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Future Challenges for Cable Accessories in Medium Voltage Networks

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Abstract: In recent years, the architecture of the power system has been the subject of a major change. The commonly known structure with centralized generation and one directional power flow, gives gradually the place to the new concept of the power network where both the energy generators and consumers are distributed. Particularly, the continuously increasing environmental concerns as well as the legal regulations result in a widespread installation of renewables. In addition, storage devices are incorporated in the network in order to cope with sudden increase of the generated energy. To facilitate the energy flow from the renewables towards the power network, the proper voltage level is maintained by means of transmission controllers. Such controllers consist of high frequency switching elements and the operation of such devices introduces high frequency harmonics that are propagated in the vicinity of the installed controller. On the one hand, a high content of harmonics is an emerging issue for the power network. On the other hand, some researches show the deleterious effect of high frequency signals on the reliability of electrical insulation. Finally, for many years, the harmonic content was not considered neither during the design nor the component's testing phase. In our paper, we will firstly review the published researches regarding the influence of harmonics on the reliability of cables, terminations and transformers. Further on, an approach to model the influence of high frequency on the electric field and temperature distribution in two types of medium voltage cable termination, will be made.

1 INTRODUCTION

For decades, the power system was providing a continuous and one directional power flow from the centralized power plants, through the transmission and distribution network up to the end consumer. The daily-cycled demand for the electrical energy was balanced by the prognosis of generation. In fact, all the components installed in the network were stressed accordingly to the voltage level, the transferred power as well as to the environment in which they were operated. Simplifying, the electrical components consists of two major structures that are being stressed during operation. The active part being responsible for conducting current is the first one. The electrical insulation structure constitutes the second part and is responsible for insulating the parts with different electrical potential.

When considering the failures of power network components, detailed investigations show that more than 70% of the failures is related to the problems of the insulating systems [1]. In addition, [2] states that the life of the electrical equipment is determined by the life of the electrical insulating system. The same source categorizes the electrical insulation system aging factors into electrical, thermal, mechanical and chemical ones. Over the past decades, the types of stresses affecting the electrical equipment, although characteristic for certain types of network and geographical areas, led to the development of the test procedures as presented in IEEE or IEC standards. The main goal of such tests (e.g. type test) is to verify the hypothesis if an equipment of a given design is able to operate for the period of e.g. 30+ years. However, as stated, the test procedures have been developed on the past experience, and, by default do not include new phenomena. As an example, the effect of harmonics caused by new network components or thermo-mechanical stresses due to high load variation can be put forward.

2 THE NETWORK OF THE FUTURE

In recent years, the existing power network faces major changes with respect to the type of energy sources and their deployment. Next to the conventional power plants (gas, oil, coal and nuclear), more and more renewables are installed. The wind parks often connected to the transmission lines while the solar systems (photovoltaics) are connected to the distribution network of low and medium voltage level [2]. Next to these, energy storage systems are incorporated in the distribution network to accumulate the surges when the supply exceeds demand.

The changeability of the weather conditions determines the amount of the generated energy. To facilitate the energy flow at peak-periods while maintaining the proper voltage level, the usage of high-frequency power converters is necessary. The converters are meant to switch the input DC voltage at high frequency in order to produce a wave shape as close to AC as possible at the output [4]. In such way, a converter can be used as a link between the DC and AC systems (renewables) or between AC and AC systems of different frequency. However, the desired shape of the created wave is often far from purely sinusoidal. Depending on the load and the topology of the network, the distortion of the base harmonic can reach several per cent. Figure 1 presents an example of a sine wave distorted by respective harmonics generated by Eagle-Pass converter station connecting the US and Mexican grids [5].

3 THE PERIL OF HARMONICS

The adverse effect of harmonics on the reliability of power components was noticed for the first time in 1950 in the supply system of the London's underground transport. The oil-impregnated paper insulated cables connected to the mercury arc rectifiers, were showing high failure rates. The generated harmonics turned out to be the culprit of the occurring failures [6]. Since that time, the harmonics were mentioned and proven to be responsible for the deterioration and breakdowns of the insulation system in the liquid filled transformers [8], capacitors [9] and underground polymeric cables [7], [10].

