International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 07, July-2015

An Evaluation of Techniques for Monitoring the High Voltage Insulator Pollution

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***Abstract*- Leakage current monitoring associated with the method for measuring the pollution levels on High Voltage insulator of overhead transmission line. This paper describes the various pollution monitoring techniques of High Voltage insulator such as frequency characterization, pattern-recognition, optical detection of partial discharge, sensor system with satellite communication link etc. By using the combinations of sensors, processing techniques & electronics set up, the characteristics of the leakage current can be evaluated. Frequency characterization investigated with artificial contamination tests & field tests. Pattern recognition technique classifies the state of insulation structure in online application. The system comprises a fiber-optic sensor, directly connected to one insulator of the string that emits a sample of the leakage current waveform to a processing module via an optical link. Satellite based monitoring along with the Important results were achieved during the field implantation, mainly related to system design & features that need to be applied during the building of tower with transmission line of High Voltage. Experimental activities & field system records the relevant status of pollution level.**

***Index Terms*-Corona Effect, Flashover, leakage current measurement, Optical detection, satellite communication, Signal analysis.**

I.INTRODUCTION

When insulator strings of overhead transmission lines are exposed to polluted environments under high humidity, their insulation capacity is reduced due to the coexistence of, partially conductive, wet and dry regions on the insulator's surface. Due to high voltage stress, corona forms the small discharges in the form of light, heat or sound, etc. Under high humidity, the pollutants form conductive, wet and dry regions on the insulator surface [6]. The concentrating the electric field, leading to the creation of partial discharges (PDs) can increase its rate and intensity until a complete discharge from line to ground, known as flashover [2]. Failures in the transmission lines are mainly due to the flashovers [1]-[3]. It is necessary to develop the measurement system which capable of monitoring and characterizing the main features of the leakage current flowing on a polluted insulator string of a high-voltage transmission line [1]-[10].

Due to difficulties involved into mathematical analysis, many researchers have proposed the objective through the stastical analysis of signal achieved from the monitoring. The various techniques for contamination monitoring and inspection with antenna have suffered through the Electromagnetic Interference (EMI) [4]-[12]. It is expected to design the monitoring system without EMI disturbance in lab as well as in field experiment, with easy installation, low-cost & easy maintance features [1]-[4]. The various techniques for monitoring the state of pollution are described in the methodology i.e. second section. Different issues & solutions related to different methods are described in third section. Summary of the techniques for monitoring the high voltage insulator pollution is described in the last section.

II. METHODOLOGY

In order to establish a method for monitoring whether flashover occurs or not in a string of insulators based on leakage current waveforms and their frequency characteristics. The leakage current waveforms and the frequency characteristics of a string of suspension insulators were investigated with artificial contamination tests and field tests. Pattern-recognition techniques were used to introduce the methodology used in the process of characterizing the features. The development of a measurement system provides monitoring and characterizing the main features of the leakage current flowing on a polluted insulator string of high voltage transmission line. Optical system for monitoring that stores information on relevant parameters associated with the leakage current. The integration of the measurement system with a satellite-communication system was proposed as a strategy for remote sensing, and preliminary one-month activity data in the field were reported from a network of six sensor systems [1]-[12].

This section explains the various techniques for monitoring the state of pollutions along with the features.

A. Frequency Characterization in fog

Frequency analysis of leakage current waveform & magnitudes of leakage current were detected by the current transformer, amplified by dc amplifier & recorded on a data recorder. The experiment was conducted at a fog chamber. The fundamental characteristics of leakage current waveform of contaminated insulator were clarified using a string of five units of suspension insulators. Frequency spectrum analysis was performed with a real-time signal. Insulators were contaminated by a spray containing contaminated suspension or by soaking in contaminated suspension for ten seconds. Three kinds of contaminated suspension with varying quantities of salt were prepared in order to simulate light, intermediate & heavy contamination respectively .Contaminated insulators were dried in a drying room and moved to the fog chamber. Total seven tests were conducted [2] & [7].

In the case of no flashover (light and intermediate contamination), the peak values of leakage currents gradually increase with time from the beginning of voltage application, become maximum during about 20 min, and then gradually decrease. Leakage current waveforms become similar to the symmetrical wave in the presence of strong local arcs on the surface of an insulator that is heavily contaminated and wetted sufficiently. Hence, the intensity of the odd order of harmonic components is high. There are total six stages of leakage current waveforms such as follows. At the beginning of rainfall; sinusoidal and ohmic leakage currents flow because no discharge occurs due to the slightly wet surface. Faint discharges occur and leakage current waveforms become saw tooth like [12].

