Propagation of transients in extruded MV and HV cables considering typical thickness and resistivity values of commercial semiconductive compounds

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Abstract—The effect of the semiconductive layers on the propagation of transients along a cable line has been considered in the light of the cable line model recently introduced by Ametani et al.. The analysis has been addressed on different cable line lengths and considering the cable line installed in a typical layout between an overhead line and a transformer. Fast and slow front voltage shapes impinging the cable line, simulated via the Heidler function with selected parameters, has been considered coming from the overhead line. Actual cable formations of typical 20 kV and 150 kV cable ratings have been adopted. The characteristics of the semiconductive compounds in terms of dielectric constant, resistivity and thickness values have been selected from commercial compounds.

The results obtained using an accurate cable line model that takes into account the semiconductive layers in the cable formation and a less accurate one that disregards such layers are compared and discussed. Although the analysis shows that the differences in the propagation of transients using the mentioned models are not strong, the advanced models is in any case to prefer in order to avoid possible misleading results.

Keywords: cable line, semiconductive compounds, frequency dependent cable line model, transients on cable line.

I. Introduction

STATISTICAL approach to insulation coordination of cable lines is based on the knowledge of probabilistic distribution of the overvoltages stressing the cable insulation and consequently their exact estimation is fundamental for the evaluation of the risk of failure [1]. Lightning and switching overvoltages, traveling along the cable and reflecting at cable ends, are attenuated and distorted on the wave shape due to the intrinsic characteristics of the cable (manufacturing materials, cable formation, radial geometry, cable length) and to the boundary conditions (power system configuration, resistivity of soil, etc.). The semiconductive layers, obligatory for cable with voltage rating above 3 kV, can sometime play a not negligible role in the propagation of the surges along the cable line. Their thickness (inner and outer semiconductive layers) is usually a function of the cable voltage rating while the resistivity (temperature dependent) is related upon the carbon black content in the compound varying from manufacturer to manufacturer [2]-[8].

Therefore for the assessment of the overvoltages, the modeling of a cable line becomes essential and the frequency dependent cable line Shelkunoff model is the right one for the voltage transients studies. In two recent papers [9]-[11] the semiconductive layers have been implemented for the first time in a frequency dependent parameters cable line model improving the model reported in a basic paper [12].

On the light of this improvement the two models are here used in order to evaluate the real influence of the semiconductive layers in the propagation of lightning and switching impulses. Typical values of resistivity and thickness relevant to different commercial semiconductive compounds for MV and HV extruded cables applications are considered.

II. Semiconductive Compounds Characteristics

Semiconductive layers used in extruded power cables are compounds in which the base polymer is generally a polyethylene copolymer of the ethylene ethyl acrylate (EEA) or ethylene ethyl vinyl acetate (EEVA) [3], [7]. For ethylene-propylene (EPR) insulation compounds, semiconductive compounds with a base copolymer of EPR or a base terpolymer of ethylene-propylene-diene monomer (EPDM) have also been used. A predicted quantity of carbon black is added during the compounding process in order to give at the final compound the desired resistivity.

The carbon black generally used in the cable manufacture belongs to two classes relevant to type of production process: the furnace black, in which the raw material is a heavy aromatic petroleum, and acetylene black in which is derived from acetylene gas [7]. In both case the methods of production are based on a dehydrogenation process performed at temperature in the order of 1500 °C [7]. In any case the final product properties are strictly related to the production process [2]-[5], [7]. The primary particle size are in the order of 15 ÷ 50 nm [2], [7], while the final product are aggregates of primary particle size in the order of several hundred of nanometers.

The optimum concentration of carbon black in the final semiconductive compound is a compromise between resistivity and processability. The concentration in the compound generally varies between 15 to 50 parts per

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hundred of the base polymer (phr) depending on carbon black type [7]. DC conductivity follows the percolation theory: it remains poor up to a concentration threshold in which it dramatically increases up to a saturation limit where the further increase of carbon black volume fraction has no longer effect [4].

During the compounding process of the semiconductive compound, beside the carbon black, stabilizers and curing agents are also added. The first ones impart at the final product invariant characteristics over time that prevent degradation of the compound during the fabrication and service, the latter one achieves the crosslinking of the compound. In EPR and EPDM base polymer semiconductive compounds, waxes and oils are also added as processing aids.

