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Fully Automated MV Cable Monitoring and Measurement System for Multi-Sample Acquisition of Artificial Aging Parameters

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Abstract. The Power quality of our networks is influenced by transients, short- and long-duration variations, voltage unbalance, waveform distortions, voltage fluctuations and power frequency variations. These impacts affect the aging rapidity of the electrical equipment and finally the entire electrical network. By partial discharge (PD) and tan(δ) analyses, it is possible to determine the electrical equipment's condition. The significance of the results depends on the quality of the measurement system and of the data interpretation. Based on these results, a reliable maintenance and investment strategy could be made, and the reliability of the network could be improved. A specially designed aging system for the accelerated aging of MV cables has been developed to point out the most relevant aging parameters and their limits, and, in this way, to upgrade the accuracy of the MV cable diagnostics. In this paper, the system's "intelligence", which controls the aging process and acquires, evaluates and stores all necessary data is presented.

Key words

CAMAC (Computer automated measurement and control), Partial discharges, Power cable insulation

1. Introduction

Partial discharges (PD) are local dielectric breakdowns of small portions of solid or liquid electrical insulation medium under high or medium voltages. In high and medium voltage networks, PD measurement and/or monitoring are used to observe the equipment's state of health (such as power cables, power transformers, switchgears, motors, generators, etc.). Partial discharges occur with the advancing age of the insulation material and once existent become the major source of isolation breakdown. The uncontrolled PD activity could finally lead to a catastrophic failure, which can cause external equipment damage, fires and loss of revenue due to an unscheduled outage. Cables and their equipment represent one of the major investments for power supply companies. In addition, cables and sleeves are a frequent source of damages and accordingly a source of network faults and supply discontinuities, [1], [2]. Since unexpected cable faults in MV cable networks accumulate, a lot of scientific research has been directed to determine the remaining cable life time (time to the first failure). In many cases PD and tan(δ) measurements and analyses are used for the prediction of failures, their localization and selective replacement of defective cable sections, [3]. Thus far, there are some aging systems developed for XLPE (cross-linked polyethylene) cables. In case of lead shielded cable types, these prediction systems do not deliver reliable prognostic data because the physical and chemical backgrounds are not comparable.

Therefore, in 2006 a new and worldwide unique accelerated aging project for MV cables has been started. The final goal of the project is to define the suitable parameters that describe the aging process of PILC (paper insulated lead covered) cables, [4]. Furthermore, the accuracy of the measurement system must assure the reliability of the formed database. Besides the resolution and precision of the acquisition system, the continuity of the aging and monitoring process is of highest importance. In this paper, the measurement, control, monitoring and data acquisition structure of the implemented accelerated aging system is described. According to the functional tasks, it can be structured in a general framework defined by the hardware control- and monitoring-system and a customized software design and implementation.