B. Pattern recognitiation

In order to construct recognition systems, ultrasound and current leakage sensors, very-high frequency antenna, and thermo vision instruments were employed to acquire signals and images .A number of specific features such as time, frequency, and wavelet domains were applied to verify their importance during the classification process. Features were obtained in the two groups of pattern-recognition techniques were applied: linear and nonlinear. The input patterns which are signals acquired by sensors forms the vector & provide the input for the feature extraction routine. The features extracted by this routine can be grouped to form the vector called the features vector. It is processed by the classifier to make a decision i.e. the state of the insulator. In device that groups data in specific classes named as classifier.

Fig. 1 shows the tests were performed. The fog chamber was constructed in acrylic and measures at 0.90×0.90m^2 its base and is 1.40 m high. The ultrasound sensor was directed toward the insulator and is sensitive to signals between 20 and 40 kHz; with a transducer, these signals were transformed into audible noises and saved through the digitizer in the computer. The protection circuit is an electronic device, specially constructed to insulate the acquisition system from a high-voltage circuit by optical coupling. The VHF antenna is sensitive to signals between 20 and 100 MHz and is coupled to the computer by the spectrum analyzer; the spectrum is constructed and saved in the computer [3].

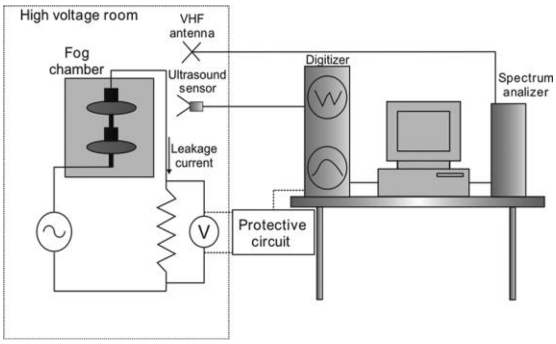

Fig.1. Pollution tests set-up [3].

Fig.2. presents typical signals acquired through the ultrasound sensor, current leakage sensor, VHF antenna, and images registered. The signals are grouped in function of the pollution level deposited on the insulators surface. Two mathematical tools take on important roles .in the digital processing of signals such as the Fourier transform and the wavelet transform. As wavelet analysis allows for the use of extended time intervals, with more precise low-frequency information and smaller areas to obtain high-frequency information, it is more frequently used for signal processing. When comparing wavelets with sine waves, which are the basis of Fourier analysis, it is possible to conclude that sinusoids are not of limited duration .They extend from minus to plus infinity; whereas sinusoids are smooth and predictable. Wavelets tend to be irregular and asymmetric. Fourier analysis consists of breaking up a signal into sine waves of various frequencies [3].

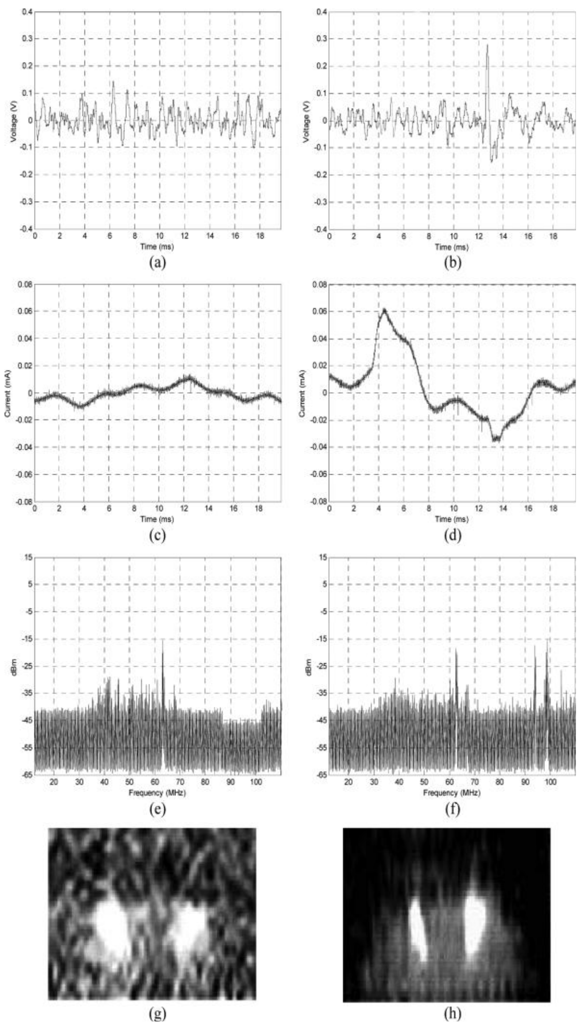

Fig.2. Typical signals for different pollution levels deposited on the insulator surface. (a) Ultrasound signal without pollution. (b) Ultrasound signal with pollution level (c) Current leakage signal without pollution. (d) Current leakage signal with pollution level (e) VHF spectrum without pollution. (f) VHF spectrum with pollution level (g) Insulator thermo image without pollution. (h) Insulator thermo image with pollution level [3].

