# Analyzing the Impact of Short-Term Cyclic Thermal Ageing on PVC Insulated Low Voltage Samples with Polarization/Depolarization Current Measurement

**Semih Bal, Zoltan Adam Tamus**

Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics
Egry József u. 18, H-1111 Budapest, Hungary
E-mail: semihbal@edu.bme.hu; tamus.adam@vik.bme.hu

*Abstract: Cables are critical elements of the network. Therefore, their integrity is of utmost importance. Many factors influence the insulation integrity of the cables, such as manufacturing procedures, operating conditions, and various stresses, during their lifetime. Increasing the number of renewables resulted in increased distributed generation, which may cause reverse power flow. The electricity demand is constantly growing with the increased number of novel appliances on the consumer side, electric vehicles, etc. This fact can create short-term overloads, which may cause a temperature elevation beyond the cable's maximum operating limit, compromising insulation degradation. Therefore, this research investigates the impact of short-term cyclic thermal ageing on SZRMtKVM-J 4 x 6 mm PVC insulated low voltage cable using the polarization/depolarization current measurement (PDC). Accelerated thermal ageing tests were performed by placing the samples inside the temperature-controlled oven for 6 hours/round. After each round, the polarization and depolarization currents were measured. DIRANA Dielectric Response Analyzer by Omicron has been employed for the measurements. The results have shown an increase in the polarization and depolarization current.*

*Keywords: PVC Insulation; Thermal Ageing; PDC Measurement; Polarization/ Depolarization Current*

## 1 Introduction

PVC insulated low voltage (LV) cables are commonly used in several applications, like electric distribution, power plants, communication, security systems, etc. [1] [4]. The 2030 Climate Target Plan encourages countries to minimize greenhouse gas emissions by at least 55% by 2030, aiming at achieving climate neutrality by 2050 [5]. Therefore, countries are abandoning fossil fuels to reduce greenhouse gas emissions, meaning more share for renewables. The term smart grid is getting more attention as we move towards the decentralized generation with increased renewables. The distributed generation means the current can flow in both directions, from load to the grid and vice versa. The new appliances connected to the network can cause short-term overloads. These overloads may increase the temperature above the operation limit, which leads the insulation degradation [4], [6], [7]. Therefore, the impact of cyclic short-term thermal ageing has been the focus of this research.

Variations of PV power generation can be modelled in several ways [8]. This paper employs a similar method by utilizing a constant ageing temperature on cable samples in order to simplify the laboratory simulation of accelerated ageing [9]. The purpose is to model the peak power generation of photovoltaic (PV) systems that typically occurs around noon when production is at its highest.

It is vital for the system's safety and reliability; the insulation should perform its intended function, preventing current from flowing [10]. The cables are faced with some stresses in normal operation, which causes a mutation in the molecule structure and degrade the insulation. This is known as insulation ageing [11]-[14]. The electricity market is growing in a direction in which several independent companies compete, such as transmission operators, system operators, and distribution operators. These companies must cut costs while keeping the supply up and running. Costs will not be reduced with the "unscheduled maintenance" philosophy. As the name implies, unscheduled maintenance occurs only when necessary, such as when a transformer or cable fails. However, this usually interrupts the energy supply, making breakdowns much more expensive than preventative maintenance [15]. Therefore, the condition monitoring (CM) of the cables in the network is essential.

Several condition-monitoring techniques are employed by researchers. These CM techniques can be destructive and non-destructive [16]. Since most LV distribution cables are buried underground, a non-destructive CM technique has been used in this study.

Polarization-Depolarization (PDC) measurement is a well-known condition monitoring technique based on the dielectric relaxation for the transformers and cables [17]. It is based on the measurement of polarization (charging, absorption) current and the depolarization (discharging, desorption) current. Morsalin et al. stated that the time constant of polarization/depolarization currents correlates well with ageing and insulation deterioration [18].

