Online Monitoring of High Voltage Polluted Insulators Severity

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Abstract —**This article describes on line monitor of the pollution severity of heavy polluted insulators of power lines in a polluted atmosphere. The suggested monitor works by sensing and analyzing the leakage current bursts. If these bursts are judged by the monitor as corresponding to a potentially dangerous level the monitor transmits an alarm signal to the service crew so that they would clean the insulators of the line or substations in time before a sudden line outage occurs, with entailed excessive expense loss of power supply and annoyance to customer. Line insulator cleaning is thus carried out, when necessary, which adds to the economy of the power system operation. The suggested monitor based on the artificial neural networks, which are fed by the leakage current bursts, and also the environmental conditions collected from the field. The monitor gives a good operation performance when tested in practical simulated conditions. The hardware schematic is presented to act the function of online monitoring system.**

Keywords − **Artificial neural network - Flashover Voltage - Leakage current bursts – Monitor - Polluted Insulator - Pollution severity.**

I. INTRODUCTION

When contaminations accumulate on the insulator surface and its soluble ingredients dissolve in the moisture accumulated from fog or dew a conducting resistive path gets established on the insulator surface. Thus, leakage currents flow with non-uniformities in pollution layers and hot spots, dry bands and partial arcs develop on the insulator surface. These partial arcs may either get extinguished or otherwise may develop into a complete flashover of the whole insulator chain under the normal operating voltage. Pollution flashover of HVTL insulators is a problem that faces the Egyptian electricity network until now [1-15]. The practical importance of this problem can be assed from fault statistics of high voltage transmission lines in Egypt, which showed about 82 % of the total number of 220 kV lines' faults, is due to pollution of the insulators [1]. Methods currently are in use for monitoring the severity of polluted insulators by indirect measuring of auxiliary insulator string conductivity or equivalents sat deposited density (ESDD) [4].

Solving of the problem depends on the online monitoring system used and how effectively it can predict the flashover event before its occurrence. Monitoring leakage current is a tool used from early time depending on leakage current measurement [16-24] and discharging pulses counters [16]. Nowadays, data acquisition techniques, optical sensors, optical transmission sensors and on-line wireless detectors of leakage current pulses are used for leakage current monitoring [20] to produce more accurate measurement tools. Recent measurement tools encourage researchers to use computer advanced programming, mathematical methods and artificial intelligent tools [25, 26] to carry out analysis of the leakage current parameters or parameters surrounding the insulation site (i.e., weather data) in order to study the insulator surface condition during pollution existence and to predict the flashover event early [21]. Investigation on flashover prediction principles showed that many characteristics can combine together to form an alarm of approaching flashover [21].

II. LEAKAGE CURRENT BURSTS

When 10 kV is applied on suspension type insulator polluted by dry layer 20 us conductivity, the average leakage current reaches to 0.01 mA. When the pollution layer absorbs moisture from the humid air, the pollution layer becomes conducting and the leakage current in sinusoidal form flows depending on the applied voltage, as an example test voltage of 12.5 kV gives 168 mA peak values of leakage current average of five different tests carried out on five insulators when the insulator surface conductivity was 10 µS. Similar results are given in table 1. Suspension type insulators used in the testing are given in Fig. 1. The dimensions of such insulator unit are 336 mm diameter, 203 mm spacing, and 394 mm leakage path length.

As a result of joule heating due to the flow of leakage current in the conducting polluted layer dry bands are formed at several points on the insulator surface, the leakage current losses its sinusoidal wave shape and its

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magnitude dropped to 14 mA at 25 µS surface layer conductivity under 12.5 kV test voltage. A finite zero leakage current periods are observed every half cycle. Since a considerable amount of moisture still continues to precipitate on the insulator surface with high voltage still applied across the insulator, partial arcs are noticed on the insulator surface, each is accompanied by brief leakage current bursts having high amplitude with large zero current period and lasting for only few cycles. Samples of leakage current peak values bursts and number of pulses when applying different test voltages are given in table 2; surface Layer conductivity is 25 µS.