One important property of the carbon black is the grade of cleanliness. The presence of contaminants as sulfur and a variety of inorganic residues within the ash can reflect on the final cable performances [4], [13], [14] especially for the water tree growth [7], [15]-[18]. Such impurities can even affect the smoothness [4], [7], [19], [20] (another important property) of the semiconductive layers and can incur on micro protrusion that can enhance the electric field on the semiconductive-insulation interface giving rise to possible weak point for the formation of electrical treeing. Smoothness is also affected by the extrusion process: in this case one of the most important surface defect is due to scorch [4], [7].

Cables manufactured with the same insulation compound, but different semiconductive compounds can have not negligible differences on both AC and impulsive breakdown strength [21]-[23].

AC resistivity values of commercial black compounds typically used on XLPE and EPR insulated cables are in the range of 0.1 ÷ 100 Ωm. The manufacturers usually declare that the volume resistivity is less than 100 Ωm at room temperature and less than 10 Ωm at 90 °C. Although some laboratories have revealed also different values [3], [4], [6], they are in accordance with the standards specifications, i.e. less than 1000 Ωm for the inner (conductor screen) semiconductive layers and less than 500 Ωm for the outer (insulation screen) semiconductive layer [24], [25].

The dielectric constant value usually ranges between one hundred to several thousand [6]. Semiconductive compounds with a dielectric constant in the order of 10 has been also traded by one manufacturer [6]. In any case the stress control is well realized if the product of the dielectric constant time frequency is much greater than the semiconductive resistivity [6]. It is also interesting to note that high value of the overall cable loss (tanδ) is achieved with relatively low value of the dielectric constant and high value of resistivity [6]. Furthermore the dielectric constant generally decreases with the resistivity and their values are temperature dependent, consequently the likelihood to have simultaneously a low dielectric constant with a high resistivity is quite small. It is also been shown that both dielectric constant and resistivity can ranges widely and, in the worst condition, only a 1% of overall cable loss increase can occur [6].

III. Analyzed Configuration

In order to analyze the effect of the semiconductive layers in the propagation of transients along a cable line, a typical layout in which the cable line is connected between an overhead line and a transformer has been taken into account as reported in Fig. 1. For simplicity the overhead line has been considered of infinite length and the transformer simulated with a capacitance of 1 nF for each phase. The space distribution of the overhead line conductors has been appropriately chosen if a medium or a high voltage line has been considered. The cable screen has been grounded at both ends of the cable line with a resistance of 30 Ω at the overhead/cable transition end and a resistance of 10 Ω at the transformer side end. Such values take into account the surge impedances [26]. No surge arrester are considered at both ends of the cable line.

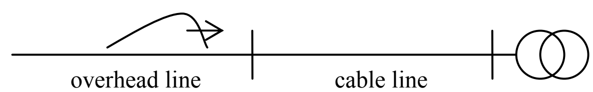

Fig. 1. System configuration considered in the analysis.

The stressing wave shape impinging the cable line has been considered coming from the overhead line as a phase-to-ground overvoltage with the same amplitude and the same wave shape for each phase.

Three different voltage shapes have been considered: the 1.2/50 μs standard lightning impulse, the 250/2500 μs standard switching impulse and the 0.5/6 μs in which represents a sort of fast transient. The wave shapes have been simulated by Heidler function [27] with adequately selected parameters, which is more realistic than the typical double exponential function. In fact, the first derivative of Heidler function is zero at the foot of the wave in spite of the double exponential wave.

IV. Cable Lines

Typical 20 kV and 150 kV cables have been considered. The typical formation of both 20 kV and 150 kV EPR insulated cables is reported in Fig. 2.

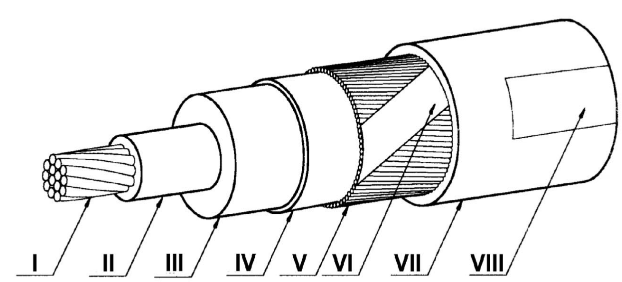

Fig. 2. Typical EPR cable formation: (I) conductor, (II) inner semiconductive layer, (III) insulation wall, (IV) outer semiconductive layer, (V) wire screen, (VI) equalizer tape, (VII) thermoplastic jacket, (VIII) stamping.