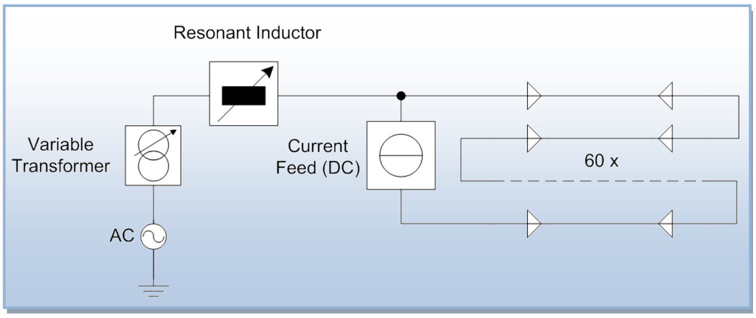

Fig. 1 General Structure

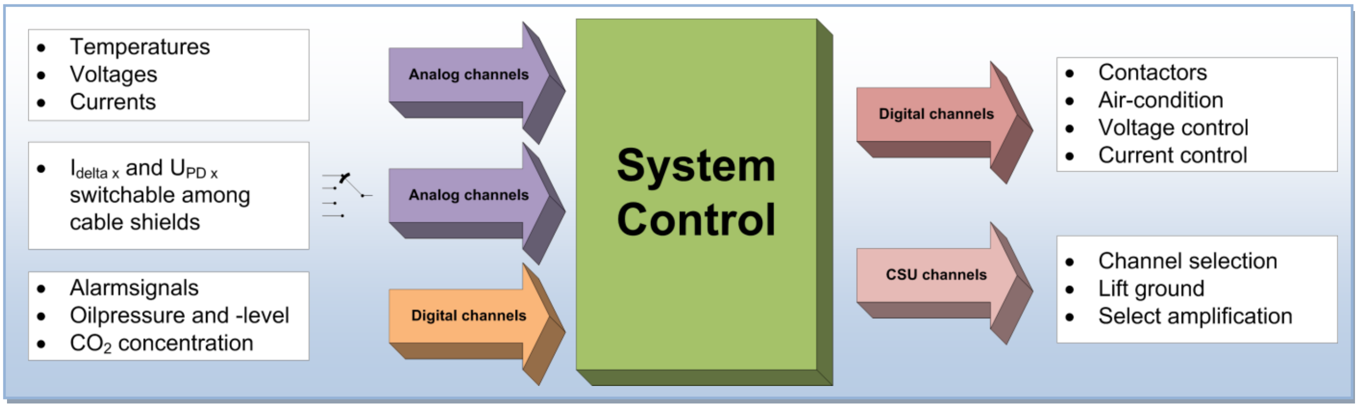

Fig. 2 Input/Output Flowchart

2. System Structure

A. Physical Structure

The accelerated aging of the cable samples is accomplished by dielectric and thermal stress. Dielectric stress means up to four times nominal voltage, generated by a resonant system which works at mains frequency (50 Hz). Therefore, a variable inductance was developed and constructed in-house, with an inductivity of about 500H. The inductance value can be regulated by a variable air gap. Thermal stress is applied by a specially manufactured current transformer and rectifier, which feeds in about two times equivalent nominal current on high voltage level. The cables themselves are situated in an air-conditioned container. Besides the circulation ventilators, there are several cooling ventilators and an additional heating facility installed, [4], [7], [8].

B. Measurement and Control

The measurement and control system consists of a great number of integrated hardware units. Most of these single units are specially developed and constructed to build up an automatic and, in addition, remote-controllable accelerated aging system. The core is represented by a personal computer, equipped with two high-speed data acquisition PCI-boards. Therefore, the "System Control" realizes the control, acquisition and measurement of nearly 100 analog and digital in- and outputs. All relevant parameters, like e.g. voltages, currents, temperatures, characteristic aging values and security information are acquired, evaluated and stored by this central control system. The main tasks of the system control can be divided according to the different operational phases of the aging system, which are the realization of the continuous (normal) aging operation and the cable diagnostic measurement cycles (several times a day). Simultaneously, it has to be assured that the system is still able to react to security relevant signals besides the normal aging operation. These are triggered i.e. by trespassing the restricted area, cable faults or system hardware faults.

To get a quick overview of the physical condition of all technical equipment, an audio-visual observation system has been developed and installed. It consists of several video cameras and microphones connected to a dedicated computer, and an in-house engineered software package.