This work presents a novel approach to studying the behaviour of insulating materials exposed to short-term, cyclic thermal stress. It is known that each material responds in distinct way when subjected to these stresses [19]. To assess the changes in conductivity, a PDC measurement technique is employed on a specific type of cable (SZRMtKVM-J 0.61/1 kV 4x6 mm$^2$ PVC insulated) after each thermal ageing cycle. DIRANA Dielectric Response Analyzer, commonly used for condition monitoring of power and instrumental transformers, is utilized as a measuring device for this low-voltage (LV) cable type. This research extends the application of the DIRANA and provides valuable insights into the unique responses and conductivity changes exhibited by insulating materials under short-term cyclic thermal stress conditions.

This paper presents an experimental study of PVC insulated LV cable exposed to cyclic thermal stress. Following the introduction section, a brief explanation of PDC technique is given. The experimental work is given in the third section, where a detailed introduction about the cable sample, ageing temperature and how it was chosen, the measurement setup, and accelerated ageing tests are presented. The fourth chapter is dedicated to the results and discussions. Last, but not least, the fifth chapter is the conclusion. It is worth mentioning that this is an ongoing study, and the preliminary results are presented here. The dielectric relaxation measurement was applied on thermally aged cable samples in the time domain, and polarization/depolarization currents were measured.

# 2 Methodology

Researchers widely accept Dielectric Response Measurement (DRM) in their study to investigate the insulation's dielectric characteristics like tanδ, capacitance, insulation resistance, polarization, and depolarization current [20]. It is possible to conduct DRM in the time domain or frequency domain. These dielectric measurements are non-destructive, which is quite advantageous because these techniques can make it possible to measure the dielectric parameters without removing the samples from their network.

The PDC measurement is based on two processes. These are charging and discharging the test sample. The circuit diagram of PDC measurement is shown in Figure 1. The sample is charged with a voltage source ($V_{ch}$) for a definite time through a closed $S_1$ switch. The flowing current is called the polarization current ($i_p$) during charging—the polarization current's amplitude changes by orders of magnitude over time. $I_p$ is dependent on the insulation conductivity. Once the charging period is over, $S_1$ opens and $S_2$ closes to discharge the sample. The depolarization current ($i_d$) is measured. It is shown in Figure 1 that $i_p$ and $i_d$ flow in opposite directions.

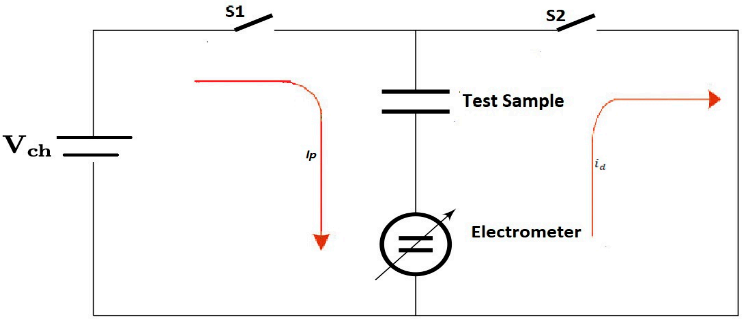

Figure 1
The circuit diagram of PDC

The polarization current is explained in Equation 1:

$$i_p(t) = C_0 U_c \left[\frac{\sigma}{\varepsilon_0} + f(t)\right] \tag{1}$$

Where:

$C_0$ is the geometric capacitance, σ is conductivity and *f(t)* is the dielectric response function.

The depolarization current is explained in Equation 2;

$$i_d(t) = C_0 U_c [f(t) - f(t + t_c)] \tag{2}$$

If the polarization process is sufficiently long enough, conductivity σ can be expressed as in Equation 3.

$$\sigma = \frac{\varepsilon_0}{C_0 U_c}[i_p(t) - i_d(t)] \tag{3}$$

Figure 2 depicts the timing diagram of PDC measurement. The polarization and depolarization currents are both affected by the insulation geometry and material properties [21] [24].

The polarization and depolarization currents are influenced by the properties of the insulation material and also by the geometric structure of the insulating system [25-26].