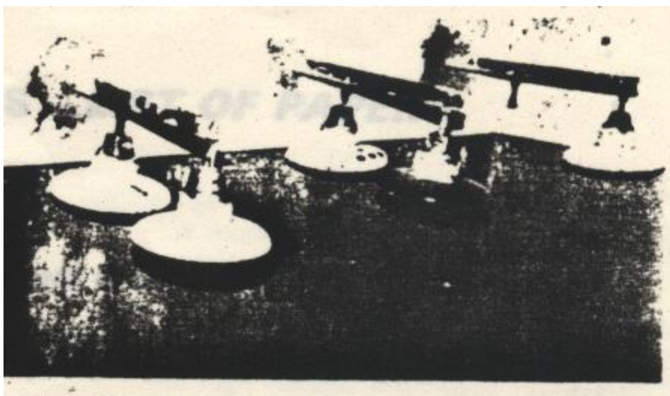


Fig. 1 Suspension type insulators used in testing

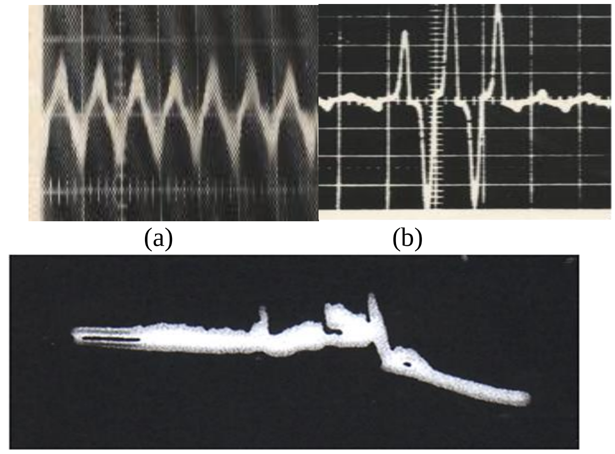
TABLE 1 SAMPLES OF SINUSOIDAL LEAKAGE CURRENT PEAK VALUES

Applied Voltage (kV)	Surface Layer Conductivity (US)	Peak Leakage Current (mA)
10	20	120-140
7	30	140-160
5	35	160-200

TABLE 2 SAMPLES OF THE NUMBER OF LEAKAGE CURRENT PULSES DURING TESTING INSIDE FOG CHAMBER (LABORATORY TEST)

Applied voltage (kV)	Number of leakage pulses ≥ 100 mA	Number of leakage pulses ≥ 40 mA	Number of leakage pulses ≥ 10 mA	Number of leakage pulses ≤ 10 mA
10	11	27	32	20
8	4	22	35	40
6	2	10	38	70

Samples of leakage current are given in Fig. 2.



(a) (b)

(c)

Fig. 2 (a) sinusoidal leakage current, (b) leakages current with zero current periods and (c) pulses of leakage current versus time in mille seconds (50 mv /division, 0.5 ms/division), 25 µS

The leakage current pulses are recorded during testing the insulator string in fog chamber completely filed with vapor having relative humidity 100%.

III. HARDWARE SCHEMATIC PROPOSED TO BE USED WITH THIS TECHNIQUE

Preventing or at least minimizing, the pollution flashover of external insulation has been important target for maintenance engineers. This part of paper presents hardware of novel monitor used leakage current signals, weather records, and applying new algorithms in predicting the flashover accidents, and, due to the existence location of this hardware in special type environmental surrounding (i.e., high stresses and fields) so it needs to be with specific nature that shows less relation when proposed to these electrostatic or electromagnetic fields or lightning surges. The design schematic for the proposed online monitoring system hardware is shown in Figs (3 and 4) in general details. Specific details on the material or values of the components used in this schematic are left for the designers and producers.

The suggested monitor contains two main hardware components as follows:

A. Monitor Transmitter

As shown in Fig. 3 the leakage current signals are taken from the insulator string through a cupper ring to an earthed resistor or clip-on current transformer as given in Fig. 3. For protection purposes the earthed resistor link is involved with a fuse to blow out whenever a complete flashover occurs in order to prevent the high currents from affecting the monitor. The resistor is connected in parallel to surge arrestor to protect the device from over voltages and surges. The optical voltage sensor is connected through the resistor to sense voltage signals proportional to the leakage current and transduce it to optical pulses with specific wavelength. The meteorological site data is sensed [27] through five optical sensors for measuring temperature, relative humidity, rainfall precipitation, and wind speed and wind direction. Each optical sensor output is characterized by specific different wavelength. A design schematic, shown in Fig. 4, is proposed to implement the methodology proposed in this paper. The protection elements in this apparatus are fuse for the over current protection and surge arrestor for over voltages protection. The voltage signal is taken from the resistor terminals. The meteorological site data is measured using electronic/digital sensor (transducers) including measurements for temperature (Temp. Sensor), rainfall precipitation (R.F. Sensor), relative humidity (R.H. Sensor), wind speed (W.S. Sensor) and wind direction (W.D. Sensor). The output of the sensors is in the form of analog or digital signals varying proportional to the measured quantities. All signals enter to a data acquisition unit (DAU) where all the above signals are amplified, sampled, multiplexed, converted to digital and then coded and exit in one data serial line as coded digital data. A link is required between the data acquisition unit and the optical transmitter, which designed in a way to convert the signal-coded data to optical wavelength to be transmitted through the single mode optical fiber cable. The optical signal is received at the other end (i.e., control room) by an optical receiver to convert the light wavelength to its original form of data (i.e., serial coded data). A serial data cable is required to be linked to a personal computer or a (Digital Processing Unit). A DC source is required in the sending end (i.e., transmission end) to supply the power required to the DAU and to the transmitter. The surge arrestor, DAU, the transmitter, and the DC source are all included in a shielded metal enclosure to reduce the effects of electric fields interference. Software compatible with a personal computer is required for purposes of storage, analysis, implementing algorithms and showing results. The advantage of this method is summarized in using fiber optical transmission system and simple electronic components which is easily found in national stores, markets and laboratories.