The 20 kV cable formation is: 150 mm^2 of aluminum conductor cross section, 0.7 mm of inner semicondutive layer, 5.5 mm of EPR insulation wall (2.6 of dielectric constant), 0.5 mm of outer semiconductive layer, 25 mm^2 of cupper (wire) screen cross section and 2 mm of PVC thermoplastic jacket (5 of dielectric constant).

The 150 kV cable formation is: 1600 mm^2 of aluminum conductor cross section, 2 mm of inner semicondutive layer, 20 mm of EPR insulation wall (2.6 of dielectric constant), 1 mm of outer semiconductive layer, 85 mm^2 of cupper (wire) screen cross section and 4 mm of PE thermoplastic jacket (2.3 of dielectric constant).

The cable lines have been considered buried at 1 m depth in a 100 Ωm soil. The 20 kV cable line has been considered laid in a trefoil formation while the 150 kV cable line in a flat formation in which the minimum distance between the jackets of two adjacent cores is 20 cm.

A Matlab program implementing the Shelkunoff theory [9]-[12], [28]-[31] for the advanced cable line model has been implemented. For the cable line model which concerns the presence of the semiconductive layers, impedance and admittance of such layers has been considered taking into account the last developments performed by Ametani et al. [9]-[11]. The ground return has been considered using the Wedepohl-Wilcox's approximated Pollaczek formula [30], [31].

V. Discussion of Results

Two cable line models relevant to two configurations of cable formation are here considered: a very accurate one in which the semiconductive layers are taken into account and a less accurate one in which the semiconductive layers are not considered at all in the formation of the cable. In the first model the cable formation is that reported in Section IV. In the second model the cable formation is the same but the semiconductive layers are simply eliminated and consequently a reduced overall cross section of the cable is achieved: the insulation layer is directly upon the conductor and the wire screen is directly upon the insulation. Hence, all the results discussed in this Section are strictly related to this two types of cable formation.

Although such comparison appears unrealistic, yet it is a possible condition that one can incur during a simulation. In fact the characteristics (resistivity, dielectric constant and thickness) relevant to the semiconductive layers of a cable are usually not available.

Considering the dielectric constant, the resistivity and thickness of the semiconductive layers, three sub-analyses have been performed:

- the dielectric constant varied between 20 and 1000 with a resistivity fixed at 1 Ωm and the thickness at the values reported in Section IV;
- the resistivity varied between 1 Ωm to 500 Ωm with a dielectric constant fixed at 500 and the thickness at the values reported in Section IV;
- the thickness of both layers varied up to twice the values reported in Section IV and both the dielectric constant and the resistivity fixed at 500 and 1 Ωm respectively.

The last case has shown to be the most sensitive among the others to the attenuation of the voltage transients traveling the cable line, thus the last point has been developed more accurately afterwards. The analysis is reported separately for the medium voltage and the high voltage cable lines. In this paper only conductor-screen voltages are reported.

A. MV cable line (20kV)

Fig. 3 shows the variation of the maximum overvoltage $V_{c\text{-}max}$ stemming from the cable line as percentage of the impinging voltage V_h coming from the overhead line for different values of cable length and for the three impulsive wave shapes. The $V_{c\text{-}max}$ value is defined here as:

$$V_{c-\max} = \max(V_s, V_r) \tag{1}$$

where V_s and V_r are the voltage waves at the sending end and at the receiving end respectively.

Beside the important role played by the length of the tail of the impinging wave shape, the difference between the $V_{c\text{-}max}/V_h$ ratio disregarding and considering the semiconductive layers is in the order of 1% for very short lengths of cables. Such difference tends to increase with cable length with a 250/2500 µs wave and tend to decrease with cable length for the 0.5/6 µs and 1.2/50 µs wave. In particular for 1.2/50 µs and 0.5/6 µs wave shapes such difference becomes negative starting from a certain cable length. Fig. 4, which is a zoom of Fig. 3, highlights such turnaround for the 0.5/6 µs and the 1.2/50 µs impinging waves.

