FIELD OF INVENTION

The present invention relates generally to a system for monitoring the condition of electrical equipment, such as transformers and bushings where the internal insulation of the electrical equipment is composed of oil-paper composite. In particular, the invention relates to an integrated portable system for detecting condition of oil-paper composite insulation in electrical equipment. The invention further relates to a process for detecting the condition of oil-paper composite insulation in electrical equipment.

BACKGROUND OF INVENTION

Transformers and bushings form an integral part of any electrical power distribution and transmission system that also include other type of transformers like rectifier transformers, locomotive transformers.

One of the important components of the insulation of oil filled transformers comprises paper which is wound around the copper windings. There are spacers, washers, seals, separators, composed of paper or compressed board having characteristics that of paper. In order to enhance the insulation integrity and thermal stability, paper is impregnated with transformer oil, for example, silicone oil or a derivative of mineral oil, which essentially fills the transformer. This insulating oil also serves as a coolant by dissipating heat through convection flow. There are some other types of transformers like high frequency transformers, gas filled transformers and low voltage air cooled transformers that do not fall under the category of the transformers under the purview of this invention.

The operating lifetime of a transformer can easily extend upto 35-40 years depending on its location and usage. Location typically includes the environment it faces during majority of its service. This lifetime also depends on the quality of the aforesaid materials used during manufacture. In the course of usage, due to heat and moisture absorbed into the oil as well as paper, the quality of transformer insulation gets deteriorated. The rate of degradation is substantially influenced by the workload and the internal operating environment of the transformer, such as temperature, moisture content, pH of oil and similes. Gradual deterioration of the insulation condition, if not monitored, can lead to severe internal discharges, short circuit between conductors of winding, between discs, irreversible faults and catastrophic failure. Such failure can result in reduction or loss of supply to the power system, considerable expense for the replacement or repair of the transformer and further entails a serious risk to nearby personnel and the environment.

Apart from aging, problems in insulation condition can also occur in a transformer due to defective manufacturing, water trapping in the installed area. Such typical situations further accelerate the deterioration of a transformer compared to the normal degradation by ageing only. It is imperative that such typical cases be awarded a high priority for regular assessment of the condition of the insulation as a preventive measure.

In electrical power transmission and distribution, transformers are essential. Majority of these transformers contain oil-paper combination as their insulation. With aging, the quality of insulation deteriorates. Since these devices are concealed, actual condition of the insulation cannot be determined from outside. Sometimes sudden failure occurs in transformers resulting in huge loss of money and time.

At present, non-invasive and non-destructive diagnostic techniques that predict the insulation condition are gaining popularity. Polarization and Depolarization Current (PDC) and Recovery Voltage (RV) measurements are two such state of the art techniques.

Dielectric polarization occurs in a dielectric material when it is placed in an external electric field and results in a Polarization Current that is dependent on the characteristics of the dielectric material. Upon withdrawal of this external field a depolarization or relaxation process starts which gives rise to another current in the reverse direction called Depolarization Current. Both Polarization and Depolarization Currents (PDC) are dependent on the nature and ageing of the dielectric material.

When a step DC charging voltage (U_0) is applied to a test object, the Polarization Current $i_{pol}(t)$ flows through it and the nature of time variation of this current is shown in Fig. 1.

Polarization Current measurement is stopped when the current becomes stable. Thereafter, if the test object is short-circuited, the Depolarization Current $i_{depol}(t)$ starts flowing and the nature of time variation of this current is also shown in Fig. 1.

A further investigation on the above phenomena, i.e. the "after effects" of the PDC measurement, involves what is called Recovery Voltage Measurement (RVM). The sample under RV measurement is charged for a definite period of time (t_{ch}) with a step voltage and then earthed for discharging through a period, half that of charging ($½t_{ch}$). Thereafter the voltage across the unearthed sample is recorded as the RV. This voltage arises due to active relaxation processes inside the dielectric material, which did not relax fully during the insufficient discharging period. So, this RV is also a characteristic of the insulating property of the dielectric material. The curve in Fig. 2 shows the nature of a typical Recovery Voltage waveform.