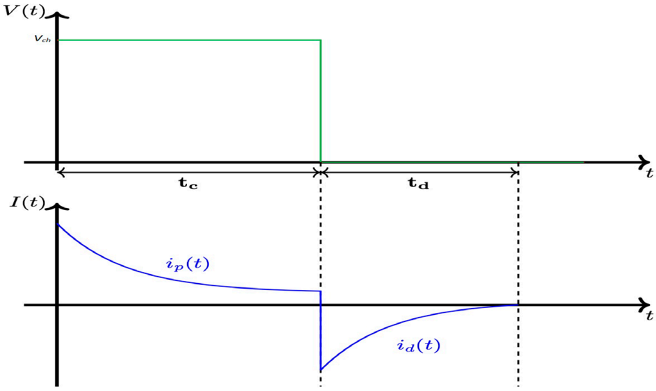

Figure 2
The timing diagram of PDC

# 3 Experiment

## 3.1 Cable Sample

In this experiment, 0.6/1 kV 4 x 6 mm2 PVC insulated cable (type SZRMtKVM-J) samples, made by Pyrismian Hungary Kft., were used. Three cable specimens, each of 50 cm, were cut from the bulk of the cable. The cable samples meet the requirements of IEC 60502-1, which specifies the standards for power cables with solid insulation in terms of design, dimension and testing. According to the cable datasheet, the maximum operating temperature is 70°C. The cable consists of five layers, which is illustrated in Figure 3.

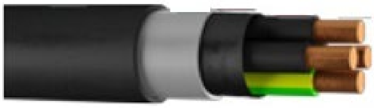

Figure 3
The cable structure

The layers from inside to outside as below:

1. 4 x copper conductor.
2. PVC core insulation.
3. PVC tape belt.
4. Steel armour.
5. PVC jacket.

## 3.2 Thermal Ageing

As mentioned, the cable temperature may rise beyond the maximum limit due to short-term overloads. Therefore, this paper aims to observe the effect of these short-term temperature rises. The accelerated thermal ageing was performed by placing the samples in the temperature-controlled oven for a short time and was repeated over the cycles. The ageing temperature was set to 110°C.

IEC 60502-1 states that thermal ageing can be performed at least 10±2 °C higher than the maximum conductor temperature [27]. Figure 4, taken from IEC 60502-1, shows that the maximum conductor temperature of PVC insulated cable can be 70 °C in normal operation and 160 °C in short-circuit operation.

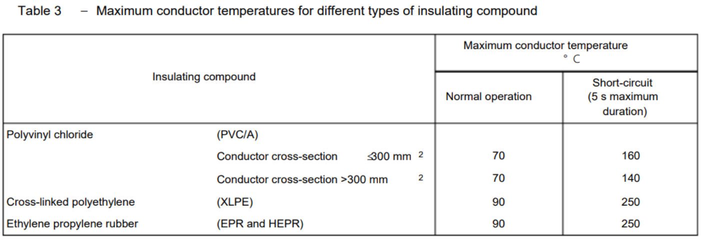

Table 3 – Maximum conductor temperatures for different types of insulating compound

| Insulating compound | | Maximum conductor temperature °C | |
|---|---|---|---|
| | | Normal operation | Short-circuit (5 s maximum duration) |
| Polyvinyl chloride | (PVC/A) | | |
| | Conductor cross-section ≤300 mm $^2$ | 70 | 160 |
| | Conductor cross-section >300 mm $^2$ | 70 | 140 |
| Cross-linked polyethylene | (XLPE) | 90 | 250 |
| Ethylene propylene rubber | (EPR and HEPR) | 90 | 250 |

Figure 4

The maximum conductor temperature [27]

By choosing 110 °C as the ageing temperature, it is desired to apply higher thermal stress to the samples than given in the standard. Also, it is aimed to make the comparison more effortless with the previous studies [4], [6], [7], [28], [29]. Eighteen hours, 6 hours/round, ageing time have been reached. Equivalent ageing time can be calculated using the Arrhenius equation, which is Equation 4.

$$\frac{t_s}{t_a}=e^{\frac{E_a}{k}\left(\frac{1}{T_s}-\frac{1}{T_a}\right)} \tag{4}$$

Where:

- $t_s$= Operating time.
- $t_a$=Equivalent ageing time.
- $E_a$=Activation energy, taken from the literature and set to 80kJ/mol (0.829eV) [30].
- k=Boltzman constant: $8.617333262\times10^{-5}$ eV/K.
- $T_s$=Absolute temperature (70°C) in Kelvin: 343.15 K.
- $T_a$=Absolute ageing temperature (110°C) in Kelvin: 383.15 K.