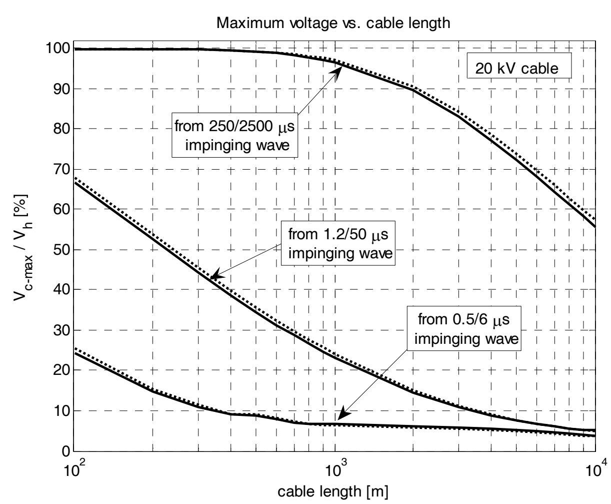

Fig. 3. Maximum voltage stemming on the cable / maximum impinging overvoltage ratio in percent on a 20 kV cable line vs. cable length for different impinging wave shapes when semiconductive layers are disregarded (dashed lines) and 0.7 mm and 0.5 mm of inner and outer semiconductive layers respectively are considered (solid lines).

The overvoltage stressing the cable insulation is even higher when the semiconductive layers is considered and the cable length is higher than 800 m for the 0.5/6 µs wave and higher than 8 km for the 1.2/50 µs wave. Such turnaround can be explained considering Fig. 5 where the voltage wave shape at the sending end V_s of the cable line in p.u. value of the impinging peak value is reported for the 1.2/50 µs wave and the cable line is 10 km long. After the first reflection (second peak) the attenuation is higher if the semiconductive layers are taken into account. On the contrary, the highest values are reached if the semiconductive layers are considered. The voltage stemming at the receiving end of a cable line 10 km long when the impinging wave shape at the overhead/cable transition (sending end) is 1.2/50 µs, is reported in Fig. 6.

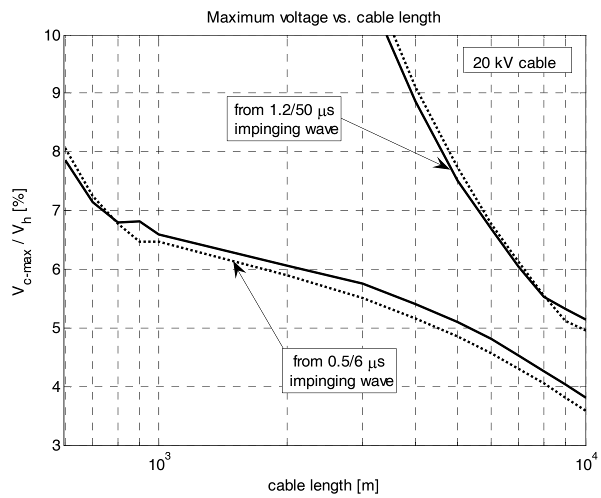

Fig. 4. A zoom shot of Fig. 3.

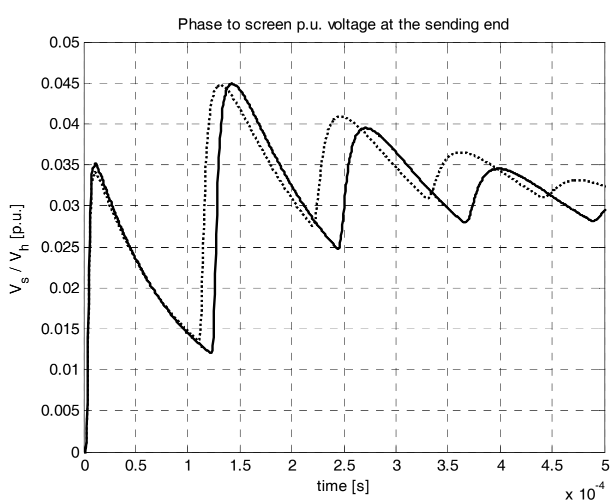

Fig. 5. Cable line voltage at the sending end in p.u. value of the maximum impinging voltage on a 20 kV cable line 10 km long for the 1.2/50 µs impinging wave shapes when semiconductive layers are not taken into account (dashed lines) and 0.7 mm and 0.5 mm of inner and outer semiconductive layers respectively are considered (solid lines).