According to the RVM methodology the charging time is increased gradually with the corresponding increase in discharging time from a small initial value and the peak value of Recovery Voltage, $V_{recovery}$(peak) is recorded each time. Peak values obtained for different charging times (t_{ch}) can be plotted to yield a $V_{recovery}$(peak) vs. t_{ch} curve, which is called Recovery Voltage Spectrum. This Recovery Voltage Spectrum is analyzed for condition monitoring. Both PDC and RV waveforms are capable of predicting the condition of insulation.

Two important aspects of these measurements are (i) the currents that are to be measured would be in the order of nanoamperes and (ii) the voltages are to be measured with very high input impedance. This needs the use of a special measuring instrument at the front end.

Power authorities typically test transformers by sampling the mineral oil within the transformer about once a year to determine the dissolved gas concentration in oil by analysis (DGA), water in oil in ppm by Karl-Fischer titration analysis and dielectric loss analysis (tanδ). If unusual readings are obtained in the above tests, frequencies of these tests are increased for its condition monitoring. But, these tests cannot predict the actual condition of the paper, the moisture trapped in the paper and the degree of degradation. The accuracy of life expectancy data from these general tests is poor. Hence unexpected failure can occur in spite of this general condition monitoring. Hence, an advanced method of condition monitoring is highly desirable in these cases where the predictions can be as close as possible to the actual condition.

Recovery Voltage method of condition monitoring in a transformer is known in the art and the necessary instruments are marketed by the Tettex instruments. But the inventors have found that for better condition assessment, both PDC and RV measurements are required. However, a significant amount of human intervention and expertise are required to complete two separate testing procedures and for evolving decisions on the basis of the test results. It would be thus needed, in particular for power utilities if a system integrating both PDC and RV measurements is provided which would require minimum human intervention to perform the testing and analysis.

Accordingly, the technique of condition assessment of the insulation of different power equipment with noninvasive and nondestructive techniques, has become one of the important aspects of power system reliability.

Oil-paper insulation is used extensively in equipments of power generation and distribution i.e. in transformers and bushings. Condition assessment of this oil-paper insulation can be successfully performed by modern techniques such as Polarization and Depolarization Current (PDC) and Recovery Voltage (RV) measurements.

Considering the power equipments, PDC and RV measurement would be fruitful if the measuring instrument is a single, portable unit for easy on-site testing that requires minimal expertise for electrical connections and performing the test. Moreover, the ideal condition for the testing equipment would be to analyze and give the test report automatically on-site.

The theory and procedure of performing PDC and RV-measurement separately including the analysis of the obtained data to predict the insulation condition of different power apparatus are available in literatures such as "Investigation of an Expert System for the Condition Assessment of Transformer Insulation Based on Dielectric Response Measurements" by T K. Saha and P. Purkait in IEEE Trans. On Power Delivery, vol. 19, no. 3, pp. 1127-1134, 2004, in which the authors reported the concept of an expert system that can analyze the waveforms obtained from PDC and RV measurements and give an assessment of insulation condition. The inventors published a paper titled "A Hybrid Filtering Scheme for Proper Denoising of Real-Time Data in Dielectric Spectroscopy" by D. Dey, B. Chatterjee, S. Chakravorti and S.Munshi in IEEE Trans. on Dielectrics and Electrical Insulation, vol. 14, No. 5, 1323-1331, Oct 2007, in which they have implemented an on-line filtering technique for denoising the data from PDC and RV measurement.

But in these literatures, the experimental setup consists of some discrete units like measuring electrometer, communication module, electrical contactor, etc., that is controlled by a computer. This requires a complex electrical wiring needing a spacious setup. One of the significant aspects is that, PDC and RV measurement requires entirely two different electrical wiring arrangements and connections. To perform both the tests, a skilled technician is required and a significant amount of time is wasted in changing the connections. Moreover, the analysis is to be performed separately in-house in a computer after the test is completed. Thus, the systems are not portable and suitable for easy on-site testing.

There are instruments commercially available like PDC-ANALYSER-1MOD from Alff Engineering which performs the PDC measurement and RVM 5462 from Tettex instruments, ETP-2 from EuroSMC, which performs the RV measurement. Neither of these instruments performs both the measurements. Instruments like ETP-2 have a pre-programmed total testing time of 40 mins. Moreover, these instruments require a separate computer through which they communicate through RS-232. Separate software is provided with the instruments to load into the computers through which they communicate for the analysis of the data. Thus the overall system is not a self-contained unit.

