | 0.472    | 0.00014  | 0.0014   |
| 0.3     | 0.709    | 0.00013  | 0.0013   |
| 0.4     | 0.944    | 0.00012  | 0.0012   |

The disparity in induced EMF on the cable sheath acknowledges the accumulation of induced EMF on the sheath until it is released to the earth (ground) point, verifying that the design consideration for the grounding terminal is not just a practical aspect of the cabling system but also an engineering choice affecting the distribution of voltage through the system. A systematic engineering approach will utilize the selection of the grounding point as an essential architectural decision that results in an optimal design within which to develop a safe and efficient cable system.

**Table 3. Sheath Sending End Grounded  $R_{sh} = 0.1 \Omega$**

| IL (kA) | Vs1 (kV) | Vs2 (kV) | Is1 (kA) |
|---------|----------|----------|----------|
| 0.1     | 0.00017  | 0.2      | 0.0017   |
| 0.2     | 0.00018  | 0.235    | 0.0018   |
| 0.3     | 0.00019  | 0.705    | 0.0019   |
| 0.4     | 0.0002   | 0.939    | 0.002    |

### 3.1. Influence of Load Current on Sheath Voltage

Figure 3 shows how the end sheath voltage ( $V_{S2}$ ) on the receiving end of a medium voltage (MV) feeder cable varies with respect to load current ( $I_L$ ). Sheath voltage varies in a nearly linear fashion with load current ( $V_s \propto I_L$ ), because as conductor current increases, the strength of the magnetic field around the wire increases; hence according to equation 16, this creates more voltage in the adjacent metallic/metal reinforced sheathing. The electrical properties of the cable also contribute to how the sheath voltage varies depending on the length of the cable. The sheath voltage will double or triple over longer cables due to an increase in the electromotive force (EMF) resulting from the cumulative induced EMF along the length of the cable ( $V_s = \int I_L \omega M dl$ ), and thus an increase in the steepness of the voltage-current ( $I_L$ ) curve for longer-distance installations. For example, a 15 km-length cable under the same loading conditions will experience approximately ten times as much sheath voltage ( $V_{S2}$ ) compared to a 1 km length cable, due to the cumulative effect of induced EMF along the cables' lengths as in equation 16.

The importance of these electricity transmission characteristics lies in the potential for high sheath voltages to place excessive stress on cable insulation, result in partial discharge activity and greatly increase the potential for catastrophic insulation failure in long-distance electrical transmission systems from an operational perspective. As a result, the findings from this analysis indicate that regular sheath voltage monitoring based on load requirements is a best management practice that should always be employed to maintain operational reliability and longevity of MV feeder systems.

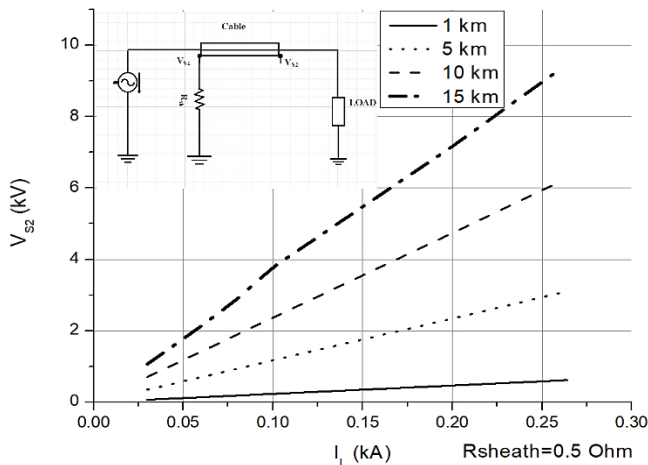


Figure 3. Impact of cable length on sheath receiving end voltage levels under varying load current conditions

### 3.2. Influence of Cable Length on Sheath Overvoltage

Cable length is the most important factor determining the magnitude of the induced sheath voltage. While the effect of length on induced sheath voltage is complex and not simply linear, the increasing lengths of cable lead to higher induced sheath voltages. Two primary coupling mechanisms along the

cable lead to super-linear increases in induced sheath voltage. First, the inductive coupling effect of all of the cables over their entire length cumulatively creates an increased sum of IV excitation or induced electromotive force along the entire cable length. This increased sum of IV excitation creates a significantly higher differential voltage between the ends of the cable which are grounded and the ungrounded end resulting in the quickly increasing voltage increase after 10 km. Second, the capacitive coupling of longer cables affects the amount of charge that can be stored in the cable as longer cables have more surface area in proximity to the conductive/shield and, therefore, have increased capacitance. As a result, the increased capacitance creates more capacitive charging current and therefore greater stress on the surrounding electric field and changes in the way the voltage wave travels along the cable. These two coupling mechanisms are not independent; they are interdependent and the total impact of both is a voltage build-up much greater than the build-up from linear projection. Therefore, from an engineering standpoint, the length-based super-linear relationship between cable length and induced sheath voltage is significant.