It can be calculated that eighteen hours of ageing at 110°C would equal 330 hours at 70°C. Table 1 shows the equivalent ageing times after each round.

Table 1

Equivalent ageing time

| Round | Ageing time (hours) ($t_a$) | Equivalent time in operation (hours) ($t_s$) |
|---|---|---|
| 1 | 6 | 110 |
| 2 | 12 | 220 |
| 3 | 18 | 330 |

## 3.3 PDC Measurement

In the time domain, $i_p$ and $i_d$ currents were measured using DIRANA. The general dielectric configuration was chosen from DIRANA library. This configuration can be seen in Figure 5.

The parameters of the measurement were set as follows:

- Test voltage: 200 V.
- Polarization time: 5000 s.
- Depolarization time: 1000 s.

Zaengl et al. suggested that the polarization time should be at least five times higher than the depolarization time [15]. Therefore, the polarization and depolarization times were chosen accordingly. The reason for choosing 1000 s for discharging time is to investigate the slow polarization process. Faraday cage was used to avoid external disturbances. The measurement was performed inside the laboratory, where the temperature was constant at 24±0.5°C.

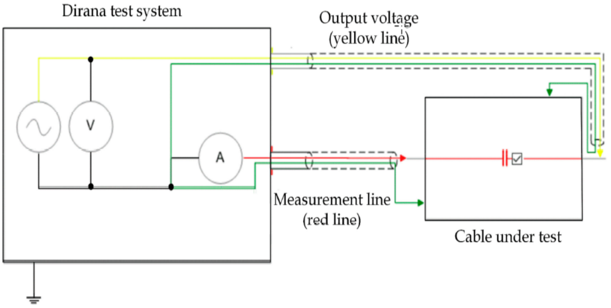

Figure 5

General dielectric measurement configuration from DIRANA library

$i_p$ and $i_d$ current for the core and jacket were measured. 30 cm length of aluminium foil is used to create a conductive surface by wrapping the jacket with it.

For core measurement;

- The measuring probe is connected to the conductor of the cable.

- The other cores and the aluminium belt were short-circuited, and the output probe is connected to them.
- The guard probes are connected to the core insulation, which is being measured.
- The ground probe is connected to the earthing point of the Faraday cage.

For jacket measurement;

- The measuring probe is connected to the jacket and wrapped with aluminium foil.
- All core conductors and aluminium belt were short-circuited, and the output probe is connected to them.
- The guard probes are connected to the jacket.
- The ground probe is connected to the earthing point of the Faraday cage.

The guard probes are used to eliminate the surface leakage current. A single-point grounding was used to prevent any circulating current that could interfere with the results. The sample measurement arrangement is shown in Figure 6.

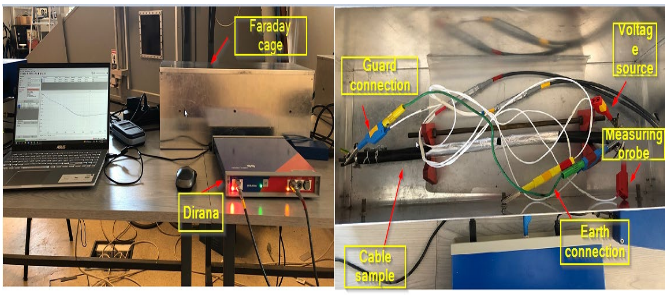

Figure 6
PDC measurement arrangement – Core measurement

The cable samples were short-circuited to the ground between each measurement round to ensure that no remaining charges existed to affect the results. The polarization current curves show a similar trend after each round. This proves that the samples were discharged adequately after each round [15].