All the optical signals enter to special type optical multiplexers called Wave Division Multiplexers (WDM) [28]. The output WDM travels through single mode fiber optics cables through long distances till reaching the control room of the substation. Then as shown in Fig. 3 the traveling optical signals received from the optical cables are de-multiplexed to its original multiple wavelengths signals. These signals are converted from optical to electrical through several optical receivers [29, 30].

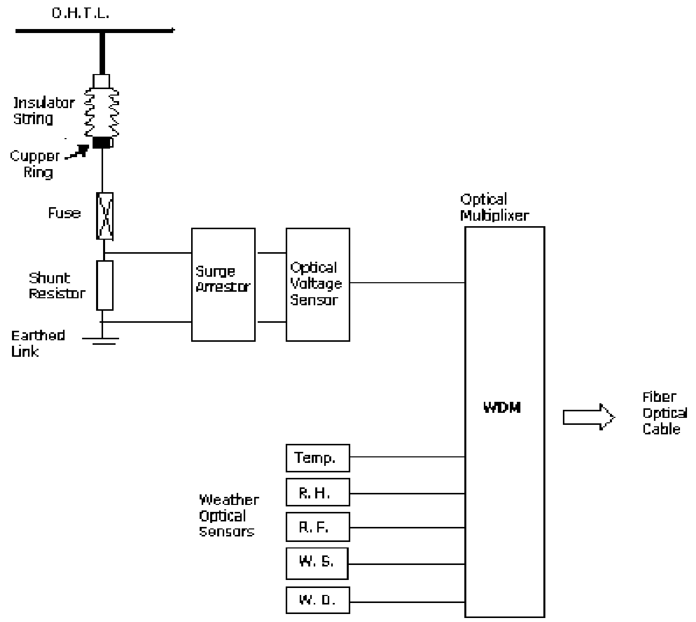


Fig. 3 Schematic proposed for the on line monitor hardware (from the sending side).

B. Monitor receiver and controller

The several electrical signals are combined through Data Acquisition Unit (DAU) to be converted to serial data code and enter to any digital processing unit though RS 232 cable or any data transfer bus. All the digital processing unit components including hard disk for storing of captured signals, high resolution RAM to perform temporary storage faster, and microprocessor unit for programming algorithms can be either provided by a personal computer or microprocessor based unit (i.e. it consists of RAM, ROM, hard disk, microprocessor or micro controller and other extension required). Software compatible with a personal computer is used to introduce the programming algorithms required to the monitor and link it with the captured and stored data. Also, this software provides an interface of graphics, captured data, results of algorithms to the monitor user and provide special functions for alarming process (i.e., sound, animations displayed on screen, etc.). When using microprocessor based unit, the algorithms and all the required functions will be programmed to the microprocessor chip itself. There is no interface available between the monitor and the user except using lead or small lamps to indicate different status of leakage current on insulators and an audible sound alarm to indicate approaching flashover. See Fig. 4.