The last two figures highlight that an accurate cable model gives rise to a higher attenuation for transients in respect of a less accurate one that disregards the semiconductive layers. On short cables the peak value of the transient is reached after several reflections and in this case the attenuation plays its role. On long cables when the impinging wave has a relatively short tail the attenuation of semiconductive layers is not revealed within the very first reflections, consequently the turnaround reported in Fig. 4 is possible.

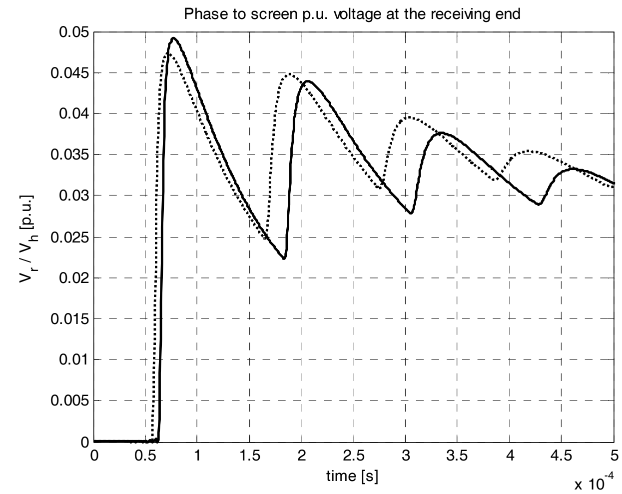

Fig. 6. As Fig. 5, but at the receiving cable end.

It is also to note a not negligible difference in wave propagation delay due to the influence of the semiconductive layers on cable surge speed, as already revealed in [9]-[11].

Fig. 7 shows the variation of the maximum overvoltage $V_{c\text{-}max}$ stemming from the cable line as percentage of the impinging voltage V_h coming from the overhead line for the 1.2/50 µs wave shape when no semiconductive layers and different possible values of the semiconductive thickness are considered. The differences, although noticeable, are of the order of some percent for short cables and such difference fades out as the cable length increases (Figs 3 and 4).

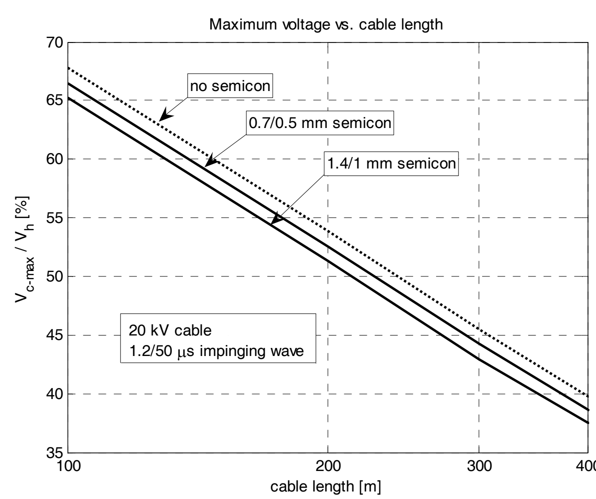

Fig. 7. Maximum voltage stemming on the cable / maximum impinging overvoltage ratio in percent on a 20 kV cable line vs. cable length for the 1.2/50 µs impinging wave shape when no semiconductive layers, 0.7 mm/0.5 mm of inner/outer semiconductive layers thickness and 1.4 mm/1 mm of inner/outer semiconductive layers thickness are considered.

B. HV cable line (150kV)

In Fig. 8 the variation of the maximum overvoltage $V_{c\text{-}max}$ stemming from the cable line as percentage of the impinging voltage V_h coming from the overhead line for different values of cable length and for the three impulsive wave shapes is reported. Such plot very similar to that of Fig. 3, shows a reduced attenuation in the case of the 150 kV cable in respect of the 20 kV cable. The same turnaround in the $V_{c\text{-}max}/V_h$ ratio is revealed at 800 m and 8 km for the 0.5/6 μs wave and 1.2/50 μs wave respectively.