Similarly, wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or mother) wavelet. Sharp changes might be better analyzed with an irregular wavelet than with a smooth sinusoid. Local features can be described better with wavelets. The network can be trained by function approximation (nonlinear regression), pattern association, or pattern classification, and requires a set of examples that represent the expected behaviour of a proper network. [3].

C. Fiber Network

For optical sensing of leakage current optical transducer such as LED (Light Emitting Diode) or LASER can be used. The selection of LED is based on the current rating, conduction threshold, sensitivity, power emission & central wavelength. The electrical characteristics of various LED's are shown in fig.3. By considering all the parameters, Off-the-shelf LED or infrared LED is preferred which is used for remote controls of electronic appliances. Optical sensing of leakage current follows the better electromagnetic immunity, possibility of easy fabrication, replaceable, high reliability & low cost [5].

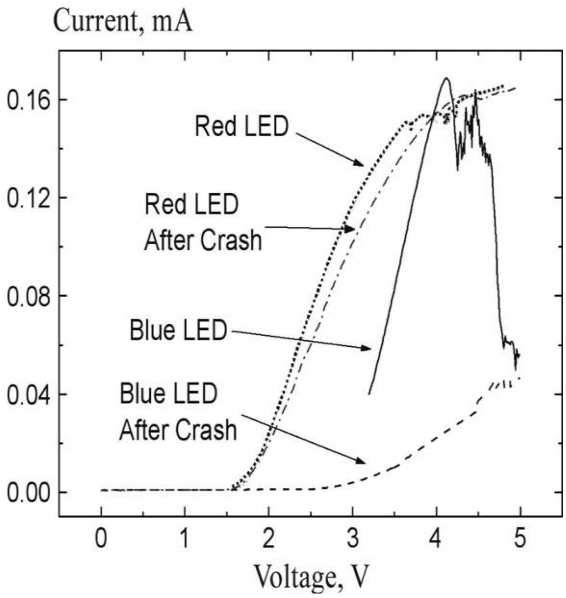

Fig.3.Electrical characteristics of LED's[5].

The cathode of LED is grounded to the tower structure & anode is connected to the cap of second insulator. Light signal reaches at the processing module via optical fiber as shown in fig.4. LED emitting surface & fiber core surface is 5mm. The LED emitting region is 200μm×200μm square surface. The capillary flat surface is optically polished & brought in contact with the LED. The other end of the fiber is terminated on a ferrule connector (FC) for transmission of the coupled light with another optical fiber. Fiber material may be plastic or silica because plastic optical fiber provides larger cores & coupling efficiency whereas silica fibers are available in market widely. A simple shunt diode used for protecting the LED against a high reverse bias across its terminals [5]-[4].

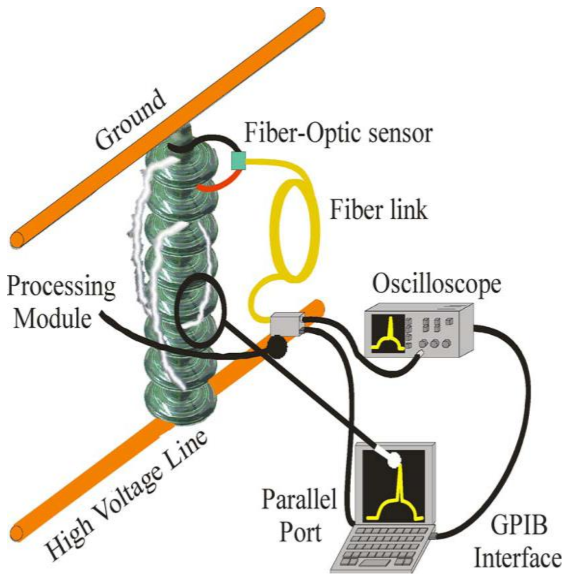

Fig.4.Leakage current detection & processing [4]

Optical sensor consists of a Light-Emitting Diode (LED) having 840nm central wavelength in pigtail configuration to improve the signal coupling. Optical sensing of leakage current follows the better electromagnetic immunity, possibility of easy fabrication, replaceable, high reliability & low cost [6]. This fiber is mounted on a glass capillary tube with the help of UV-curable epoxy. With multimode optical fiber having core & cladding diameters of 65 & 125 µm respectively. When two insulators subjected to a voltage drop of 120kV.It is qualitatively shows the conduction & ionization components of the signal.Fig.6.Shows the leakage current waveform for two polluted glass insulator [5].