OBJECTS OF THE INVENTION

It is therefore an object of the invention to propose an integrated portable system for detecting the condition of oil–paper composite insulation in electrical equipment such as transformers and bushings, which eliminates the disadvantages of the prior art.

Another object of the invention is to propose an integrated portable system for detecting the condition of oil–paper composite insulation in electrical equipment, which integrates both the Polarization and Depolarization Currents (PDC), and the Recovery Voltage (RV) to provide improved detection results.

A still another object of the invention is to propose an integrated portable system for detecting the condition of oil–paper composite insulation in electrical equipment, which adapts a hybrid filtering scheme for online denoising of different signals of time-domain dielectric response measurements.

A further object of the invention is to propose a process for data acquisition for detecting the condition of oil-paper insulation in electrical equipment.

A still further object of the invention is to propose an integrated portable system and process for detecting the condition of oil-paper composite insulation in electrical equipment, which incorporates an expert system for analyzing the acquired data for assessment of the life expectancy of the insulation.

SUMMARY OF THE INVENTION

The present invention in a first aspect provides a system for detecting the insulation condition of oil-paper composite. The terminology condition specifically will be used as a combination of (a) the moisture content of oil equivalent to PPM of water in oil, (b) the moisture content of the paper equivalent to percent of water in paper in weight/weight, (c) Overall insulation resistance, (d) Overall degradation of the condition of the insulation, specially with respect to the aging and (e) life expectancy of the insulation considering the installed location and usage. The inventive system is a single, portable, integrated system is capable of measuring the oil-paper insulation condition by both PDC and RVM method. The system comprising:

- at least one precision measuring instrument capable of (a) measuring current as low as 1 pA, (b) measuring voltage with input impedance greater than 500 MΩ, (c) converting analog measured data to digital format and (d) communicating the digital data through two transmit-receive (T_x-R_x) lines;

- at least one main processor with clock speed of at least 2.8 GHz with 533 MHz FSB and 256 kB L2 Cache for digital signal processing and computation;

- at least one display board capable of visual display of the output from the instrument;

- at least one two-way contactor capable of connecting a single terminal of a test object to two different potentials;

- a multiple voltage output SMPS capable of delivering :

    - 230V to 1kV, 5W regulated DC power supply having output regulation of 0.1% to provide the DC charging voltage to the test object, and

    - 230V to 12V, 10A and 5V, 20A regulated DC power supply for powering the controller board;

- a main board that is capable of communicating with all the constituent components of the system using different communication protocols;

- a software support structure capable of implementing an online hybrid filtering denoising technique in order to filter the random and/or impulse noises from the acquired data; and

- means for analyzing the data.

In a second aspect, the present invention provides a process for detecting the insulation condition of an oil-paper composite. The process comprises the following steps:

- detecting the nature of current waveforms generated due to the phenomenon of Polarization Current in the insulation within a device or an equipment;

- detecting the nature of current waveforms generated due to the phenomenon of Depolarization Current in the insulation within a device or an equipment;

- detecting the nature of waveforms generated due to the phenomenon of Recovery Voltage in the insulation within a device or an equipment; and

- analyzing the detected quantities and the nature of the curves obtained to determine the condition of the insulation and to predict the life expectancy.

The term analyzing as stated hereinabove includes execution of various processes and tasks comprising configuration of the hardware by the central processor under appropriate software instructions.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRWAINGS

Fig. 1 – graphically represents the time variation of Polarization and Depolarization Current on application of a step DC charging voltage on a test object.

Fig. 2 - graphically shows a typical Recovery Voltage (RV) waveform which constitutes characteristics of the insulating property of the dielectric material.

Fig. 3 – a block diagram of the system of the invention.

Fig. 4 – shows a top view of a prototype of the system of the invention.

Fig. 5 – shows a pictorial view of the system disposed in a casing.

Fig. 6 – shows a real-life recording of the Polarization and Depolarization Current (PDC) containing noise in the signals.