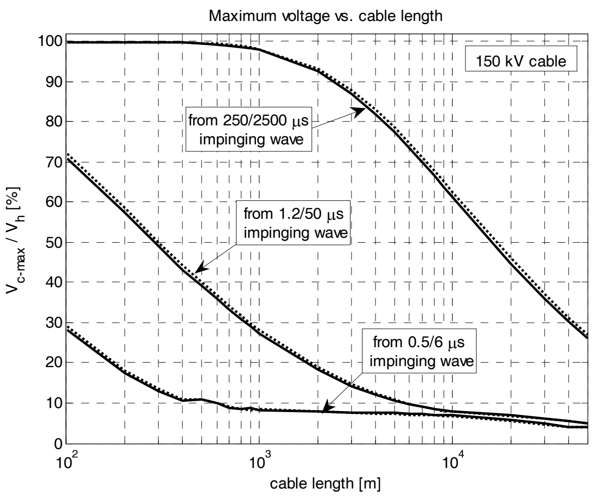

Fig. 8. Maximum voltage stemming on the cable / maximum impinging overvoltage ratio in percent on a 150 kV cable line vs. cable length for different impinging wave shapes when semiconductive layers are not taken into account (dashed lines) and 2 mm and 1 mm of inner and outer semiconductive layers respectively are considered (solid lines).

If beside the case of no semiconductive layers and the case 2/1 mm of inner/outer semiconductive layers reported in Fig. 8, the 4/2 mm of inner/outer semiconductive case is added, Figs 9 and 10 show the $V_{c\text{-}max}/V_h$ ratio versus cable length for the 1.2/50 μs case.

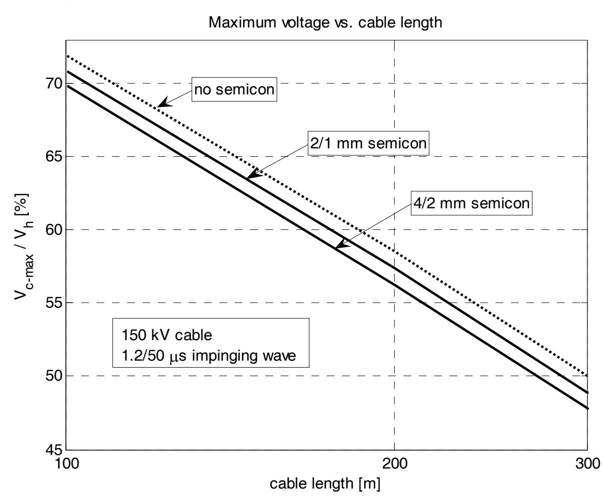

Fig. 9. Maximum voltage stemming on the cable / maximum impinging overvoltage ratio in percent on a 150 kV cable line vs. cable length for the 1.2/50 μs impinging wave shape when no semiconductive layers, 2 mm/1 mm of inner/outer semiconductive layers thickness and 4 mm/2 mm of inner/outer semiconductive layers thickness are considered.

In particular Fig. 9 highlights that the differences among the three curves are of the order of 2% if the cable length ranges between 100 m to 300m. Furthermore such differences decrease as cable length increase. On the other hand, Fig. 10 points out the turnaround of the $V_{c\text{-}max}/V_h$ ratio with the cable length at 8 km, showing that beyond 8 km the highest is the thickness of the semiconductive layers, the highest is the peak value of the voltage in the cable line.

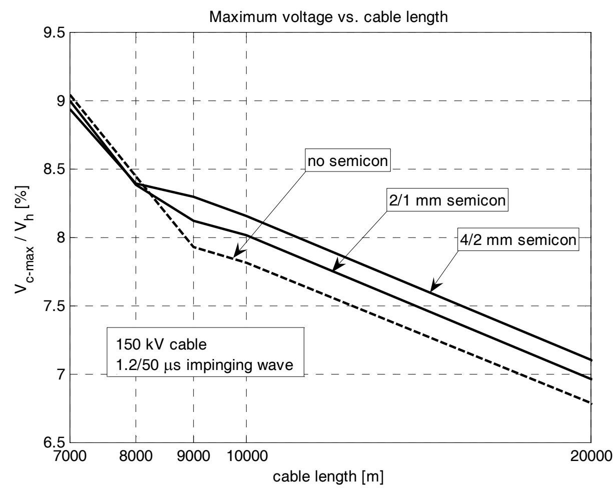

Fig. 10. As Fig. 8 but for a different range of cable length.