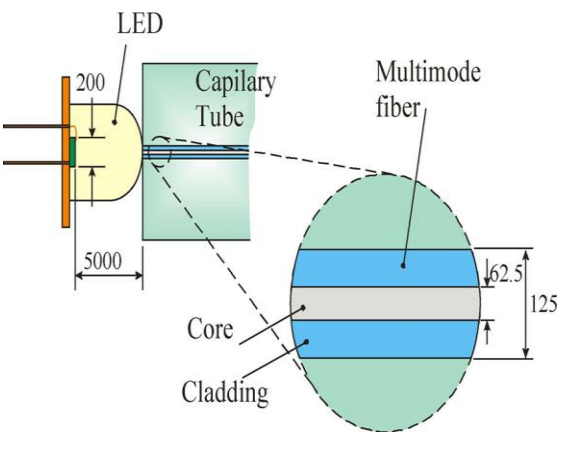

Fig.5.Sensor head fabrication [5]

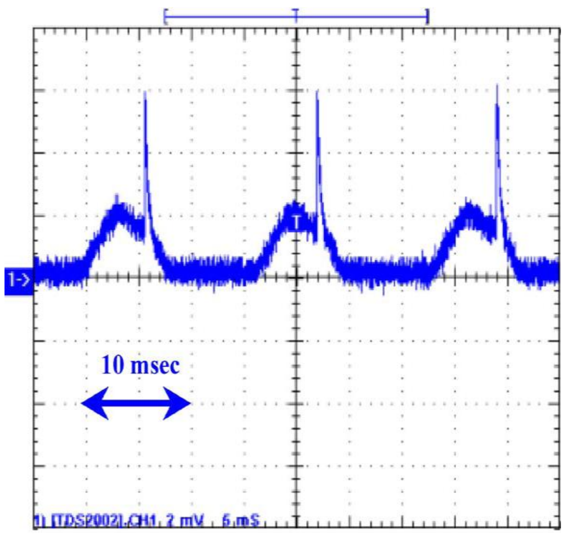

Fig.7. Leakage current waveform [4]

Electronic set up for the detection of leakage current is consists of detection, amplification, comparison and data storage. The system detects the N1, N2 & N3 levels for 5mA, 10mA & 20mA respectively. The processing module has capacitive humidity sensor connected on one ADC of PIC microcontroller. This module has an FC female connector for the optical fiber cable, a BNC female connector for real-time signal monitoring by an oscilloscope, and a parallel-port female connector for the PC interface. The processing module block diagram with parallel port interface is shown in Fig.8. & the activity on 230-KV insulator for 15 days is shown in fig.8. Interruption routines are used to count cycles for temporization purpose. For effective system, real-time clock IC is under the investigation. The optical fiber provides electrical insulation & processing module can be installed inside the command room [5]- [6].

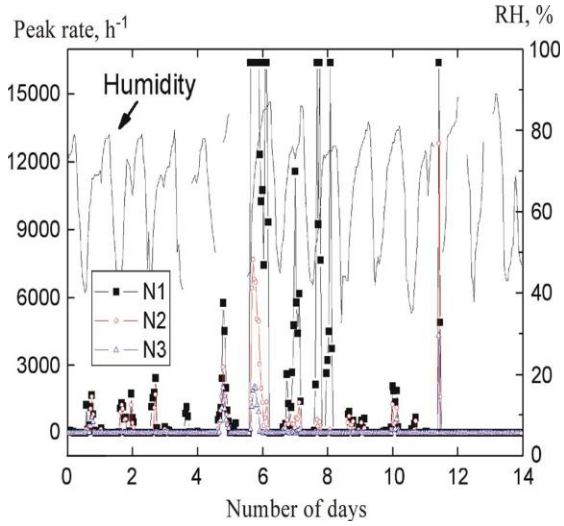

Fig.8.Activity on a 230-kV insulator for 15 days [5]

D. Sensor Network with satellite

Sensor network monitoring system consists of six-seven monitoring system, a private service network to acquire the information via satellite, and a client intranet network with access to the server database.Fig.9.Shows the real-time monitoring of the PDs on the surface of HV insulator strings as well as the environmental temperature and humidity were considered here. Monitoring system spread over the various locations of the states which measure the quantity of leakage current, humidity & temperature. The resultant information is send to the satellite via satellite modem [1]. Earth substation receives those packets through the private service network [4]-[6].