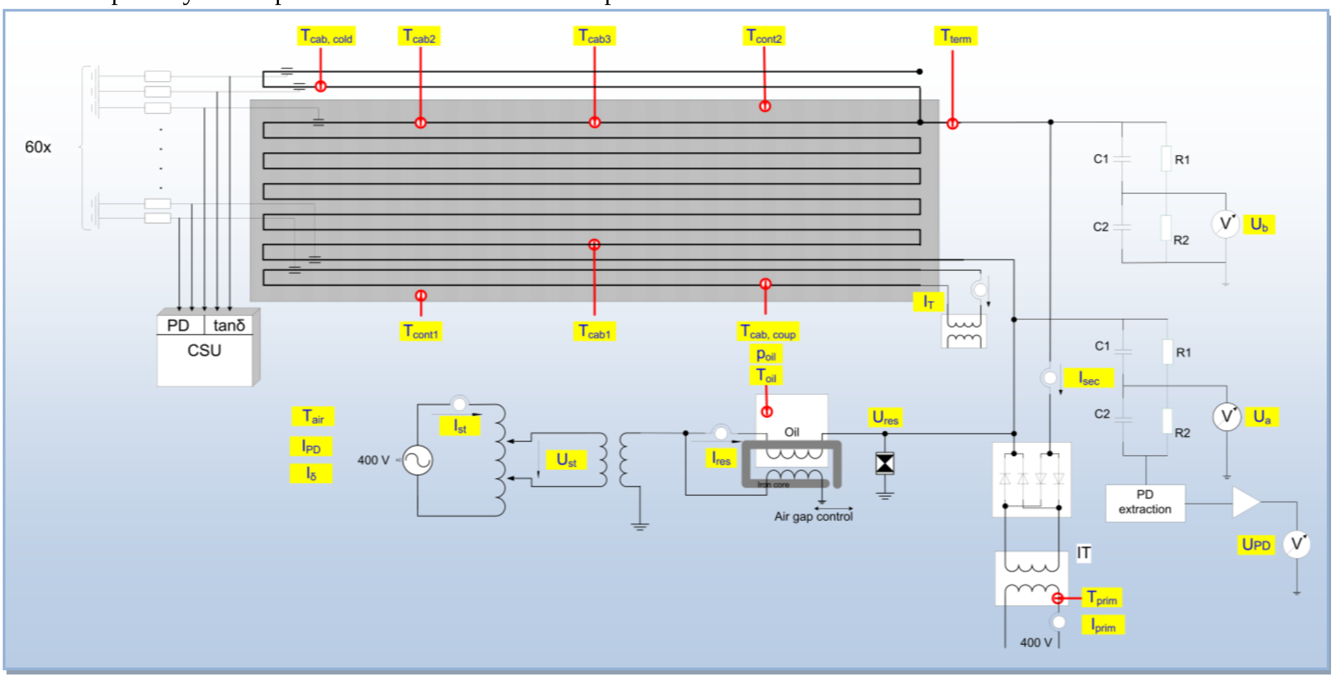

Fig. 3 System Overview, Analog Input Values

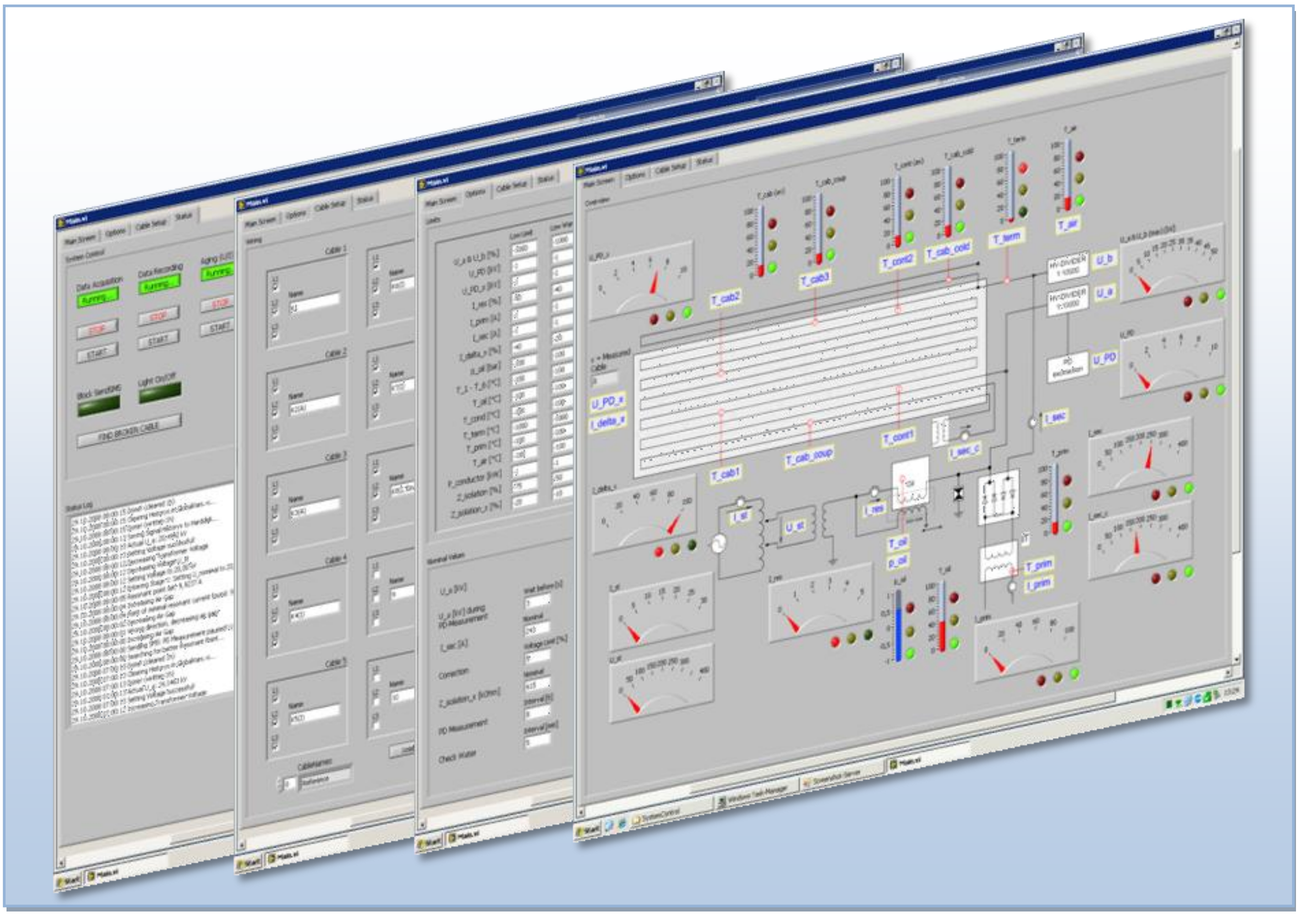

Fig. 4 Screenshots of the measurement and control software

As the system is designed to run twenty-four-seven for several years, the continuity and security of the aging process was focused especially. The security is assured by a combined, double layer hard- and software system. As the uncontrolled opening of contactors may result in hardware damage, the primary layer is completely software controlled. The pushing of one emergency-stop button or the access to the restricted area during operation will result in a safe shutdown triggered by software. If the first layer fails and for additional security, the second layer will trip the main power supply immediately, for example if the grounding lance is taken.
To gain reliable and comparable diagnostic data, all relevant aging parameters, namely the aging voltage, the aging currents and the cable temperatures are closed-loop controlled. If, anyway, values reach predefined limits, warning messages are generated and/or the system is shut down automatically.
The entire system is constructed to be operated remotely worldwide via internet by all authorized personnel. Furthermore, the control system is designed to generate and to send SMS-messages like regular status messages, warnings and error messages. If necessary, personnel can react fast and efficiently, [5].

3. Software Design and Implementation

The major parts of the software implementation are realized in National Instrument's "LabVIEW", which is especially designed for data acquisition and control tasks.

