CHAPTER 2

Development of a PXI controller based data acquisition system for online remote monitoring of leakage current on RTV coated insulators

2.0 Introduction

The continuous operation of the transmission system is very important. For ensuring high levels of continuous operation it is not only important to select appropriate insulation withstand levels for various power apparatus, insulators etc., but it is also necessary to consider the pollution withstand levels for external insulation. Problems arise when the insulators, which are polluted and exposed to fog and light, rain, under ambient conditions, flashover at the operating voltage itself. The moistened pollution layer on the insulator surface conducts, thereby increasing the leakage current, in the field. To monitor the status of the insulator surface, leakage current is used as indicator worldwide. Researchers have developed online data acquisition systems for monitoring leakage current continuously. Long-term studies of the electrical phenomena on the polluted insulator surface necessarily demand the usage of an online data acquisition system (DAS) to continuously record the leakage current pulses caused by dry band and corona discharge activity. A brief review of a few data acquisition systems are discussed below.
The DAS used by Vlastos et al. [35] was for field measurement where, in all, the channels are scanned every 10 seconds. Protection for the measuring circuit is obtained by a zener diode and a switch. It works on the Unix system and measures the basic and the highest component of the leakage currents for long periods of time. Although the DAS used by Gorur et al. [5] was based on Reynaert et al. [36], it was modified [37] and used in the field where the computer is capable of remotely changing the values, sampling rate and time interval. They used Lab VIEW software for the DAS, which has 16 channels. With a maximum sampling rate of 4038 samples/s (when testing only one sample), 64k memory, it monitored I speak, time of occurrence, and classified the leakage current into various bins based on pre-set threshold levels.

The DAS used by Kawa et al. [38] is a 16-channel, 8 bit A/D card and measures the leakage current across 56 Ω. They have used only six channels. Protection for the measuring circuit is obtained by a gas-filled spark gap, zener diode and a set of back-to-back diodes. It measures I peak, I average on both positive and negative cycles of leakage current and total charge.

The commercially available IH 48 logger system [34] analyses the online leakage current and logs the values of the cumulative integral of leakage current (charge), the cumulative integral of current squared, surge count, the maximum leakage current, positive and negative peaks and time to flashover.
Kim et al. [20] used a 12 bit A/D converter with a frequency range of 400-800 Hz for each channel. They used a 8086, 10 MHz computer with a 8087 Math co-processor, and the input voltage was ±5 Volts. Protection was obtained by using a spark gap and zener diode arrangement. Software was written in ‘C’ language. The buffer size was 32,000 bytes. Eight channels were used in the data acquisition system.

The DAS used by Devendranath et al. [39] is a 8 channel PC based MCIC with a maximum sampling rate of 10000 samples per second per channel. Protection for the measuring circuit is provided by back to back diode arrangement and isolation amplifiers. It measures the peak leakage current, average leakage current, pulse count and computes the charge and integral of current squared. This system does not have remote monitoring features apart from the possibility of counting corona pulses too.

The peripheral component interconnect extensions for instruments specification [ PXI ] controller based data acquisition system developed for the present work [ 40 ] has four input channels with a maximum sampling rate of 4000 samples/second per channel to obtain a very low error in the numerical integration of samples to obtain a smooth output waveform. The new data acquisition system analyses the leakage current on-line and stores the values of average leakage current, peak leakage current, pulse count, charge and
integral of current squared. A back-to-back diode arrangement and isolation amplifiers protect the measuring system from flashovers. The newly developed system is portable and can be used for remote monitoring of leakage current on-line using LAN. The system parameters can be changed and controlled from remote PC.

2.1 **PXI controller based data acquisition system**

The new data acquisition system is designed to monitor leakage currents in a maximum of three insulators. An additional sinusoidal input voltage is used as a reference for analyzing and classifying leakage currents occurring in each input channel during every half cycle of the reference channel. Peak leakage currents in each half cycle of reference sinusoidal input can be classified into a maximum of seven preset levels.

2.1.1 **Description of the PXI controller based data acquisition system**

Unlike a PC based MCIC [39], the newly developed data acquisition system measures voltage on four channels using a PXI data acquisition card. Four isolation amplifiers are added in to PXI chassis before the input to the DAQ card.

Custom based software developed in Lab VIEW has two parts. The first part is called Field Monitor (FM), which runs on the PXI system. The FM software performs unattended operations for extended periods of time. FM software performs data acquisition, on-line
analysis, local display in graphical and tabular format, stores data on system hard disc and communicates with second part of the data acquisition system which runs on a remote PC. The second part of the software is called the Remote Monitor (RM). This software developed in LabVIEW runs on a remote PC with no data acquisition hardware. RM communicates with FM software over local area network (LAN) to control and monitor data acquisition operation remotely. The overall system block diagram is shown in Fig. 2.1. The sampling rate of the data acquisition system is fixed at 4000 samples per second. The voltage appearing across the shunt resistors due to flow of leakage current is acquired by the FM software which divides it by the resistor value to get the leakage current. A sinusoidal input voltage is used as a reference for analyzing and classifying leakage currents occurring in each input channel during every half cycle of the reference channel. Peak leakage currents in each half cycle of reference sinusoidal input can be classified into a maximum of seven preset levels.