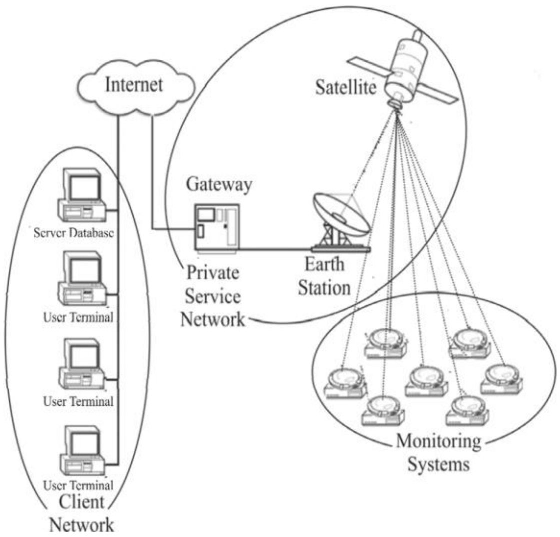

Fig.9.Satellite telemetry system[6]

Semiconductor temperature sensor & capacitive humidity sensor is used to measure the temperature & humidity respectively. Processing module processes the optical signal along with the measured humidity & temperature signal. Packet signal sends towards the satellite via satellite modem which installed on the top of metal cabinet. Metal cabinet encloses the processing module, battery, charge controller etc. Humidity sensor connects the external environmental condition to the laboratory experiment. Fig.10. shows the sensor system configuration in the tower [5]-[6].

Optical sensor consists of a Light-Emitting Diode (LED) having 840nm central wavelength in pigtail configuration to improve the signal coupling [1]. The optical sensor supports a maximum direct current of 300 mA and 1 A of maximum pulsed current amplitude. Sensor head start up as shown in fig 11.a). & Protection circuit is shown in fig. b).

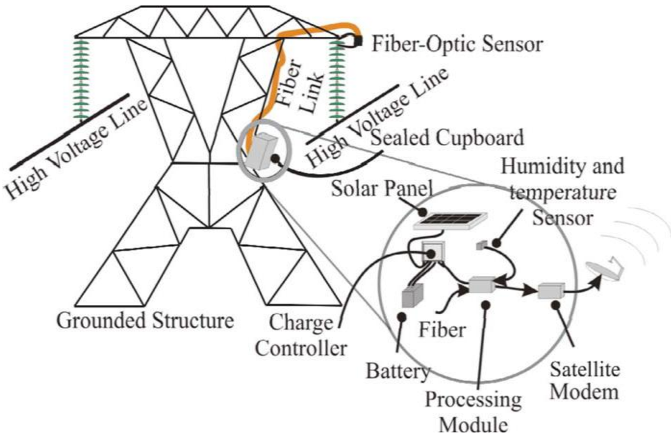

Fig.10.Sensor system configured in the tower [6]

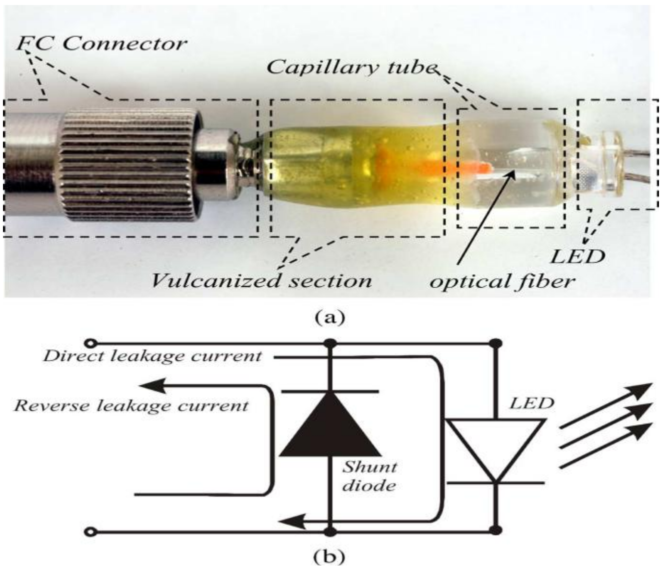

Fig.11.a)Optical sensor head b)optical sensor circuit[4]

Processing module is configured as shown in fig.12. It includes following blocks as:-detection, amplification, comparison & data processing etc. The signal from the optical fiber is received by the processing module. Detection stage uses the PIN silicon photo detector with a 100-kΩ low-power resistor for reduces the effect of high junction parasite capacitance. The detector has 13mm^2 active area. The FC female connector is used to connect the fiber. The active area of connector should be large enough to emerge the all light within the detector. Detected signal is followed by the amplification stage. It consists of four fast response invert configuration op-amp amplifier. Each amplifier has its individual adjustable gain. Selection of amplifier is based on the reducing inter-level noise caused by comparator’s feedback. Each amplifier is connected to the single level comparator with hysteresis. The output of the all comparators are given to the PIC microcontroller 16F877A.There are four peak levels of leakage current are amplified & detected such as N1, N2, N3 & N4. Each peak level of leakage current has its own limit defined in the standard such as follows:-