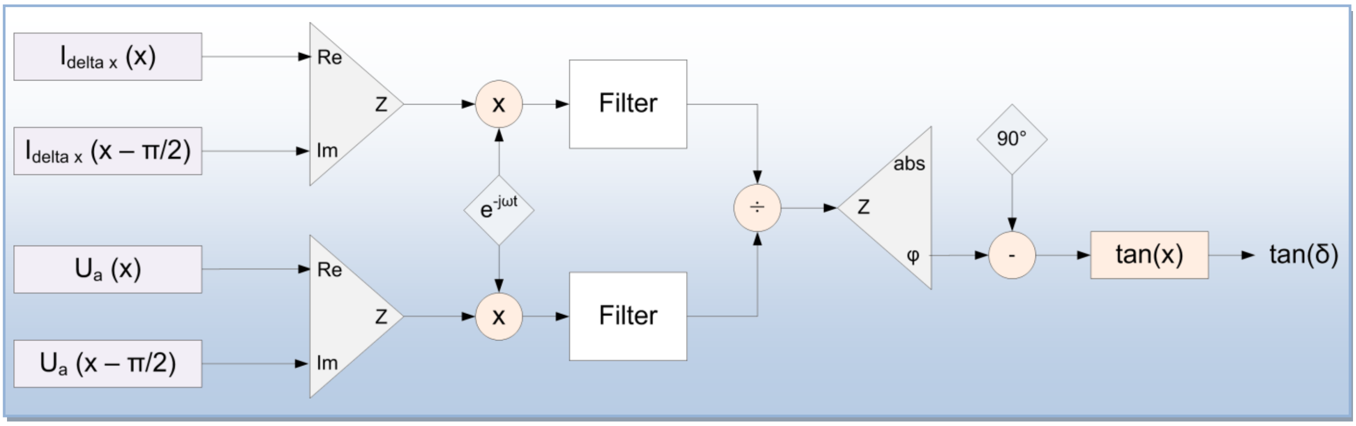

Fig. 5 Flowchart of the tan(δ)-measurement algorithm

Only the security-relevant program parts, like the reaction to the emergency signals are backed up by a particularly designed software running as a system service. As the complete aging system is software controlled, an additional hardware watchdog system was integrated to recognize eventual software hang-ups and to achieve a safe operation mode again. Therefore, a software generated “heartbeat signal” is transmitted to the hardware watchdog, which recognizes a system hang-up in between a definable time interval. As the consequence, the main contactors are opened and the control system is rebooted to accomplish a normal and remotely controllable status again.
The LabVIEW program carries out all data acquisition and control tasks in several modules called VIs (Virtual Instruments) to simplify the expandability and the debugging. All recorded data is merged in memory with a unique time-stamp and saved to hard disk after a certain time-interval. All system’s actions are logged into a file for documentation and later analyses. Once a day the data- and log-files are uploaded via FTP to a server and database computer for backup and evaluation purposes. To obtain a sophisticated mathematical model for the aging process, data acquisition, data logging and data integrity are the major topics of the designed soft- and hardware control-system. The different tasks of the control-software are managed in a set of setup and monitoring screens. The waveform and the time response of the RMS-values of all measured variables are plotted on signal graphs and may be zoomed or navigated in, [5].

4. Cable Diagnostics

To reduce hard- and software effort for the sequential tan(δ)- and PD-analyses of the cable samples, a 64-channel analog/digital switching matrix, called CSU (“Cable Selection Unit”) was developed and realized. It enables the diagnostic kernel to be focused on a single cable and to measure all relevant parameters with the highest achievable accuracy.

A. PD-Measurement

For the determination of the PD activity, an especially designed coupling quadrupole has been developed and constructed. It delivers the by amplification adaptable PD voltage which is adjacently transferred to a high precision industrial measurement system with peak detection, hence the PD intensity is proportional to the maximum of the standardized PD voltage. The measurement system is controlled by the main control system via USB port, so the PD peak voltage for each cable sample is acquired, transferred and stored in a data table individually.