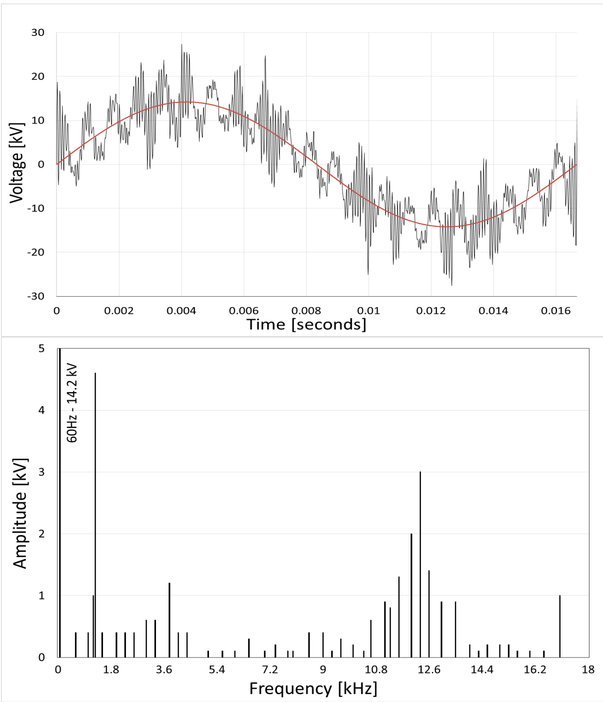

Figure 1 The shape of the base harmonic (60 Hz) with higher harmonics superimposed (upper) and the frequency spectrum (lower) [5].

In [15], the authors investigated the influence of high frequency voltage on a cable termination with a non-geometrical field control. The infrared scans of the investigated objects revealed increased temperature in the vicinity of the of the field control. It has been concluded that the hot spot temperature is proportional to the applied frequency and voltage.

Source [5] presents details of high frequency tests performed on cable terminations with geometrical and non-geometrical (resistive/refractive) stress control arrangement. Here, the terminations were run at the rated voltage where the frequency of the base harmonic is 60 Hz. On top of the base frequency, high frequency signal up to 10.6 kHz was superimposed. The test run several hundreds of hours. The terminations with geometrical field control did not show any abnormal behaviour. Contrarily, all terminations with refractive stress control method have failed. The authors point two reasons for the occurred situation. First of all, for the non-geometrical field control method, the field distribution around the edge of the semi-conductive layer is strongly related to the frequency value. Second, the increased field results in higher amount of losses generated. The latter brings a commonly known concept of the power dissipated in the insulation as caused by the dielectric losses (1) [13].

$$P = U^2 \omega C \tan\delta \ [W] \quad (1)$$

Where:
P – is dissipated power [W]
U – is the voltage across the insulation [V]
C – is the sample capacity [F]
tan δ - is the dissipation factor characterizing given insulation

4 NUMERICAL SIMULATIONS

To gain better understanding of the problem, it has been decided to investigate further the influence of different frequencies on geometrical and resistive field grading systems. The distribution of the electric field was simulated in Comsol Multiphysics. An exemplary cable was considered with the dimensions as specified in [12], [16].

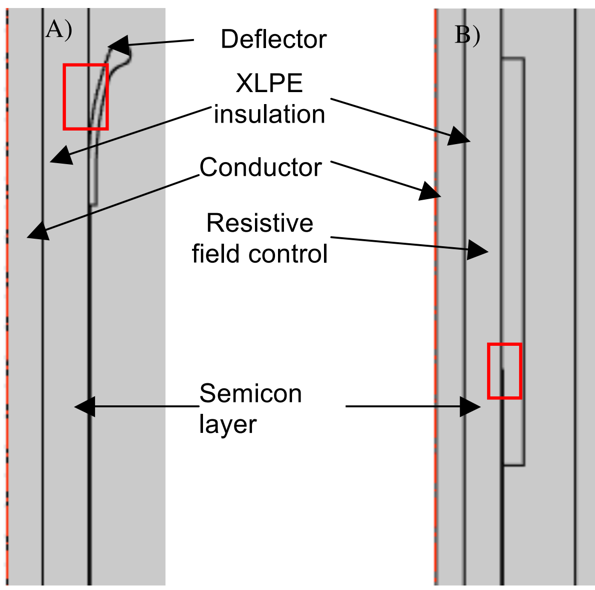

Figure 2 Investigated types of field grading: geometrical type (A) and resistive type (B)

The cross sections of the simplified arrangements can be seen on **Figure 2**. For the arrangement with geometrical field control, the focus was on the area between the deflector and XLPE insulation of the cable. In the case of the resistive field control, the vicinity of the edge of the semi-con layer edge was investigated. Both spots are marked with red square, Figure 2. Such choice can be justified by the fact that that in these areas experience relatively high values of the electric field.

The values of the electrical parameters characterizing the materials in the simulated arrangement are summarized in **Table I**.