Fig. 7 – shows a real life recording of the Recovery Voltage (RV) waveforms containing noise in the signals.

Fig. 8 – shows a typical structure of an adaptive weighted median (WM) filter.

Fig. 9 – shows an adaptive weighted median to arrive at optimum set of the filter weights.

Fig. 10 – shows a configuration of WM filter and a low pass digital IIR filter disposed in parallel to implement hybrid-filtering technique.

Fig. 11 – shows a switching means configured though a cascade combination of the WM filter and the IIR filter.

Fig. 12 – shows a control flow-chart and the corresponding sequential hardware operation during the Polarization and Depolarization Current measurement.

Fig. 13 – shows a control flow-chart and the corresponding sequential hardware operation during the Recovery Voltage Measurement (RVM).

Fig. 14 – shows a data acquisition window for measurement of Polarization and Depolarization Current (PDC).

Fig. 15 – shows a data acquisition window for Recovery Voltage Measurement (RVM).

Fig. 16 – shows the main window of the user interface.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 3 illustrates in a block diagram a system according to the invention. The system comprises:

- a computer controlled programmable electrometer (1) for measuring the current and voltages obtained from PDC and RV measurements;

- a two-way contactor (2) which is capable of connecting the high voltage power supply to the terminal of a test object (3) during charging and capable of earthing the high voltage power supply terminal during discharging;

- the 230V coil of the contactor (2) is interfaced with a 5V digital line through an optically isolated triac;

- a switching mode power supply (4) providing the following output:

  (a) 230V to 1kV, 5W regulated DC power supply having output regulation of 0.1% to provide the DC charging voltage to the test object and
  (b) 230V to 12V, 10A and 5V, 20A regulated DC power supply for powering the main controller board;

- a main controller board (5) consisting of a 2.8 GHz Processor with 533 MHz FSB and 256 kB L2 Cache, for performing the control and computation, a two-wire transmit-receive (T_x-R_x) line communicating with a RS-232 socket of the electrometer (1) and the main controller board for data transfer; and a control line provided from the parallel port of the main board (5) for switching the contactor (2) through the optically isolated triac;

The design of the apparatus is to draw power from a single AC wall outlet (8) to avoid any complication due to multiple supply requirements in the instrument.

The system (Fig. 3) has only one external input line as power supply, three test lines as HV, LV (6, 7) and ground wires for connection with the test object (3).

Fig. 4 illustrates one possible way as to how the components could be packed into one unit. Since noises are the greatest impediment to data acquisition, the disposition of the parts is important. The external box (body) (9) is made up of GI sheet of 0.3 mm thickness for a shielded housing. The contactor (2) handling 1 kV is encapsulated in separate GI sheet box inside the main unit.

The actual photograph of the prototype specimen in a carrying case is shown in Fig. 5.

For testing purpose, all the high voltage terminals of the device under test (3) are shorted to bring one terminal and all the low voltage terminals are shorted to bring another terminal. The HV and LV lines (6, 7) coming out of the system (as shown in Fig. 3) are connected with these two terminals, respectively, of the test object (3). The body of the tank and body of the testing device (9) are grounded before the power supply is switched on.

One of the significant aspects of the condition monitoring is that the signals to be acquired are of low magnitude and hence are more prone to be affected by external noises; especially in the case of acquiring data for condition monitoring of outdoor transformers. So during on-field measurement of these condition-monitoring signals, significant amount of noise may pollute the actual waveforms. Therefore to extract important information from the recorded data, a suitable denoising scheme should be adopted. Considerable amount of noise in the signals is evident from the real life recordings of PDC and RV waveforms, shown in Fig. 6 and Fig. 7, respectively.

As mentioned previously, due to outdoor-environmental condition and several hours of experimentation, different types of noises can contaminate the actual signal, such as, random noise with some unknown distribution, periodic or aperiodic noises having stationary or non-stationary properties etc. In Fig. 6 the PDC signal is buried in random high frequency noise and also contaminated with impulses (spikes). Whereas in Fig. 7 the RV waveform is mixed with random noise but the time variation of the noise is quite different in nature from that present in PDC waveform in Fig. 6. These noisy signals may lead to wrong conclusions and also make it difficult to distinguish between different insulation conditions.