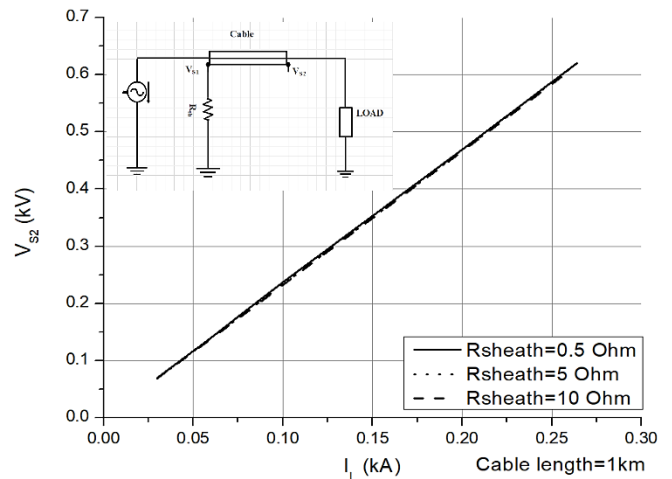


Figure 4. Sheath receiving end voltage vs. load current across multiple sheath resistances (1 km cable length)

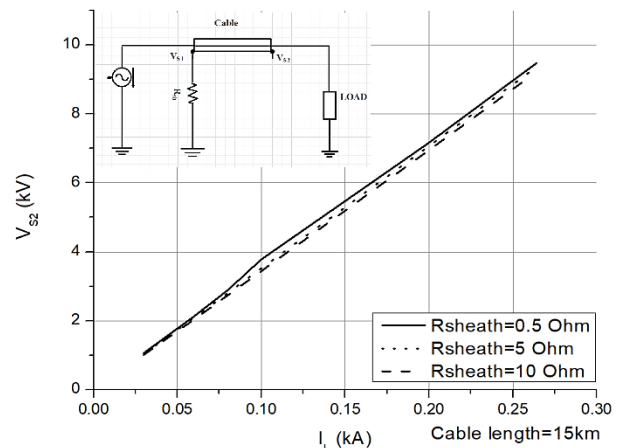
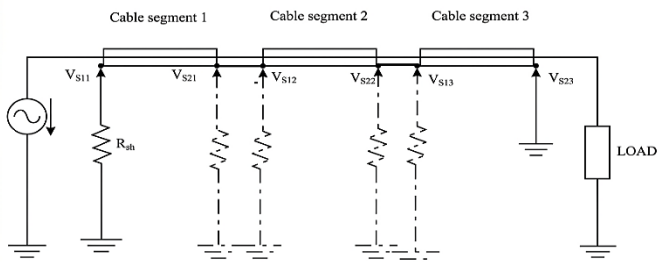


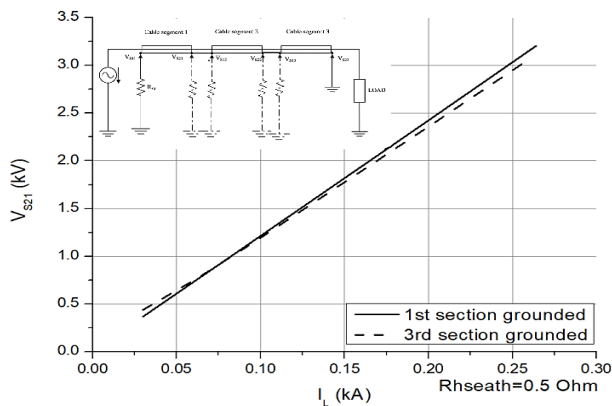
Figure 5. Sheath receiving end voltage vs. load current across multiple sheath resistances (15 km cable length)