## 4 Results & Discussions

The presented results in this chapter are measured quantities. The represented graphs were plotted in a log scale based on the obtained measurement results. The mathematical representation of PDC has been given in Chapter 2. The polarization and depolarization currents given here are measured quantities by DIRANA. From these results using Equation 3, the change in the conductive current due to ageing is obtained. Even though Equation 3 would allow the specific conductivity to be determined, considering the complexity of the cable structure, it would be difficult to calculate accurately [31]. Hence, the conductive current change with ageing was analyzed here. The conductive current has been calculated by subtracting measured polarization and depolarization currents. It is essential to mention that this paper discusses the initial stage of the ongoing research. As a result, no evaluation of performance has been conducted yet. To obtain a comprehensive performance measurement, additional ageing cycles would be required.

## 4.1 Core

Figures 7 and 8 illustrate the polarization and depolarization currents in a log scale over time at different ageing rounds. Figure 7 shows that the polarization current rose over ageing as the whole curve shows an increasing trend. It could be said that the polarization process has increased due to chemical and physical reactions [24]. It was already mentioned in the literature that the magnitude of PDC currents elevates with the temperature [32].

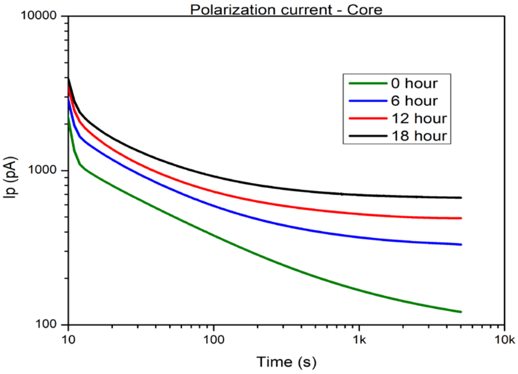

Figure 7
Polarization current – Core

The absolute values of depolarization current were used to plot Figure 8 for easier comparison. When the first and the last round is compared, $i_d$ increased due to ageing up to 200 s. After this point, it goes even under the first round. The reason could be the diffusion of the plasticizer between PVC layers and new molecule bounds, which affects the conductivity [4], [6].

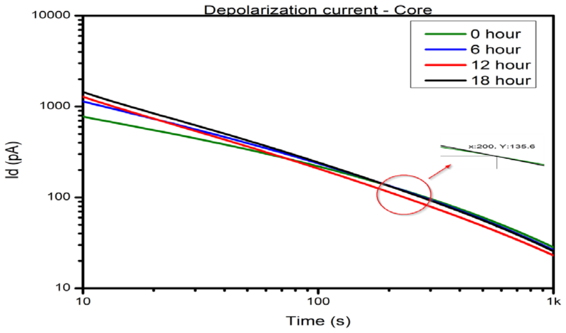

Figure 8
Depolarization current – Core

As given in Equation 3, the conduction current ($i_c$) can be calculated as the difference between the polarization and depolarisation currents. Based on this, the conduction current was calculated. The sampling time is taken as 1 second. $I_c$ is calculated up to 1000 seconds, the duration of discharging period. Figure 9 depicts the conduction current versus time in the log scale for core insulation. It is visible that the conduction current has increased with ageing.

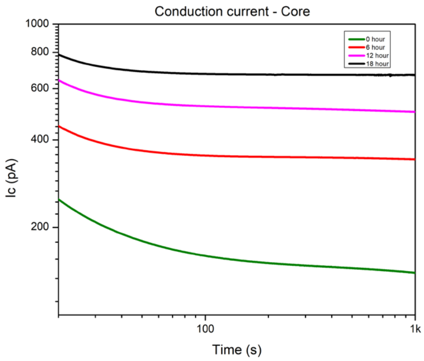

Figure 9
Conduction current – Core

## 4.2 Jacket

The curves of the PDC measurement of the jacket is shown in Figure 10 and 11. By looking at the results, it is possible to see a clear increasing trend for both $i_p$ and $i_d$. The growing trend of polarization current indicates an increase in the polarization level [21]. It is also possible to observe the rise in the depolarization current. The reason could be that plasticizer evaporation from core insulation and PVC belt towards the jacket may raise the conductivity [4], [6], [7], [28]. As a result, the depolarization current has shown an increasing trend. However, this plasticizer behaviour would require further chemical studies.