The FM software analyses digitized data according to a specified algorithm, incorporated with a digital capacitive current compensation technique to nullify the capacitive component of the total leakage current on the RTV coated porcelain insulator. The software accepts user inputs like number of input channels, sampling rates etc. and provides final outputs in graphical, tabular and spreadsheet file formats.

This four-channel system consists of a set of input signal conditioners and a PC-based plug-in multifunction card for digitizing
the eight input signals. The FM software analyses digitized data according to a specified algorithm, incorporated with a digital capacitive current compensation technique to nullify the capacitive component of the total leakage current on the RTV coated porcelain insulator [41, 42]. The software accepts user inputs like number of input channels, sampling rates etc. and provide final outputs in graphical, tabular and spreadsheet file formats. The first channel (i.e. channel) 0 is programmed to be the reference channel. The reference channel is given a sinusoidal power line signal as input. Zero crossovers of this signal are recognized by the FM software program to carry out peak classification on all input channels in each half cycle. A loss of this reference signal affects the output of the whole program.

The leakage currents from a maximum of four specimens (insulators) are applied to a set of seven precision (1%) resistors. Voltage developed across each of these resistors is applied as input to channels 1 to 4. The resistors are provided with a diode clipping circuit. The maximum input isolation provided is 1500 volts. The diode is used as shunt element and restricts the signals transmitted to data acquisition system to be within ± 10 V.

2.1.2 Leakage current integrator

The leakage current flowing on an insulator has resistive and capacitive components. The voltage applied across the insulator is constant throughout the test/service. The leakage current flowing over
the insulator has two components. They are capacitive and resistive in nature. The resistive component is a function of the resistance of the coating of the insulator. Since the resistance of the coating degenerates with respect to time, the resistive component of current increases. However, the capacitive component is a function of the insulator dimensions and the dielectric constant of the material of the insulator. Since the change in the dielectric constant of the material is negligible, the capacitive component of the leakage current is constant. To analyse pollution phenomena in an RTV coated insulator, we measure the resistive component of the leakage current. A digital capacitive current compensation technique [42] has been used in the program. The leakage current measurement is started only after the program detects a positive moving zero crossover of the voltage applied to the test sample. The program causes the capacitive component of leakage current to be nullified, thus giving the resistive leakage current shown. As soon as the program detects the positive-moving zero crossover of the sinusoidal voltage, it starts acquiring leakage current from the samples. The peak value of the resistive component is determined, and the counts maintained for different ranges are held in separate bins. Initialization of all bins to zero is done at the beginning of the program. The ranges defined are 0-50, 50-100, 100-200, 200-300, 300-400, 400-500, 500-600 and 600-880mA. The maxima of the peak values, the average value of leakage current and the integral of the leakage current are determined and stored.
2.2 **Program inputs**

The PXI controller based data acquisition program accepts the following user inputs:

2.2.1 **Integration interval (in minutes)**

The sampled values of input signals are integrated over this period. The minimum interval is one minute and maximum is 60 minutes. The integration interval corresponds to the frequency at which the parameters have to be logged.

2.2.2 **Total time of Integration (in minutes)**

This is the period over which the complete monitoring and analysis has to be performed. User can enter this input in minutes up to an equivalent period of 300 days. The total time of integration (TTI) corresponds to the test duration. Thus,

$$TTI = n \times \text{integration interval}, \text{ where } n = \text{number of intervals}.$$

2.2.3 **Number of Input channels**

There are 4 input channels starting from 0 and ending at 3.

2.2.4 **Scanning Rate**

User can select up to a maximum of 30,000 scans per second if only one channel is being monitored or up to a maximum of 4,000 scans per second when all 4 channels are being monitored.
2.2.5 Number of leakage current levels

It can be programmed up to a maximum of seven levels in to which the input signal peaks are to be classified during each half cycle of reference sinusoidal input at channel 0.

2.2.6 Value of shunt resistor (in Ohms)

Since A/D input is basically a voltage signal, leakage currents through the insulators are to be measured in terms of voltage drop across suitable resistors (a few ohms) connected across isolation amplifier inputs. Value of these resistors are same for all the inputs. Value of the resistor was so selected such that the maximum expected leakage current through the insulator causes a voltage drop across the resistor to be within +/- 10 Volts input range of isolation amplifiers as well as with in the clipping voltage of diodes connected across the input, which acts as a protection for the data acquisition system, as shown in Figure 2.2. Accordingly, the maximum expected leakage current level is also fixed up. Also, the computerized on-line remote data acquisition system with its hardware compartment (PXI controller) is shown in Figure 2.3.