### 3.3. Effect of Grounding Resistance on Sheath Voltage

Even though grounding resistance may have a limited effect on sheath voltage (*i.e.*, for a given value of grounding resistance of 0.5, 5 and 10 ohms respectively) in conjunction with the effects of inductive coupling on voltage drop at level 1 (shown in *figures 4 & 5*), the influence of grounding resistance is ultimately minor. In fact, with short versions (approximately 1 km) of these cables, the measured sheath voltage dropped by only 3% or less due to the resistive voltage drop at the 1 km termination and, therefore, there is no significant effect of the resistivity on the resultant EMF at this length. The difference in sheath voltage measurements is even lower (*i.e.*, 5 to 8%) for longer cables (15 km) because, although the EMF for these longer cables is substantially greater, the relationship for calculating each of these two capacitance levels is still the same (*i.e.*  $V_s \propto \omega MI_L$ ). Because grounding resistance does not provide a way to diminish the EMF present along the entire length of the cable; instead, it only affects the voltage at the cable's terminating end, thus, using lower grounding resistances benefits safety by allowing for an improved section of an electrical system (*i.e.* *section 4*, *figure 5*); however, even for the longer cable types, lower grounding resistance does not eliminate the reason for the occurrence of over-voltages, as this is an inherent effect of the cumulative inductive coupling occurring. Therefore, the conclusion drawn from this analysis indicates a need to utilize methods to mitigate the EMF that cause both short and long cables to develop over-voltages by concentrating on the root cause cumulative inductive coupling rather than only improving the grounding resistance to control sheath voltage in extensive medium voltage installations.



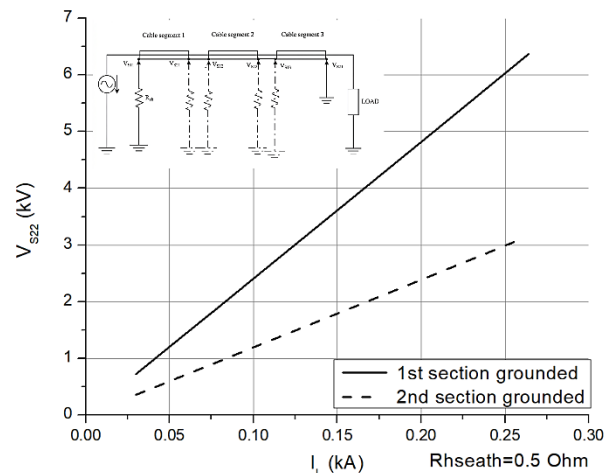
**Figure 6.** Schematic diagram of the simulated test case for system under study power system



**Figure 7.** Relationship between induced sheath voltage and load current for a 1 km cable, influenced by sheath resistance positioning

### 3.4. Effect of Grounding Location in Segmented Cables

*Figures 7 through 9* offer insight into segmented urban cable networks, with emphasis placed upon the importance of placement of ground points, or local grounding. It has been determined that the location where these ground points are placed has a significant impact on voltage stress and system reliability. When considering the placement of ground points, one of the most important considerations is that, at or near the location of a ground point, sheath voltage will be the lowest along a cable segment due to a low-impedance path providing a path to ground for the local potential. On the other hand, a location with no ground connection will cause the entire length of the segment to have the total amount of induced EMF. This situation will create the highest sheath voltages along that cable segment, increasing the chance of Partial Discharge (PD) and ultimate failure of insulation. These voltage distributions occur through a redistribution mechanism. Changing the location of the ground point will alter the circulating sheath current paths, alter the local voltage gradient distribution, and alter the mutual inductive coupling between parallel segments of the cable system. Thus, the essential recommendation from an engineering standpoint is to place the ground point in such a manner to provide the greatest use of the natural tendency of grounding to clamp voltages. Following best practices when determining where to place grounding points requires that ground points be placed near the heaviest loaded sheath segments in order to reduce the maximum amount of induction, thus minimizing the length of ungrounded runs and eliminating conditions that would expose the insulation to elevated risks.