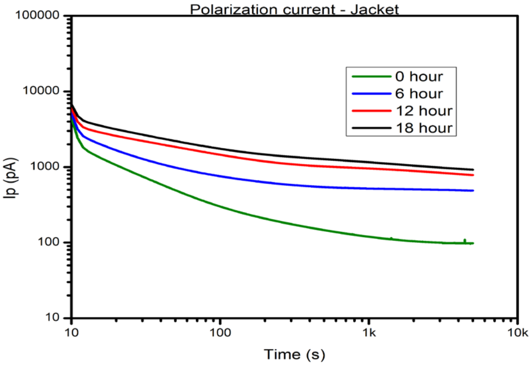

Figure 10
Polarization current – Jacket

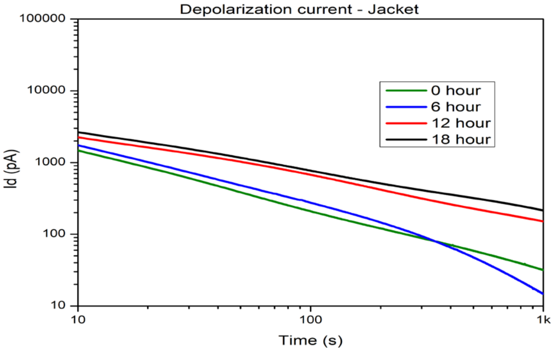

Figure 11
Depolarization current – Jacket

The conduction current of the jacket has also shown a similar trend to the core. It has increased after each ageing cycle. This trend can be seen in Figure 11. It is also noticeable from the chart that the conduction current has increased significantly after the first round of ageing compared to the unaged condition. However, the difference between the other rounds has shrunk with ageing. The same trend can be observed for the core, as well. As mentioned, the reason could be the diffusion of the plasticizer between the PVC layers.

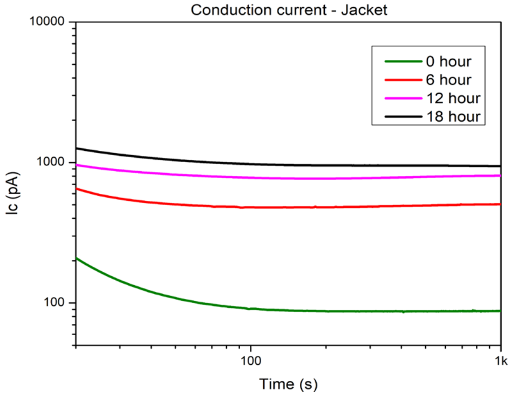

Figure 12

Conduction current – Jacket

## Conclusions

The PVC insulated low voltage distribution cable samples were exposed to the short-term cyclic accelerated thermal ageing in the temperature-controlled oven at 110°C. Each round lasted six hours, and eighteen hours of total ageing time was reached. The equivalent ageing time of 330 hours was calculated using the Arrhenius equation. Non-destructive PDC measurement was used to explore the impact of thermal ageing on the cable insulation. The results so far show that ageing affects the polarization and depolarization current. The observed elevation in the polarization current for the core and jacket indicates the polarisation level's rise.

It is possible to see that the jacket's depolarisation current rises due to ageing. The migration of additives and plasticizers towards the jacket from core insulation and PVC belt might be the reason behind this. The depolarization current of the core has shown an unclear trend. It has increased due to ageing up to 200 s. After this point, it goes even under the first round. The reason could be that the new molecule bounds are being established, affecting conductivity. More ageing cycles are needed to get a clear understanding.

## Acknowledgement

Project no. 142814 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the FK_22 funding scheme.