Consider the test set up having a clipping voltage of 7 V. For this condition and a maximum expected leakage current of 1000 mA, the resistance value to be chosen is 7.0 Ohms. Since, 7.0 Ohms is not a standard value of resistance, 6.8 Ohms is chosen, which will in turn give maximum voltage drop of 6.8 V which is with in the clipping limit
for a leakage current of 1000 mA. Consequently, the highest level of leakage current is fixed as 1000 mA for peak classification purposes.

2.3 Leakage current levels

Based on the selected ‘number’ of leakage current levels in to which the peaks are to be classified, user has to enter the threshold for each level in mA. The highest level will be the maximum expected leakage current through the insulator, say 1000 mA like in the above example. The lowest level should be so selected to keep all noise-induced peaks within this level. The inherent noise in the PXI controller based DAQ system due to input amplifiers and A/D converter is observed as 1 mA based on the specifications of components used. Noise measurements were not made as such. Any additional noise from the external electrical network should also be taken into account while fixing the lowest level for peak leakage current classification.

2.4 Integration

Integration is carried out for user-selected channels over the user-selected integration interval. Since leakage current is measured in terms of voltage developed across input shunt resistor, the leakage current to be integrated is obtained by dividing A/D value of each sample by the value of shunt resistor. The value of this leakage current sample is in amperes and is termed ‘i’. Reciprocal of sampling
rate gives sampling interval ‘ΔT’. Integration is carried out for the following two parameters.

(i) absolute of \( I \times ΔT \) and (ii) square of \( I \times ΔT \)

Integration (or Summation) of the above two values is carried out on all A/D sampled values channel-wise over the user-selected integration interval (1 to 60 minutes). Since \( i \times ΔT \) gives the value of charge flow on the insulator during the sampling period, the integrated value at the end of the integration interval gives total charge flow during that integration interval.

As an example, if a sampling rate of 4000 samples/second is selected, \( ΔT \) is equal to 0.000025 seconds or 25 microseconds. For a typical power line frequency of 50 Hz, this sampling rate gives about 40 A/D samples for each channel during each half cycle. Hence, a fairly smooth integration is achieved. If the selected integration interval is 1 minute, 14400000 summations will be carried out during each integration interval.

### 2.5 Peak classification

Continuous monitoring of the current is done to determine the peak of the current, charge (\( it \)) and current squared integral (\( i^2t \)) in each half cycle. For analysis purposes the range of peak values of current is divided into eight sub ranges. Every peak current measured is classified and counted in the corresponding range by the program. The counts are registered in eight bins identified for this purpose. The
“it” and “i²t” values are continuously added. This process was continued till the end of the integration interval.

At the end of the integration interval the counters of all bins are reset to zero and a fresh integration interval is commenced. The cumulative values of “it” and “i²t” are also reset. The whole process is repeated similarly for every interval till such number of intervals required to reach the total test time.

In addition to finding and classifying peak leakage currents in each integration interval the PXI controller based DAQ program also finds and stores in file the average of peak leakage currents that have occurred during each half cycle of that integration interval. This is achieved by adding the peak leakage current of each half cycle throughout the integration interval and dividing the total value by the number of half cycles in that interval. The highest peak leakage current that occurred during an integration interval is also determined and stored in respective output file by the PXI controller based DAQ program using a comparison process during each integration interval.

2.6 Output files

The integration and peak classification results for each input channel are stored in output files after each integration interval during a monitoring session. Output data gets stored in distinct files for each input channel. The format of typical output file is shown in Annexure-1.
2.7 Specification of the PXI controller based data acquisition system

No. of input channels=4 (channel 0 to channel 3, channel 0 is the reference channel)

Maximum sampling rate: 4000 samples/sec per each channel

Sampling Mode: Simultaneous sampling on all 4 input channels using 4-ch simultaneous sample/hold amplifier board

Input voltage range=+/− 10V (Analog devices signal conditioning modules)

Input isolation=1500 V

2.8 System requirements

The PXI controller data acquisition system is run on a PC with Pentium 120 MHz processor and 16 MB RAM or on any other higher configuration working under Windows 95 or later versions of Windows operating system. The associated software loaded is Labview 5.0 along with PXI controller based DAQ programs. A spreadsheet package like MS Excel is also required to view the output files.
2.9 Experimental verification of the PXI controller based data acquisition system

The PXI controller based data acquisition system was deployed to monitor continuously the leakage currents in the ageing test on i) RTV coated porcelain disc insulator and ii) Porcelain disc insulator without any coating in an ageing chamber. The leakage current is used to compute the charge, integral of current squared, average leakage current and current pulse count.