Table I. Parameters characterizing the materials used in the modelling [12], [16]

	Type A - insulating medium	Type B - field control material	XLPE
Conductivity [S/m]	1.00E-11	8.25E-07	1E-18
Permittivity [-]	2.3	15	2.3

For the FEM simulations, the frequency of the voltage varied between 50 Hz and 18 kHz. Such choice was made to imitate the span of frequency presented in Figure 1. The applied voltage was 19 kV to ground and the ambient temperature of 293 K was assumed. The simulations revealed the field behaviour in the investigated areas. In the case of geometrical field control, it was observed that the value of the electric field is independent on frequency. This is in line with the conclusion from [5]. For the resistive field control, contrary observation can be made. The value of the electric field in the vicinity of the semicon edge increased four-fold within the investigated frequency span. The details are depicted in Figure 3.

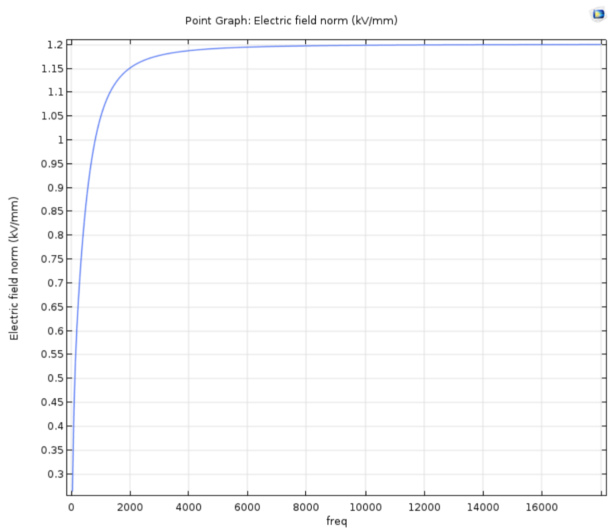

Figure 3 The influence of frequency on the value of the electric field in the vicinity of the semicon edge (arrangement B)

Taking into account the resistivity value of the field control layer, the increase in field might create a threat for the thermal stability. For that reason, it has been decided to perform the simulation of heat developed due to higher harmonics. The temperature increase of the field control layer, as caused by high frequency, was simulated.

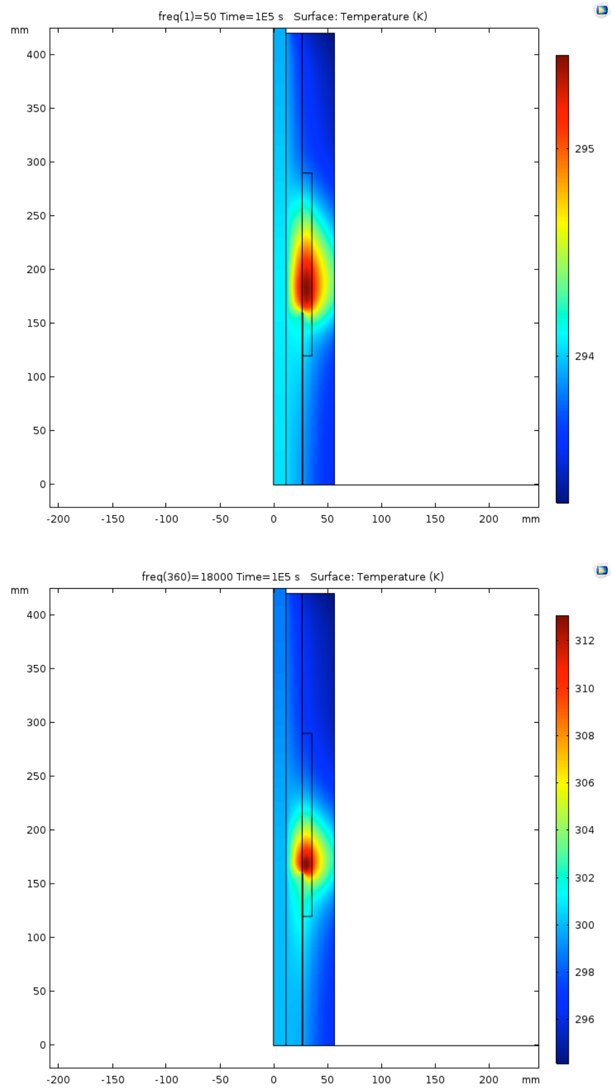

Figure 4 Temperature increase in the vicinity of the edge of the semicon layer: results at 50 Hz (upper) and 18 kHz (lower).

The result of voltage application of different frequency and so the resulting temperature increase in the field control structure, are presented in Figure 4. It can be readily seen that at the frequency of 18 kHz, the maximum temperature in the field control layer increases from 293 to approximately 312 K. This gives the temperature rise of 19 K above ambient. In addition, it must be emphasized that for the simulations, the current flowing through conductor was assumed to be 0 A (no heating from the conductor). For comparison, the respective temperature rise at frequency of 50 Hz was in the range of 3 K.