In Polarization and Depolarization Current measurement the slope of different curves (i.e. recorded PDC waveforms) may be utilized as a discriminating factor for diverse insulation conditions. However the noise present in the recorded signal may adversely affect the precision with which this parameter (i.e. slope of the curve) can be detected. It is also evident from the above argument that any filtering technique that changes the slope of the curves of Polarization and Depolarization Current must not be used for denoising. The typical PDC waveform, shown in Fig. 6, also establishes the fact that there occurs sudden change in the waveform while toggling from polarization process to depolarization. This sudden change is not a noise but is inherent in the measurement procedure. Hence this sort of jump-discontinuity in the waveform must be preserved while impulse noises need to be removed. No linear filtering technique is capable of performing this task; so non-linear filtering is an obvious choice.

Similarly for RV measurement technique, proper noise-free recordings of Recovery Voltage waveform and Recovery Voltage Spectrum are necessary. So the determination of peak values of Recovery Voltage from periodic charging and discharging of the sample with gradually increased charging and discharging times is of great importance. Here a spike or any kind of spurious noise can lead to a wrong interpretation such as incorrect evaluation of the peak magnitude and the time of occurrence of the peak. If some denoising filter removes the noise, the shape of the waveform should not be changed, because any change in the wave shape will bring about a change in the slope of the curve. It has been described hereinabove, that the initial slope of Recovery Voltage waveform bears important information about the condition of the insulation. Corrupting this data for the sake of denoising is highly discouraged. Therefore RV signals also demand a judiciously chosen filtering scheme.

In the invention a simple, fast and versatile hybrid-filtering scheme is incorporated that is very effective for on-line denoising of different signals of time-domain dielectric response measurements.

The hybrid-filtering scheme incorporates weighted median filter, which belongs to the class of non-linear filters, along with a low pass digital infinite impulse response (IIR) filter.

The weighted median (WM) filter is a generalized form of the conventional median filter, and it has several applications in image and signal processing. A brief explanation of the WM filters is given below.

Let $X = [X_1, X_2, ..., X_N]$ is the discrete time continuous valued input vector and Y is the output of the WM filter. The integer weights of the WM filter having window length N are given by the weight vector $W = [W_1, W_2, ..., W_N]$. The association of X, W and Y gives the filtering action as follows,

$Y = MED[W_1 \Diamond X_1, W_2 \Diamond X_2, ..., W_N \Diamond X_N]$

Here MED [·] indicates median operator and ◊ indicates replication operation, i.e,

$$J \Diamond X = \underbrace{X, X, ..., X}_{J\ times}$$

Fig. 8 shows a typical structure of a WM filter. For real positive weights this technique can be extended to find out θ, the weighted median value of X, by minimizing the expression,

$$L(\theta) = \sum_{i=1}^{N} W_i |X_i - \theta|$$

θ will definitely be one of the samples of X_i, as $L(\theta)$ is piecewise linear and convex for $W_i \geq 0$, for all i. So the output of weighted median filter for real positive weights is calculated as follows:

Step1. Rearranging the sample values within the filter window in ascending order.

Step2. Summing up the respective weights of the samples from the highest end of the sorted sample window,

Step3. Stopping at that sample when the sum just becomes greater than half of the total sum of the weights (i.e, $\geq \frac{1}{2}\sum_{i=1}^{N} W_i$).

Step4. the sample defining the respective output of the WM filter.

In a more general way, for real valued weights, the filter output is given in eqn. (3), Y= $MED\ [|W_i| \Diamond \operatorname{sgn}(W_i) X_i|_{i=1}^{N}]$ (3)

where, sgn(x) =1 for x > 0, sgn(x) =0 for x=0, and sgn(x) = -1 for x < 0.

For practical purposes, an optimum set of the filter weights has to be selected. To find out the optimum set of weights, an adaptive algorithm based approach is considered as shown in Fig. 9. The adaptive method assumes that observed signal s(n) is statistically correlated with the desired output signal $y_d(n)$, and reference samples of x(n) and $y_d(n)$ for training of the filter weights are available. Then the weights are optimized under the mean absolute error (MAE) criteria,

$H(W) = E\ |\ y_d(n) - \hat{y}_d(n)\ |$ (4)

where, $\hat{y}_d(n)$ is the filter output.