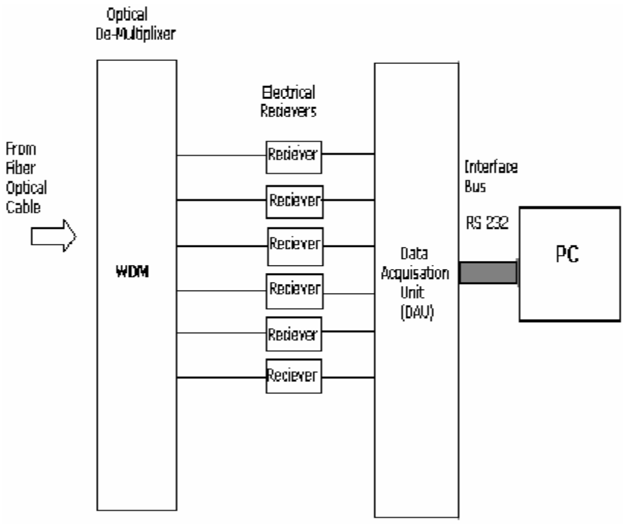


Fig. 4-a schematic proposed for the on line monitor hardware (from the receiving side)

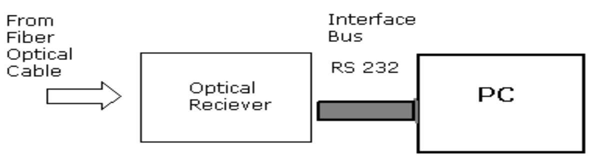


Fig. 4-b the second schematic proposed for the on line monitor hardware (From the receiving side).
Fig. 4 Monitor receiver and controller

All the components used in the installation site (high voltage side) are optical technology (i.e., sensors, links, multiplexers, cables) so there is no interference to the high electromagnetic or electrostatic fields in this side. Any metallic part in the monitor exists in the high voltage side must be shielded.

IV. MONITOR SOFTWARE METHODOLOGY

The monitor transmitter software presented in this paper is constructed of two artificial neural networks working in parallel as given in Fig. 5. Leakage current patterns are fed to the monitor to be normalized then entered to the first artificial neural network (ANN_1) to be classified according to its shape category. Three leakage current cycles' shapes are used to reflect the discharging activity on insulator surface [4, 14, 15], which are sinusoidal, nonlinear, and pulsating in order to indicate a surface completely covered by electrolyte, dry band formation, and existing partial arcs respectively. Samples of leakage current wave form experimentally recorded is given in Fig. 2. The leakage current pattern is divided into 21 inputs (i.e. each cycle sampled by 21 samples) and the output is classified into 3 categories depending on the leakage current condition. Since each pattern's shape is accompanied by specific harmonic content, the classification process of (ANN_1) achieves its targets from a spectral analysis done using Fast Fourier Transform (FFT) method.

The second artificial neural network (ANN_2) is designed for weather parameters required to be monitored by this technique. They are the temperature, relative humidity, rainfall precipitation, and wind speed and direction. These weather parameters are sensed each hour as mean records and saved to the data storage unit. The records required include the instantaneous and previous history hours' records. The inputs are 5 successive hours of the average records, which represent 25 weather parameters records. The weather parameters enter to the second artificial neural network (ANN_2) constructed and trained to classify the weather conditions responsible for flashover events on insulator surfaces in this region. The main classification process based its results on the weather records occurred during fault conditions in the installation site of the transmission lines insulators. The timing data of the monitor is extracted from more than 500 experimental tests carried out on 300 polluted insulators in the Laboratory and the reports of the Egyptian Electricity Transmission Company [1]. The methodology indicates sinusoidal (small current with no discharges), highly nonlinear (dry band formation or intermediate discharges), and pulses (severe discharges) when the outputs of (ANN_1) is 1, 2, and 3 respectively. Hence, assessment of the insulator surface condition is achieved from leakage current included information. The methodology indicated normal and bad weather responsible for insulator flashover in the region understudy when the output of (ANN_2) is 0 and 1 respectively. Hence, the assessment of the weather parameters affecting the insulators' flashover is achieved. An alarm indicating approaching flashover event is given when both networks are activated, especially when (ANN_1) indicated second or third target activation. Otherwise, no danger is concluded as the discharges are not notified or the weather parameters not helpful to the discharging continuity.

V. MONITOR ARTIFICIAL NEURAL NETWORKS STRUCTURE

The first neural network (ANN1) as given in Fig. (6-a) is considered as a classifier tool for leakage current cycles (patterns). Each leakage current pattern is considered a pattern of information with 21 inputs. The number of patterns used for training the neural networks is 660 patterns while 115 patterns are used for testing. The patterns of leakage current are extracted from the multiplexer, which in turn fed from a resistor connected with the insulator string as given in Fig. 3 or clip on transformer. The second neural network (ANN2) as given in Fig. 6-b is considered as a classifier tool for weather records. Each input pattern contains 25 information including temperature, rainfall precipitation, relative humidity, wind speed and wind direction for 5 successive hours. The number of patterns used for training the neural networks is 115 patterns while 65 patterns are used for testing. The patterns of weather are chosen according to real fault events timing on H.V.T.L [1].