N1, For Ip >5 mA
N2, For Ip >10mA
N3, For Ip >20 mA
N4, For Ip >40 mA

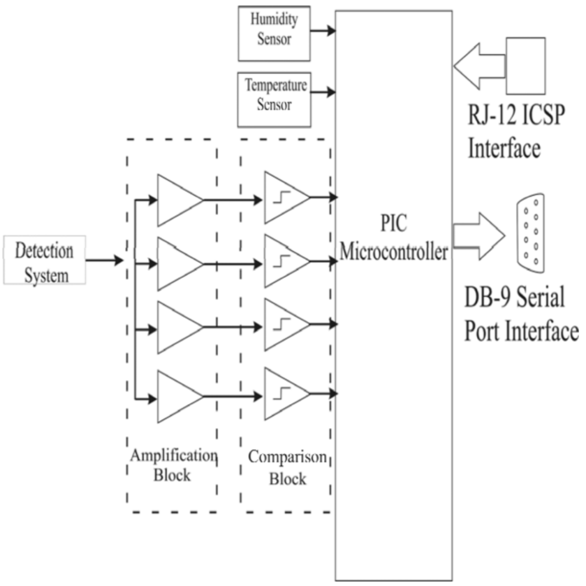

Fig.12.Processing Module[6]

In previous experiment, there were only three ranges can be calculated such as N1, N2 & N3 called as low-intensity leakage current, nonaggressive leakage current & high aggressive leakage current respectively. Leakage current is only occurs with its relative high environmental humidity which can be measured with the help of capacitive humidity sensors. This humidity sensor connected on ADC i.e. Analog-to-Digital Convertor of the PIC microcontroller. The selection of microcontroller is based on the speed, packaging, ROM & RAM etc. The humidity sensor needs to be contact with the external environment to measure the relative humidity; hence the long cable is required inside the command room of substation. Also temperature for respective conditions is measured with the semiconductor temperature sensor. The control program is explained in next chapter. The DB-9 connector is used to communicate with the satellite modem whereas the RJ-12 interface is useful for the in circuit-serial programming [6].

A satellite communication approach is used to monitor the remote areas among the four states which are unable to cover by the mobile system or another wireless data-communication approach. Monitoring system integrated satellite modem with a build-in planner antenna. The processing modules, battery, charge controller is enclosed in the metal cabinet. The satellite modem is fabricated on the top of the metal cabinet in Line-Of-Sight for the communication with the satellite. The processing module & satellite modem is energized by the photovoltaic system. Metal cabinet provides the protection from the outer environment & EMI interference. The metal cabinet is attaching such that it can be handles well.

Fig.13. shows the system design for the field experiment. The satellite service for this system is private. The monthly fee per modem is charged based on the satellite channel data allocation. Satellite modem transmitted data in packets format which are coded by the processing module. To reduce the monthly fee, the satellite modem transmitted two 64-bit packets per hour, so that monthly fee per modem is approximately that of a commercial mobile phone [1]. Whole system is controlled by the control software which loaded into the microcontroller PIC 16F877. Processing module provides the correct digital signal to microcontroller which is recognized by the CMOS logic of the controller. PIC microcontroller 16F877A receives the indentifying leakage pulses in all ranges such as N1, N2, N3 & N4. For fast response of operation, High speed crystal is used. For maintain the accurate time reference, Universal Time Clock (UTC) resistor of satellite modem synchronize with the internal clock reference. Pulse comes at the microcontroller is monitored by interrupt based routines. Counting of the pulse in each range stores the record of it into the 18-bit temporary registers. At the end of each hour, the final count is stored into the non-volatile memory of PIC [5]-[6].

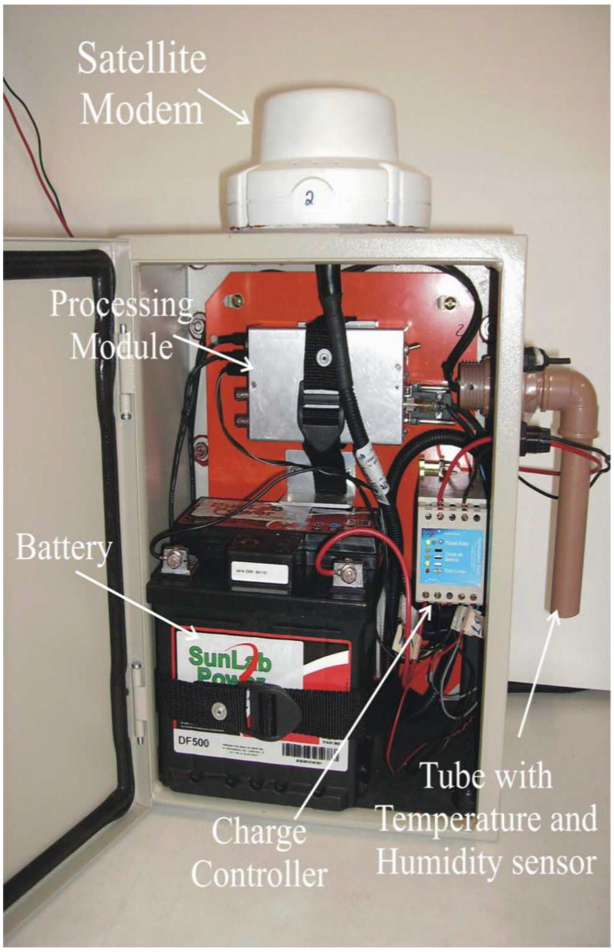

Fig.13.Photograph of sensor system in the field[6]