The updation rule of the weights according to least mean absolute (LMA) algorithm is given in (5).

$$W_i(n+1) = W_i(n) + \mu\ (y_d(n) - \hat{y}_d(n))\ \operatorname{sgn}(W_i(n)) \operatorname{sgn}(\operatorname{sgn}(W_i(n)) s_i(n) - \hat{y}_d(n)) \qquad (5)$$

Here, i =1, 2,..., N and n is the iteration number. μ is called the step-size parameter and its magnitude usually ranges within (0, 1).

In the invention a WM filter (10) is introduced to work in association with a low pass digital IIR filter (11). As stated hereinabove, the basic idea is that WM filters perform splendidly in removing impulse noises while preserving any step change in the signal, whereas lowpass digital IIR filter (11) can eliminate the effect of high frequency noises present in the signal. If the system demands that any sharp change (edge) in the signal is to be preserved as well as any impulse noise should be removed, then the WM filter (10) is the best possible choice. Yet, its performance is poor when random high frequency noise is present in the slowly varying part of the signal. In these portions of the input signal, standard lowpass filtering is done. However, being a linear system, the IIR filter (11) distorts the output if any step change or impulse signal occurs in the actual input sequence. Thus a single filtering technique cannot meet all the requirements of this measurement system. That is why hybrid-filtering technique is adopted in the present invention. It is evident that the primary aim of the scheme is simplicity without compromising the efficiency.

The hybrid filter works in conjunction with a switching scheme. This scheme dictates switching of the filtering technique between the WM filter (10) and the lowpass digital IIR filter (11) depending upon the nature of the input signal at that instant.

According to the invention, two topologies of the system are investigated. One, as shown in Fig. 10, uses WM filter (10) and IIR filter (11) in parallel, and the other, as shown in Fig. 11, is a cascade combination of the two (10, 11). The switch (12) is controlled by the switching scheme (15). Switching a particular filter [either WM filter (10) or IIR filter (11)] implies that depending upon the input signal (13) condition the output of the corresponding filter is selected as final output (14). If a sudden step change or an impulse signal occurs in the input then the switching scheme (15) selects the WM filter (10) to obtain the filtered output at that instant and for slow variation of input signal (13) contaminated only with random high frequency noise lowpass digital IIR filter (11) is selected through the switching scheme (15) to give the output (14).

The switching scheme (15) of the system is shown below (for both topologies):

Step1. Number of recent Data samples taken into account is equal to the window length of the WM filter (10).

Step2. Check whether any impulse signal or any step change occurs within this data sequence.

Step3. If YES then output is tapped from WM filter (10)
(i.e. switch to WM filter).

If NO then output is tapped from IIR Filter (11)
(i.e. switch to IIR filter).

It is further stated that that the computational complexity of the filtering technique is minimal, so it requires very little CPU time for the processor incorporated in the system of the invention, which makes the scheme suitable for real time applications.

The algorithm for PDC and RV measurement are designed in such a way that no external connection needs to be changed during the complete testing comprising two separate test procedures of PDC and RVM. The flowchart and the corresponding sequence of hardware operation of the Polarization Current measurement is given in flowchart of Fig. 12 (which also applies during Depolarization Current measurement) and the flowchart along with the sequence of hardware operation of RVM is given in Fig. 13.

Communication of the electrometer (1) is through RS-232 protocol and changing of the position of the two-way contactor (2) is through the parallel port, but is not necessarily limited to it. The real-time, adaptive, online denoising scheme is integrated in the data acquisition as a separate linking module.

User interface is an important part of the system developed. It determines the user friendliness of the instrument with respect to the operator. Interfaces from the working instrument are described as hereunder:

The system is automated for the entire test duration with timings internally set for each process. However, the user has the privilege to modify any of the timings, if required.

In both PDC and RV measurement, instructions to the user are provided at the bottom of the user interface as a guide (20, 34).

The data acquisition window for PDC is given in Fig. 14 showing all the necessary components of display, for example:

- Polarization Current chart (16) which shows the Polarization Current in Amperes vs. the plotted data points.