## References

[1] B. Kruizinga, P. A. A. F. Wouters and E. F. Steennis, "Fault development on water ingress in damaged underground Low Voltage cables with plastic insulation," 2015 IEEE Electrical Insulation Conference (EIC), 2015, pp. 309-312

[2] K. Anandakumaran, S. Barreca, N. Seidl and P. V. Castaldo, "Nuclear qualification of PVC insulated cables," in IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 8, No. 5, pp. 818-825, Oct. 2001

[3] J. Packa, M. Váry, J. Lelák and V. Šály, "Degradation of 230/400 V distribution cables with PVC insulation," 2017 18th International Scientific Conference on Electric Power Engineering (EPE), 2017, pp. 1-4

[4] G. M. Csányi, S. Bal, and Z. Á. Tamus, "Dielectric Measurement Based Deducted Quantities to Track Repetitive, Short-Term Thermal Aging of Polyvinyl Chloride (PVC) Cable Insulation," Polymers, Vol. 12, No. 12, p. 2809, Nov. 2020

[5] "2030 Climate Target Plan." [Online] Available: https://climate.ec.europa.eu/eu-action/european-green-deal/2030-climate-target-plan_en

[6] S. Bal and Z. Á. Tamus, "Investigation of Effects of Thermal Ageing on Dielectric Properties of Low Voltage Cable Samples by using Dielectric Response Analyzer," 2022 International Conference on Diagnostics in Electrical Engineering (Diagnostika), 2022, pp. 1-6

[7] Csányi, G. M., Tamus, Z. Á., Kordás, P., "Effect of Enhancing Distribution Grid Resilience on Low Voltage Cable Ageing" In: Camarinha-Matos, L., Adu-Kankam, K., Julashokri, M. (eds) Technological Innovation for Resilient Systems. DoCEIS 2018, IFIP Advances in Information and Communication Technology, Vol. 521, Springer, Cham, 2018

[8] Son, N. N., Vinh, Luu The, “Parameter Estimation of Photovoltaic Model, Using Balancing Composite Motion Optimization”, Acta Polytech. Hungarica, Vol. 19, No. 11, pp. 27-46

[9] Sami, T., A. Gholami, and S. M. Shahrtash. "Effect of electro-thermal, load cycling and thermal transients stresses on high voltage XLPE and EPR power cable life.", pp. 190-190, 2009

[10] V. Nikolic and R. Polansky, "Assessing the reliability of electrical insulating materials using accelerated aging tests," 2020 International Conference on Diagnostics in Electrical Engineering (Diagnostika), 2020, pp. 1-4

[11] S. Bal and Z. Ádám Tamus, "Investigation of Effects of Short-term Thermal Stress on PVC Insulated Low Voltage Distribution Cables", Period. Polytech. Elec. Eng. Comp. Sci., Vol. 65, No. 3, pp. 167-173, Jan. 2021

[12] A. Paramane, X. Chen, C. Dai, H. Guan, L. Yu, and Y. Tanaka, "Electrical insulation performance of cross-linked polyethylene/MgO nanocomposite material for ±320 kV high-voltage direct-current cables," Polym Compos, Vol. 41, No. 5, pp. 1936-1949, May 2020

[13] J. C. Fothergill, S. J. Dodd, L. A. Dissado, T. Liu and U. H. Nilsson, "The measurement of very low conductivity and dielectric loss in XLPE cables: a

possible method to detect degradation due to thermal aging," in IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 18, No. 5, pp. 1544-1553, October 2011

[14] Y. Zhang, X. Chen, H. Zhang, J. Liu, C. Zhang, and J. Jiao, "Analysis on the Temperature Field and the Ampacity of XLPE Submarine HV Cable Based on Electro-Thermal-Flow Multiphysics Coupling Simulation," Polymers, Vol. 12, No. 4, p. 952, Apr. 2020

[15] W. S. Zaengl, "Dielectric spectroscopy in time and frequency domain for HV power equipment. I. Theoretical considerations," in IEEE Electrical Insulation Magazine, Vol. 19, No. 5, pp. 5-19, Sept.-Oct. 2003