At starting of each new counting cycles, corresponding temporary register is reset. The pulse count, humidity & relative temperature are internally stored & formatted into packets. The processed packets are sending to the satellite modem via an RS-232 serial communication port. Each one 64 bit packet per half hour is send towards the satellite modem [6].

When the system is energized by auto-power ON signal, an *RC* circuit provides a reset signal to ensure the correct initialization sequence of the microcontroller. In the initialization stage, the special function registers are properly configured to ensure that on events of energy faults, the previously stored information is not lost. After the initialization stage, the program begins an infinite loop, as shown in Fig.5.1; that checks for incoming leakage current pulses. If there is an incoming pulse then the counter becomes increases by one. Then it checks for the commands come from the control program. Microcontroller also reads the relative humidity obtained from the humidity sensor. After the completion of one hour, final count stores into the non-volatile memory & non used flash memory. Finally it checks the operation time and returns to check for new leakage current pulses. Processing module has data capacity of two months of continuous operation without any data transmission or reset [5]-[6].

Preliminary data recorded for a 30-day period on all six monitoring points of the sensor network were reported. Sensor system was in a region characterized by a hot and humid climate. Furthermore, for the sensor system network, the latency of a packet is defined by the parameter

$$T(t) = ta-t$$

Where ta= the instant of time of arrival of the packet at the server & t=the delivery of the packet by the microcontroller. The time is originally set within the interrupt routine and packets are delivered every 30 min. Therefore, the parameter always assumes values separated by 30-min intervals. For full 24-hour period, data packet transmission value was corresponding to 48. From an average latency at time t was also useful to determine average fluctuations during the day [1]. This parameter is defined by

$$\bar{T}(t)= (1/n)\sum_{i=1}^{n} Ti(t)$$

Where n=the number of days over which the average is taken & Ti(t)= the latency measured at time t of the ith day. The measured time dependence of the parameter T(t) is given for a 30-day.

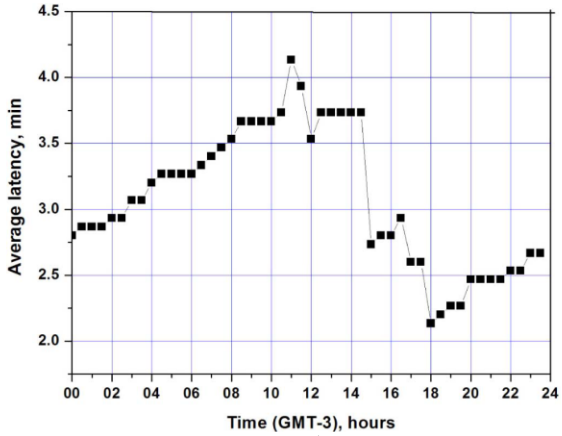

Fig.14.Average latency for one month[6]

The percentage of loss is given by

$$L\%(i)=100[1-(Pr(i)/48)]$$

Where Pr(i)= the number of packets received on the ith day.

The parameter L% for a one-month long experiment as shown in fig.9. The largest percentage of packet loss recorded for this time period was approximately 4% i.e. 2 lost packets when 48 packets transmitted. An average loss for this system obtained from the plot was 0.6% over one month. The missing data can be obtained by interpolation because maximum loss does not compromise the effectiveness of the telemetry system [6].

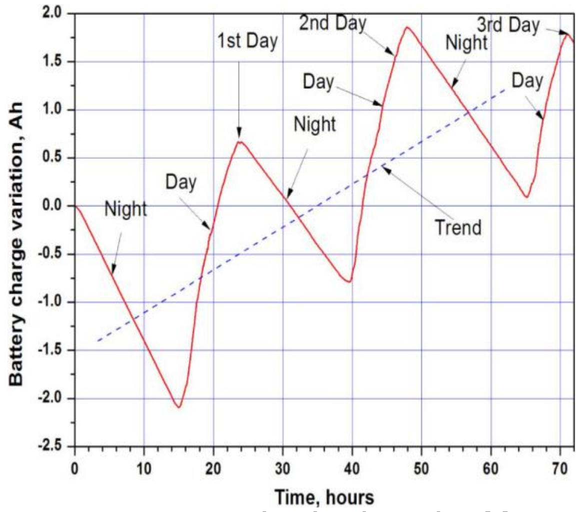

Fig.15.Time dependence battery charge[6]

The expected total daily energy consumption of the sensor system in the field was 38.2 Wh. Thus, for a supply voltage of 12 V, the solar panel should provide a daily charge of 3.2 Ah to the processing module and modem. The battery was not completely charged in the beginning of the measurement. The total amount of charge supplied to the battery during daylight is greater than that at night, except on the third day, when both contributions become approximately equal as shown in fig.15 [6].