- Depolarization Current chart (17) which shows the Depolarization Current in Amperes vs. the plotted data points.

- Display of the elapsed charging time (18) in hh:mm:ss format.

- Display of the elapsed discharging time (19) in hh:mm:ss format.

- Instructions to the user (20).

RV measurement window is displayed showing multiple acquired loops as in Fig. 15. Blocks to the left are created exactly according to the RVM algorithm as in Fig. 13. Indicators in each blocks helps to understand the ongoing operation. The following are displayed:

- Indicator of initial shorting (21) of the terminals of device under test.
- Display of applied shorting time in seconds (22).
- Display of elapsed shorting time in seconds (23).
- Indicator of charging time (24) by the application of rated voltage across the terminals of the device under test.
- Display of applied charging time in seconds (25).
- Display of elapsed charging time in seconds (26).
- Indicator of discharging time (27) by shorting the terminals of the device under test.

- Display of applied discharging time in seconds (28).
- Display of elapsed discharging time in seconds (29).
- Indicator of measurement of the process of Recovery Voltage (30) from the terminals of the device under test.
- Display of applied RVM time in seconds (31).
- Display of elapsed RVM time in seconds (32).
- RVM chart (33) which show the Recovery Voltage vs. the plotted data points.
- Instructions to the user (34) to perform the operations accordingly.

An expert algorithm is integrated into the system to analyze the obtained data and to make a decision about the insulation condition based on the analysis. While designing an expert system for insulation condition monitoring, many researchers have already reported their findings on the dependencies of PDC and RV waveforms on various insulation conditions. Moreover, studies have been made based on tests not only on different transformers with diverse ageing and loading conditions, but also on several test samples prepared with controlled accelerated ageing. Based on all these observations and trials, an algorithm is developed by the inventors to analyze PDC and RV waveforms. Typical nature and values of the real-life PDC and RV waveforms are shown in Figs 6, 7. The expert system calculates the result based on these waveforms.

In an expert system, the human knowledge is encoded into an algorithm such that a machine can take action depending on the situation on the basis of the expert rule base. For example in graph (16, 17) of Fig. 14, slope of PDC curve and the tail value of PDC give the idea of leakage resistance of the insulation and an idea of the overall insulation condition (ageing). It is also known that the RV spectrum gives an idea about the moisture content in paper of the oil-paper insulation. More the moisture content, more degraded is the insulation condition. It has been established that the peak of the RV spectrum in RVM chart (33) of Fig. 15 tend to shift towards lower values as the paper moisture increases.

The expert system analyzes the recorded data and estimates the dielectric parameters such as leakage resistance of the insulation, paper conductivity, moisture content in the paper, oil conductivity and oil moisture. The user is provided specific observations on the condition of the insulation such as dry/moderately wet/wet paper, dry/ moderately wet/wet oil etc.

The system is capable of storing data in a flash-memory-type device through pressing of appropriate key under software instruction. The communication is primarily, but not limited to, USB protocol. The type of data storage is mainly, but not limited to, ANSI type data file.

Any programming language and operating system base can be selected to suit the algorithm with the denoising scheme as a separate module like dynamic linking library to avoid the complexity.

BEST MODE FOR CARRYING OUT THE TEST ADAPTING THE SYSTEM OF THE INVENTION

Step 1. The user has to make external connections to the device under test (3). In this process all the HV terminals of the device under investigation were shorted to bring one terminal and all the LV terminals were shorted to bring another terminal. The HV (6) and LV (7) lines coming out of the developed system as shown in Fig. 3 are connected with these two terminals, respectively, of the test sample. The body of the tank is grounded and the power supply is switched on.

Step 2. The system has been so designed that each process can be executed by a single keystroke assigned to that process. The main window (35) as shown in Fig. 16 guides the user to press the appropriate key depending upon the operation required. For example, to execute PDC measurement process user has to press "P" from the keyboard in the main menu (35).

Step 3. During PDC measurement the user interface shows the denoised data that is being acquired in the user interface window (16, 17). The interface (20) guides the user about the possible options of operation that he might choose to interrupt the process if required.