A three-dimensional view of the pollution ageing test chamber along with the test specimen arrangement is shown in Fig. 2.8. The ageing chamber is built with 2.0m x 2.0m dimensions and a height of 2.5m. Nozzle columns are placed in the diagonally opposite corners. The test samples are kept in the middle of the chamber. The design of the nozzle conforms to IEC-60507, 1991. A dedicated air compressor is used to supply compressed air at a preset pressure. A roof-top solution tank delivers the saline solution at the nozzle tip through a rotameter-type flow meter at the required rate. Shown in Fig. 2.5, 2.6 and 2.7

The ageing test was conducted on two 11 kV standard porcelain disc insulators of ANSI class 52-11, creepage distance of 380 mm, height of 175 mm, and diameter of 290 mm, one of which was coated with room temperature vulcanized (RTV) silicone rubber coating of
thickness 0.20±0.01mm. The test voltage was maintained at 10 kV from a test source of 400 V/33 kV, 66 KVA transformer during the ageing period under the following test conditions.

Salinity = 1800 µS/cm
Air pressure = 330 kPa
Flow rate = 250 ml/min.

The ageing test was conducted for nearly 100 hours continuously without disrupting the power supply and fog to the test samples. The parameters monitored were leakage current, charge and current pulse counts using an online PXI controller based data acquisition system.

2.10 Results and Discussion

The results obtained on the samples along with graphs are discussed below.

2.10.1 Cumulative charge, \( i_t \) (C):

It is the summation of the product of instantaneous leakage current and the sampling period over the period of interval time. Ageing of the samples was done for 100 hours. The cumulative charge in case of the RTV coated sample is approximately three times less than the cumulative charge of porcelain sample as shown in Fig. 2.9.
2.10.2. Cumulative integral of current squared, $i^2t$ (C-A):

It is summation of product of square of instantaneous leakage current and sampling period over the period of interval time. The joule heating factor for porcelain sample is almost constant at below 0.1 C-A up to 10 hours, but it increased linearly thereafter to 0.2 C-A for period 50 hours. From a 50 to 75 hour period $i^2t$ factor increased from 0.2 C-A to 0.37 C-A and reached 0.5 C-A at the end of the ageing period. The $i^2t$ factor for an RTV coated sample increased linearly with time and reached 0.07 C-A at the end of the ageing period as shown in Fig. 2.10.

2.10.3 Average leakage current (mA):

It is defined as the value obtained by summing up the absolute values of all currents sampled during the positive and negative portions of the 50 Hz over a specified length of time (which is the integration time) and then dividing by the number of sampled currents. Owing to the hydrophilic surface, the porcelain sample has passed an average leakage current of 2 mA which is four times more than the RTV sample’s hydrophobic surface. At the end of the ageing period, the RTV coated sample passed 0.57 mA as shown in Fig. 2.11.

2.10.4 Current pulse count:

The current pulse count is the total number of current pulses (> 50 mA) for predefined period. It is very low for RTV coated sample. The
porcelain sample registered a count of 24348 pulses while RTV coated sample registered 6212 counts at the end of 100 hours.

From the above results, it is observed that the RTV coated sample has conducted much less leakage current, accumulated less charge and less pulse count as compared to the porcelain sample. The low leakage current on the RTV coated sample is attributed to the hydrophobicity of the coating, thereby causing less charge accumulation and less pulse count, where as the porcelain sample has a hydrophilic surface, which has large patches of water encouraging the leakage current to flow over the surface. Hence, the charge accumulation and pulse count are relatively more than that of the RTV coated sample.

2.11 Conclusion

A PXI controller based data acquisition system for on line remote monitoring of leakage current on RTV coated insulators is developed with a sampling rate of 4000 samples/second to obtain a very low error in the numerical integration of samples.

The PXI controller based data acquisition system analyses the leakage current on line and stores the values of average leakage current, peak leakage current, pulse count, charge and current squared integral and can also be used for remote monitoring. With minor modifications in software and hardware, the DAS can be used for remote monitoring under wireless LAN.
Figure 2.1. Block Diagram of Data Acquisition System (DAS) hardware.
Figure 2.2. Test set-up with protection scheme.
Figure 2.3. View of PXI controller.
Figure 2.4. Computerized on-line data acquisition system with its hardware compartment.
Figure 2.5. IEC standard pollution nozzle.
Figure 2.6. Rotameter type flow meter
Figure 2.7. Air Compressor
Figure 2.8. Three dimensional view of chamber with test set-up.
Figure 2.9. Charge against time trends of porcelain insulator and RTV coated porcelain insulator samples
Figure 2.10. $i^2t$ against time trends of porcelain insulator and RTV coated porcelain insulator samples
Figure 2.11. Average leakage current against time trends of porcelain insulator and RTV coated porcelain insulator samples.