VI. Conclusions

An analysis on the attenuation of transients due to semiconductive layers in typical MV 20 kV and HV 150 kV cable lines for three different impinging wave shapes using an accurate cable line model that takes into account the semiconductive layers in the cable formation and a less accurate one that disregards such layers has been performed. The results of such analysis have shown that the differences using the accurate and the less accurate cable line model respectively are in the order of some percent.

Considering the typical dielectric constant, resistivity and thickness values of commercial compounds used for power cables it has been revealed that the thickness seems the most responsible for the attenuation of the voltage transients. Although the semiconductive layers do not give rise to strong attenuation, a cable line model which implement the semiconductive layers is in any case to be recommended in order to avoid possible misleading results. In fact, on long cables, the voltage peak value stemming from the cable line due to an impulse stress from the overhead line is even higher when the semiconductive layers are taken into account.

VII. References

[1] M. Marzinotto, C. Mazzetti, P. Schiaffino, "Statistical approach to the insulation coordination of medium and high voltage cable lines", Proc. of *IEEE Power Tech 2005*, St. Petersburg, Russia, June 27-30, 2005.

[2] J.S. Dick, *Rubber technology – Compounding and testing for performance*, Hanser Gardner Publication, Inc., Cincinnati, OH, USA, 2001.

[3] R. Bartnikas, K. D. Srivastava, 2000, *Power and communication cables – Theory and applications*, IEEE Press Series on Power Engineering, John Wiley & Sons, Inc., Hoboken, New Jersey, USA.
[4] K.M. Jager, L. Lindbom, "The continuing evolution of semiconductive materials for power cable applications", *IEEE Electrical Insulation Magazine*, Vol. 21, No. 1, pp. 20-34, January/February 2005.
[5] K.M Jager, D.H. Mc Queen, J. Vilkakova, "AC conductance and capacitance of carbon black polymer composites during thermal cycling and isothermal annealing", *J. Phys. D: Appl. Phys.*, Vol. 34, pp 2699-2707, 2001.
[6] S. A. Boggs, "500 Ωm – Low enough resistivity for a cable ground shield semicon?", *IEEE Electrical Insulation Magazine*, Vol. 17, No. 4, pp. 26-32, July/August 2001.
[7] N.M. Burns, R.M: Eichhorn, C.G. Reid, "Stress controlling semiconductive shields in medium voltage power distribution cables", *IEEE Electrical Insulation Magazine*, Vol. 8, No. 5, pp. 8-24, July/August 2001.
[8] K.Y. Lee, J.C. Nam, D.H. Park, D.H. Park, "Electrical and thermal properties of semiconductive shield for 154 kV power cable", *Proc. of 2005 International Symposium on Electrical Insulating Materials*, Kitakyushu, Japan, June 5-9, 2005.
[9] A. Ametani, Y. Miyamoto, N. Nagaoka, "Semiconducting layer impedance and its effect on cable wave-propagation and transient characteristic", *IEEE Transactions on Power Delivery*, Vol. 19, No. 4, pp. 1523-1531, October 2004.
[10] N. Amekawa, N. Nagaoka, Y. Baba, A. Ametani, "Derivation of semiconducting layer impedance and its effect on cable wave propagation and transient characteristics", *IEE Proc. Gener. Transm. Distrib.*, Vol. 150, No.4, pp. 434-440, July 2003.
[11] Y. Baba, N. Tanabe, N. Nagaoks, A. Ametani, "Transient analysis of a cable with low conducting layers by a finite time-domain method" IEEE Transactions on Electromagnetic Compatibility, Vol. 46, No. 3, August 2004.
[12] A. Ametani, "A general formulation of impedance and admittance of cables", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-99, No. 3, pp. 189-197, 1980.