**Figure 8.** Relationship between induced sheath voltage and load current for a 1 km cable, influenced by sheath resistance positioning

### 3.5. Impact of ground resistance and cable length, who is the most effect

A direct quantitative comparison of the effect of grounding resistance at short and long cable lengths (per one section) is presented in *table 4*. It demonstrates that the effect of grounding resistance, as computed from the 20-fold increase of 0.5  $\Omega$ , 5  $\Omega$  and 10  $\Omega$  on sheath voltages, is insignificant. The main determinants of sheath voltage are cable length, load

current ( $I_L$ ) and mutual inductance. For example, if the cable is 1 km long, the impact of grounding resistance on sheath voltage ( $V_{S2}$ ) will be negligible as there will be less than 1 % difference between loads. With longer cables, e.g., 15-km, the impact is greater as the absolute value of sheath voltage increases significantly, but the relative effect of changing the grounding resistance (3-5%) still remains limited. Grounding resistance functions primarily as a termination impedance and its effect at the grounded end is a voltage divider effect. Therefore, the ability of a low grounding resistance to manage fault current, coordinate surge arresters and provide personnel safety is limited. Addressing the cause of inductive overvoltage requires strategies that address the overall inductive coupling, such as using cross-bonding or transposition, rather than depending on grounding resistance to mitigate sheath overvoltage (the cumulative effect of the two).

**Table 4. Comparison Between Sheath Voltage Receiving End  $V_{S2}$  For Sheath Resistances and Cable Lengths**

| $I_L$ (kA) | $V_{S2}$ (kV)         | $V_{S2}$ (kV)       | $V_{S2}$ (kV)        |
|------------|-----------------------|---------------------|----------------------|
|            | (0.5 $\Omega$ , 1km)  | (5 $\Omega$ , 1km)  | (10 $\Omega$ , 1km)  |
| 0.03       | 0.07                  | 0.069               | 0.069                |
| 0.06       | 0.14                  | 0.139               | 0.138                |
| 0.08       | 0.189                 | 0.186               | 0.185                |
| 0.1        | 0.237                 | 0.233               | 0.232                |
| 0.2        | 0.469                 | 0.467               | 0.466                |
| 0.264      | 0.62                  | 0.619               | 0.616                |
| $I_L$ (kA) | $V_{S2}$ (kV)         | $V_{S2}$ (kV)       | $V_{S2}$ (kV)        |
|            | (0.5 $\Omega$ , 15km) | (5 $\Omega$ , 15km) | (10 $\Omega$ , 15km) |
| 0.03       | 1.071                 | 1.045               | 1.018                |
| 0.06       | 2.132                 | 2.089               | 2.045                |
| 0.08       | 2.892                 | 2.808               | 2.742                |
| 0.1        | 3.78                  | 3.521               | 3.443                |
| 0.2        | 7.167                 | 7.07                | 6.951                |
| 0.264      | 9.47                  | 9.356               | 9.216                |

This comparative study evaluates the effectiveness of the proposed sheath grounding resistance configuration against existing research. As detailed in *tables 1 & 2*, the results align with the findings of [14], confirming that the suggested positioning optimizes grounding performance.

A comparative analysis highlights the superior robustness of the proposed method, particularly for long-distance transmissions. While the previous study in [28] reported sheath voltages exceeding 20 kV for cable lengths of 10 km, the suggested work successfully limits the maximum voltage to below 8 kV for the same distance.

**Table 5. Comparative Analysis of Maximum Sheath Voltage Across Different Cable Lengths**

| Parameter          | Existing Study [28] | Suggested Work) |
|--------------------|---------------------|-----------------|
| Cable length       | 10 km               | 10 km           |
| Max sheath voltage | >20 kV              | < 8kV           |
| Performance        | High voltage stress | optimized       |

## 4. CONCLUSION

The investigation of sheath voltage behavior in different loading, grounding and segmentation scenarios was conducted using detailed computer modelling (PSCAD). The findings clearly show that the greatest two factors impacting the sheath voltage are the length of cable and load current, with both of these documents as having an effect on the amount of inductive and capacitive coupling in the system. Grounding resistance was also included, but the impact on the sheath voltage was marginal, with the effect being most significant for very long runs of cable. The location of the grounding for separated cables has a significant influence on how voltage is distributed along the cable, with improper grounding causing large voltage spikes. Based on these results, useful guidelines for identifying grounding techniques and segmentation arrangements will be useful for improving the safety and reliability of medium voltage underground cable systems. As this study is simulation-driven (PSCAD) and serves as a design-oriented analytical framework, with experimental validation proposed as future work. In future research efforts, consideration of the effects of transient events during a switching occurrence, effects of soil resistivity, and the behavior of the sheath voltage limiting device will provide an even more thorough assessment of the behavior of the sheath voltage.

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