All cabinets were submitted to an electroplating process for elimination of oxidation problems. Stable sealing between modem & cabinet was obtained with the use of an enhanced silicon adhesive for high temperature application. This technique was useful for the reduction of rain water infiltration. In order to protect the cabinet from rainwater, canvas cover were designed. After installation of sensor system on the 230-kV tower, time dependence for both temperature & humidity recorded by the sensor system [4]-[6].

III. ISSUES & SOLUTIONS

Leakage current waveforms and their frequency characteristics for a string of insulators were investigated by means of artificial contamination tests and field exposure tests in order to develop a monitoring and diagnosis system for contaminated insulators. Leakage current waveforms become nearly the symmetrical wave when local arcs occur; hence, the intensity of the odd order of harmonic components is high. The thresholds by which the occurrence of flashover can be predicted exist in the peak leakage currents and the magnitude of the odd order of harmonic components. However, the threshold by which the occurrence of flashover can be predicted does not exist in the magnitude of the prominent harmonic contents while it exists in the single suspension insulator. Hence the continues monitoring for the single insulator string is required [2], [7] & [12].

The validity of the pattern-recognition methodology applied to the results obtained in the laboratory experiments and that led to characterizing and analyzing the features for diagnosing the state of the outdoor insulators submitted to a polluted environment. It is important to emphasize that moving from the laboratory stage to operational requirements at field experiments. It is necessary to pay attention in practical proposals. It is possible to monitor defects in electrical equipment with techniques using specific sensors, digital signal processing, features and pattern-recognition technology [4], [9] & [11].

The optical fiber provides electrical insulation, and the processing modules can be installed inside the command rooms of the substations without exposing the human beings to any risk. In addition, a telemetry system is required to allow remote monitoring of partial discharge activities and humidity levels on a sensor network deployed across specific towers of the 230- and 500-kV transmission line systems. The system is composed of two distinct parts linked with an optical fiber that permits safe operation, even when the electronic part is installed inside the command rooms of substations. The complete system is small, portable, and easy to install. The optical fiber provides electrical insulation, and the processing modules can be installed inside the command rooms of the substations without exposing the human beings to any risk. The microcontroller software is essential to implement a universal-serial-bus communication between the PC and the processing module [4]-[5].

The sensor network is under expansion on transmission line system in order to allow a broader coverage of pollution activities. The need for additional surge protection and improved environmental shielding of the electronic circuits of each sensor system will be analyzed prior to fabrication of the new units. Satellite telemetry system will more efficiently predict when insulator washing is implemented; plantation & growth of crops to maintance with replaceable quality of sensor system are some features of the satellite telemetry system. Prior to the fabrication of each unit the detail testing of the each unit was analysed [6].

IV.CONCLUSION

This paper describes that, the design & experiments related to the pollution monitoring of the HV insulators .Frequency chrachertization indicates occurrence of the flashover in the single suspension insulator. Pattern reorganization provides the PD detection techniques for various types of insulators. Fiber communication methodology consist the control room communication with optical sensor. A satellite telemetry system development allows remote monitoring of partial discharge activities & humidity levels on sensor network which uncovered by standard mobile or optical data-communication methods. The additional protection circuitry along with environmental shielding of electronic circuits of sensor system will be analyzed before fabrication of each unit. Measured transmission latency well below the 30-min time required for transmission of data & the percentage of packet loss is less than 2% in each sensor system.

Review of various methods along with the field results were discussed here. Satellite telemetry system provides the feasible monitoring system for the large field area unlike the fiber optic system monitoring. Field results along with the experimental setup perform the characteristics visualization of the state of pollution of high voltage insulators. Temperature & humidity measurement were required for the monitoring the leakage current levels. This paper describes the various systems for monitoring the state of pollution of high voltage insulators. The development & laboratory setup including the details of sensor network & satellite link for both short & long term measurement. Thus improving the planning & reducing the cost of operation. Easy installation, small size & proper maintance with replaceable quality of sensor system are some features of the satellite telemetry system. Longer term correlation with the short term experiment with the evolution of activity will be reported through this experiment.

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