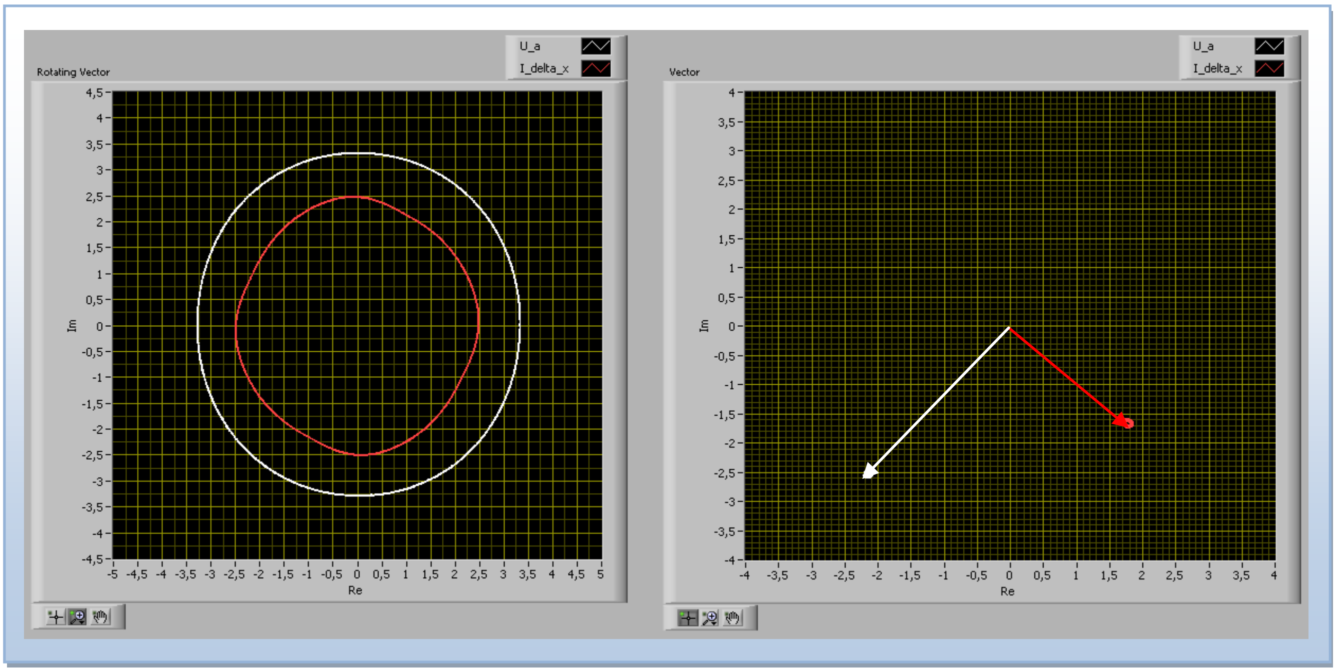

Fig. 6 Screenshots of the tan(δ)- measurement algorithm

B. tan(δ)-Measurement

Besides the PD analyses, the tan(δ)-measurement is the second important criterion for the development of an accurate remaining lifetime diagnostics. Unlike to XLPE-cable analyses, where the PD-level is already a significant indicator for the cable status, PILC-cables need an additional criterion. Because of their physical characteristics, the PD-ratio on its own may not give a reliable impression of the actual aging status. Therefore, the determination of the tan(δ) has to be achieved by a sophisticated mathematical algorithm.
To determine the tan(δ), the aging voltage U_a and the current over the cable shields $I_{delta\ x}$, which should be ideally capacitive, are acquired with maximum sample rate (250.000 Samples/s) during an interval of at least ten 50 Hz periods. The values are subsequently used to build up complex rotating vectors as shown in figure X (left side). The real part is made up by the signal itself, the imaginary part, by contrast, is built by the by π/2 shifted signal. These rotating vectors are similar to space phasors, calculated for a single phase. They are then

transformed into static vectors (Fig. 5 right side) and further transferred to suitable designed FIR-filter, which deliver a stable output signal for the following determination of the tan(δ). The angle between the static vectors can be easily determined by a division of the complex numbers. The tangent of the angle reduced by 90° delivers the desired value. The accuracy of this design is higher than 10^{-5}. The results of this algorithm can be seen in Fig. 6. In the left diagram, the calculated rotating vectors are displayed. In the right diagram, the rotating vectors are converted to static vectors and the angle between the vectors could be easily read off.

5. Conclusion

The status and the condition of the MV networks and especially cable systems can be analyzed by the measurement of characteristic aging parameters like e.g. PD-intensity and tan(δ) values. To determine the typical levels of these parameters, an artificial and accelerated aging system for MV cables has been developed and realized. In this way, all relevant aging parameters could be monitored, interpreted and the cable status could be estimated. In this paper, the principal structure and functionality of the unique software control system, which acquires, evaluates and stores all necessary data during the long-term accelerated aging test is presented. It consists of a measurement system, a control system and an integrated and combined soft- and hardware security system. To assure material and personal security, additional measures have been taken. The functionality of the whole system was proved in a pretest, which has been running since august 2008 for about six months without interruption, [6], [7], [8].

Based on a continuous and sample-wise monitoring of the PD and the tan(δ) values and their development during the aging process, an "aging" database will be built up. This database will be the fundament for the determination of the relevant electrical, physical and chemical parameters and for the further developments of cable diagnostic methods and mathematical aging models. On behalf of the created database, criteria for the development of a diagnostic system for field studies should be derived. One of the key values will be the aging factor - AF. It defines the aging rapidity, which is the rate between time to the failure under the test conditions and the characteristic cable life time for the same cable in real operation. Therefore, a condition-oriented maintenance strategy and asset management is made possible and the investment planning can be improved. Moreover, this is one way to increase the power quality and reliability in today's MV distribution networks.

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