Step 4. After the time duration for polarization process is elapsed, the depolarization process is started automatically. Proper completion of PDC measurement will show Polarization and Depolarization curves (16, 17) as illustrated in Fig. 14.

Step 5. After completion of the PDC process the program returns to main-menu (35) so that the user may select the next operation to be performed, say, RV measurement by pressing "R" from the keyboard in the main menu (35). While performing the RVM process following the PDC process, no change in the physical connection is required.

Step 6. Similar to PDC, during RV measurement procedure user will also be instructed by the user interface (34) to ensure proper operation. However, the user may interrupt the procedure at any instant if he wants to do so. In the case of no user intervention the system will operate as per default setting made during the design of the system. Proper completion of RV measurement will show Recovery Voltage waveforms (33) as presented in Fig. 15, acquired throughout the cycles of operation. After completion of the RVM process the program returns to main-menu (35) as presented in Fig. 16.

Step 7. After returning back to the main-menu (35), expert analysis can be performed by pressing "E" from the keyboard.

Step 8. After completion of the analysis, the user can take the data and analysis results in a removable flash drive by pressing "S" from the keyboard in the main menu (35).

References:

[1] W.S. Zaengl, "Dielectric Spectroscopy in Time and Frequency Domain for HV Power Equipment, Part I: Theoritical Considerations", IEEE Electr. Insul. Mag., Vol. 19, No. 5, pp. 6-19, 2003.

[2] W.S. Zaengl, "Application of Dielectric Spectroscopy in Time and Frequency Domain for HV Power Equipment", IEEE Electr. Insul. Mag., Vol. 19, No. 6, pp. 9-22, 2003.

[3] T. K. Saha and P. Purkait, "Investigation of an Expert System for the Condition Assesment of Transformer Insulation Based on Dielectric Response Measurements," IEEE Transactions on Power Delivery, vol. 19, no. 3, pp. 1127-1134, July 2004.

[4] D. Dey, B. Chatterjee, S. Chakravorti and S. Munshi, "Hybrid Filtering Scheme for Proper Denoising of Real-Time Data in Dielectric Spectroscopy", IEEE Trans. on Dielectrics and Electrical Insulations, vol14, no. 5, pp 1323-1331, 2007.

[5] M.H. Li, M. Dong, Y.M. Qu, M.G. Zhou and Z. Yan, "Return voltage measurements of oil impregnated paper insulated transformers", IEEE Intern. Sympos. Electr. Insul. Materials, (ISEIM), pp. 273-276, 2005.

[6] X. Z. Yu, S. Birlasekaran, S.S. Choi, Y.C. Yong and T.F.Lim, "Condition Monitoring of a Power Station", Intern. Conf. Power System Technology (PowerCon), Vol. 2, pp.1029-1033, 2000.

[7] C. T. Dervos, C. D. Paraskevas and P. Skafidas, "Dielectric Characterization of Power Transformer Oils as a Diagnostic Life Prediction Method", IEEE Electr. Insul. Mag., Vol. 21, No.1, pp. 11-19, 2005.

[8] T. K. Saha, P. Purkait, and Z. T. Yao, "Condition monitoring of transformer insulation by polarization and depolarization current measurements," in *Proc. Australasian Universities Power Engineering Conf.*, Melbourne, Australia, 2002.

[9] Z. T. Yao and T. K. Saha, "Analysis and modeling of dielectric responses of power transformer insulation," in *Proc. IEEE Power Engg. Soc. Summer Meeting*, vol. 1, Chicago, IL, 2002, pp. 417–421.

[10] G.R. Arce, "A General Weighted Median Filter Structure Admitting Negative Weights", IEEE Trans. Signal Processing, Vol. 46, pp. 3195–3205, 1998.

[11] G.R. Arce and J.L. Paredes, "Recursive Weighted Median Filters Admitting Negative Weights and Their Optimization", IEEE Trans. Signal Processing, Vol. 48, pp. 768–779, 2000.

[12] S. Hoyos, Y. Li, J. Bacca, and G.R. Arce, "Weighted Median Filters Admitting Complex-Valued Weights and Their Optimization", IEEE Trans. Signal Processing, Vol. 52, pp. 2776–2787, 2004.