[16] N. Sunthrasakaran et al., "Application of polarization and depolarization current in high voltage insulator-A review," International Journal of Integrated Engineering, Vol. 12, No. 2, pp. 159-169, 2020

[17] D. Mishra, N. Haque, A. Baral and S. Chakravorti, "Assessment of interfacial charge accumulation in oil-paper interface in transformer insulation from polarization-depolarization current measurements," in IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 24, No. 3, pp. 1665-1673, June 2017

[18] S. Morsalin and B. T. Phung, "Dielectric response study of service-aged XLPE cable based on polarisation and depolarisation current method," in *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 27, No. 1, pp. 58-66, Feb. 2020

[19] A. A. Suleiman, N. Bashir, N. A. Muhamad, N. A. M. Jamail and Q. E. Kamarudin, "Polarization & depolarization current (PDC) measurement in cellulose insulating materials," 2013 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, Chenzhen, China, 2013, pp. 1073-1076

[20] R. S. A. Afia, E. Mustafa, and Z. Á. Tamus, "Dielectric Spectroscopy of Low Voltage Nuclear Power Cables Under Simultaneous Thermal and Mechanical Stresses," Energy Reports, Vol. 6, pp. 662-667, Dec. 2020

[21] S. A. Bhumiwat, "Insulation condition assessment of transformer bushings by means of polarisation/depolarisation current analysis," Conference Record of the 2004 IEEE International Symposium on Electrical Insulation, 2004, pp. 500-503

[22] S. K. Ojha, P. Purkait, and S. Chakravorti, "Modeling of relaxation phenomena in transformer oil-paper insulation for understanding dielectric response measurements; Modeling of relaxation phenomena in transformer oil-paper insulation for understanding dielectric response measurements," IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 23, No. 5, Oct. 2016

[23] T. K. Saha and K. P. Mardira, "Modeling metal oxide surge arrester for the modern polarization based diagnostics," IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 12, No. 6, pp. 1249-1258, Dec. 2005

[24] R. S. A. Afia, E. Mustafa and Z. Á. Tamus, "Condition Assessment of XLPO Insulated Photovoltaic Cables Based on Polarisation/Depolarisation Current," 2020 International Conference on Diagnostics in Electrical Engineering (Diagnostika), 2020, pp. 1-4

[25] T. K. Saha and P. Purkait, "Investigation of polarization and depolarization current measurements for the assessment of oil-paper insulation of aged transformers," in *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 11, No. 1, pp. 144-154, Feb. 2004

[26] Küchler, A. and Bedel, T. (2001) Research note: Dielectric diagnosis of water content in transformer insulation systems. Euro. Trans. Electr. Power, 11: 65-68

[27] IEC 60502-1:2021 "Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)" (2021)

[28] G. M. Csányi, Z. Á. Tamus, and Á. Varga, "Impact of distributed generation on the thermal ageing of low voltage distribution cables," IFIP Advances in Information and Communication Technology, 2017, Vol. 499, pp. 251-258

[29] S. Bal, A. G. N. A. Jasim and Z. A. Tamus, "Analyzing the Effect of thermal Ageing on Low Voltage Distribution Cables in Relation to their Structure," *2023 INSUCON - 14th International Electrical Insulation Conference (INSUCON)*, Birmingham, United Kingdom, 2023, pp. 209-214

[30] M. Ekelund, H. Edin, and U. W. Gedde, "Long-term performance of poly(vinyl chloride) cables. Part 1: Mechanical and electrical performances," *Polym Degrad Stab*, Vol. 92, No. 4, pp. 617-629, Apr. 2007

[31] S. Bal and Z. Á. Tamus, "Investigation of the Structural Dependence of the Cyclical Thermal Aging of Low-Voltage PVC-Insulated Cables," Symmetry, Vol. 15, No. 6, p. 1186, Jun. 2023

[32] I. Fofana, H. Hemmatjou and F. Meghnefi, "Effect of thermal transient on the polarization and depolarization current measurements," in IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 18, No. 2, pp. 513-520, April 2011