5 SUMMARY AND CONCLUSION

In the current contribution, the influence of frequency on the field distribution in the vicinity of field control arrangement was studied for an accessory with geometrical and refractive field control. It was concluded that for materials with the given parameters (Table I), field distribution is independent on frequency for geometrical arrangement. Opposite has been observed for the refractive arrangement. Based on the simulated field changes, the temperature rise was calculated for the refractive arrangement. Obviously, for the geometrical arrangement, there is no temperature increase due increased field and such arrangement would be more suitable for the use in the network contaminated with harmonics. However, there will be certain amount of energy dissipated in the material since the dielectric loss is also dependent on frequency. This is less significant compared to the case of resistive field grading, where the loss is increased both by the frequency and the square of the electric field. The obtained results are in line with previous results [5], [15].

6 DISCUSSION

During calculations, the frequency of the voltage was increased in steps. Each field and temperature distribution was calculated for one frequency only. To complete the model, it is advised to superimpose harmonics of different frequency and amplitude onto the base frequency signal. This would result in more accurate temperature estimation. Further on, the characteristics of the simulated materials are to be measured in detail in order to complete the model. The latter would allow better understanding of the electric field and temperature distribution in the refractive layer when stressed with high frequency. Especially that higher harmonics is a relatively new type of stressing factor and it becomes more and more present in the contemporary network. Finally, network highly stressed by harmonics will exhibit higher aging rate and so the installed components might not be able to reach the assumed lifetime. This is another challenge that has to be accounted when considering the reliability of the MV network in the future.

REFERENCES

[1] A. Subramanian, A. Sahoo, S. Manohar, S. Panda - Voltage and Current-Harmonics Induced Ageing in Electrical Insulation, 2017 International Symposium on Electrical Insulating Materials, Toyhashi, Japan, September 2017

[2] Kerry D. McBee – Transformer Aging Due to High Penetration of PV, EV, Charging, and Energy Storage Applications, 9th Annual IEEE Green Technologies Conference

[3] IEC 60505 – Evaluation and Qualification of Electrical Insulation Systems, CENELEC, Brussels, 2011

[4] T. Koltunowicz, G. Bajracharaya, D. Djairam, J.J. Smit – Modelling of Fast Transients Using a High Frequency Transformer, 2009 International Symposiom on High Voltage, ISH, Cape Town, South Africa, September 2009

[5] L. Paulsson et al – High-Frequency Impacts in a Converter Based Back-to-Back Tie; The Eagle Pass Installation, IEEE transaction on Power Delivery, Vol. 18, No. 4 October 2003.

[6] S.B. Warder, E. Friedlander, A. Arman – The Influence of Rectifier Harmonics in a Railway System on The Dielectric Stability of 33-kV Cables, Proceedings IEE, Vol. 98, 1951, pp. 399-421.

[7] K.D. Patil, W. Z. Gandhare - Threat of Harmonics to Underground Cables, 2012 Students Conference on Engineering and Systems, Allahabad, India, March 2012

[8] T. Koltunowicz, G. Bajracharya, D. Djairam, Muhannad Al-Suhaily, J.J. Smit - The effects of Prolonged Exposure of Paper insulation to Fast Repeating Transients, 2011 Electrical Insulation Conference, EIC, Annapolis, Maryland, USA, June 2011.

[9] A. Cavallini, I. Ghinello, G. Mazzanti. G.C. Montanari – Accelerated Capacitor Degradation due to Nonsinusoidal Voltage Supply and Relability of Insulation Systems, 8th International Conference on Harmonics and Quality of Power, Athens, Greece, October 1998

[10] CIGRE TB 703 – Insulation Degradation Under Fast, Repetitive Voltage Pulses, WG D1.43, September 2017

[11] B. Sonerud, T. Bengtsson, J. Blennow, S. Gubanski – Dielectric Heating in Insulating Materials Subjected to Voltage Waveforms with High Harmonic content

[12] A. Lewarkar, D. Bergsma, J. Conradie, S. Buddhawar – Study of Electric Field Grading Types on Medium Voltage Polymerics and Paper insulated Cables

[13] F. Kreuger – Industrial High-Voltage, Delft University Press, Delft 1992, ISBN 90-6275562-3

[14] M. Ghaffarian Niasar, R. C. Kiiza, N. Taylor, H. Edin, “Effect of Partial Discharges on Thermal Breakdown of Oil-Impregnated Paper”, IEEJ Transactions on Electrical and Electronic Engineering, 2015, S14–S18.

[15] U. Patel, Shesha H. Jayaram, A. El-Hag, R. Seetahpathy - MV Cable Termination Failure Assessment in the Context of Increased Use of Power Electronics, , 2011 Electrical Insulation Conference, EIC, Annapolis, Maryland, USA, June 2011.

[16] Online Comsol manual: https://www.comsol.com/model/cable-tutorial-series-43431, last visited in May, 2019.