[13] A. Blhadfa, A.J. Houdayer, P.F. Hinrichsen, G. Kajrys, J. St-Pierre, G. Kennedy, J.P. Crine, N. Burns, "Impurities in Semiconductive compounds used as HV cable shields", *IEEE Transactions on Electrical Insulation*, Vol. 24, pp. 709-712, 1989.
[14] K.Y. Lee, J.S. Yang, J.C. Nam, D.H. Park, D.H. Park, "Measurement of ionic impurities and thermal properties of semiconductive shield for 145 kV power cable", *Proc. of 2005 International Symposium on Electrical Insulating Materials*, Kitakyushu, Japan, June 5-9, 2005.
[15] S. Boggs, J. Xu, "Water treeing – filled versus unfilled cable insulation", *IEEE Electrical Insulation Magazine*, Vol. 17, No. 1, 2001.
[16] F. Ombello, R.D. Rosevear, "Behaviour of extruded cables in water", *IEE Colloquium on European view of Testing and Assessment on Medium Voltage Polymeric Cables*, 1992.
[17] R. Bartnikas, R.J. Densley, R.M. Eichhorn, "Long term accelerated aging tests on distribution cables under wet conditions", *IEEE Transactions on Power Delivery*, Vol. 11, No. 4, 1996.
[18] C. Katz, M. Walker, B. Fryszczyn, "Comparative laboratory evaluation of TR-XLPE and XLPE cables with super-smooth conductor shields", *IEEE Transactions on Power Delivery*, Vol. 19, No.4, 2004.
[19] S.L. Greene, "Smoothness evaluation of clean furnace blacks", *IEEE Electrical Insulation Magazine*, Vol. 10, No. 2, pp. 23-29, March/April 1994.
[20] W. K. Lee, "Tape surface smoothness characterization and protrusion shape of semiconductive compounds for power cables", *Proc. of Conference on Electrical Insulation and Dielectric Phenomena CEIDP 1992*, pp. 469-474, October 18-21, 1992.
[21] J. Bezille, H. Janah, J. Chan, M.D. Hartley, "Influence of diffusion on some electrical properties of synthetic cables", *Proc. of Conference on Electrical Insulation and Dielectric Phenomena CEIDP 1992*, pp. 469-474, October 18-21, 1992.
[22] M. Marzinotto, C. Mazzetti, M. Pompili, P. Schiaffino, "AC strength test data of unaged and water tank aged xlpe compounds for transmission and distribution power cables" to be presented at the next Conference on Electrical Distribution CIRED 2007, Vienna, Austria, May 21-24, 2007.
[23] M. Marzinotto, C. Mazzetti, M. Pompili, P. Schiaffino, "Impulsive strength of power cables with different XLPE compounds" *Proc. of Conference on Electrical Insulation and Dielectric Phenomena CEIDP 2006*, Kansas City, MO, USA, October 16-19, 2006.
[24] *IEC Power cables with extruded insulation and their accessories for rated voltages above 30 kV up to 150 kV – Test methods and requirements*, IEC 60840 Standard, 2004, Third Edition.
[25] *ENEL Testing requirements for medium and high voltage EPR insulated cables*, ENEL DC 4584 Standard, 1996, Italy.
[26] A. R. Hileman, *Insulation coordination in power systems*, Marcel Dekker, New York, USA, 1999.
[27] F. Heidler, J. M. Cvetić, B. V. Stanić, "Calculation of Lightning Current Parameters" *IEEE Transactions on Power Delivery*, Vol.14, No.2, April 1999.
[28] S. A. Shelkunoff, "The electromagnetic theory of coaxial transmission lines and cylindrical shields", *Bell Syst. Tech.* J. 13, 1934.
[29] F. Polaczek, "Sur le champ produit par un conducteur simple infiniment long parcouru par courant alternatif", *Rev. Gen. Electr.*, 29, 1931.
[30] L. M. Wedepohl, D. J. Wilcox, "Transient analysis of underground power-transmission systems" *ibid.*, 120 (2), 1973.
[31] J.P. Bickford, N. Mullineux, J. R. Reed, *Computation of power-system transients*, Peter Peregrinus Ltd., London, 1980.

VIII. ACKNOWLEDGEMENTS

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IX. BIOGRAPHIES

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