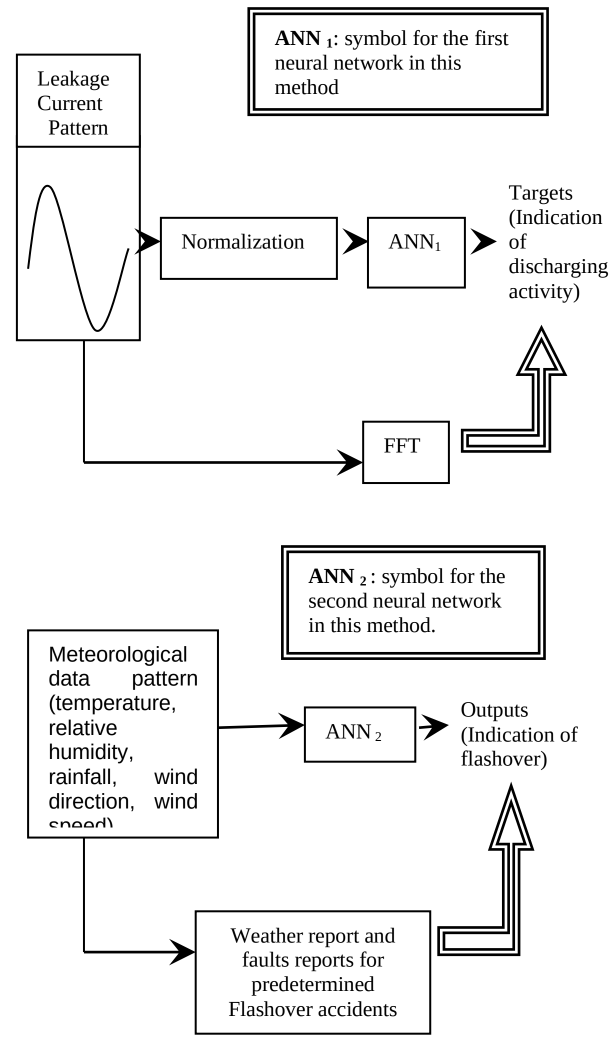


Fig. 5 Schematic diagrams for the new monitor

The construction process of the neural networks dealt with different designs of feed forward back propagation networks [31, 32], PNN [31, 32] and Rbe [31, 32] with different learning coefficient. The pairs of training data (i.e., the inputs and targets) are entered to all networks to perform the training process. The testing data inputs are entered to the trained structure. The testing patterns are completely different than the training patterns to achieve reliability of the network operation. The outputs of the network during the testing process are compared to the required outputs (targets) to measure its mean square error. The network which showed the least square error is chosen to represent the ANN1 and ANN2. The network ANN1 shows its least mean square error, which equals to 0.139 when radial basis neural network is used [16]. The network ANN2 shows its least mean square error, which equals to 0.1077 when feed forward back propagation neural network structure presented in Fig. (6-b) is used. The performance of the whole monitor is considered the performance of the two networks used. Therefore, the error of the monitor is 0.246. The monitor is tested on new data rather than that used for its training. Further improvement for the monitor reliability requires field tests for a longer time period.

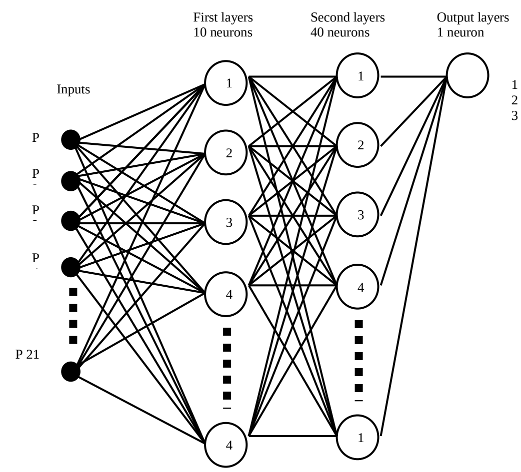


Fig. 6-a Structure of the first network (ANN1)

VI. MONITOR TESTING

In order to check the monitor performance and to decide the setting values of the monitor transmitter many tests are conducted on insulator strings. The tests are carried out using simulated condition of leakage current.

A. Leakage current

Leakage current pulses of polluted insulator string of 500 kV and 220 kV transmission lines, 25 µS and 20 µS surface layer conductivity respectively are used for testing the suggested monitor. Leakage current in ampere against time in mille seconds for Egyptian 500 kV transmission line insulators is given in Fig. 7 and for the polluted insulators of 220 kV network is given in Fig. 8.

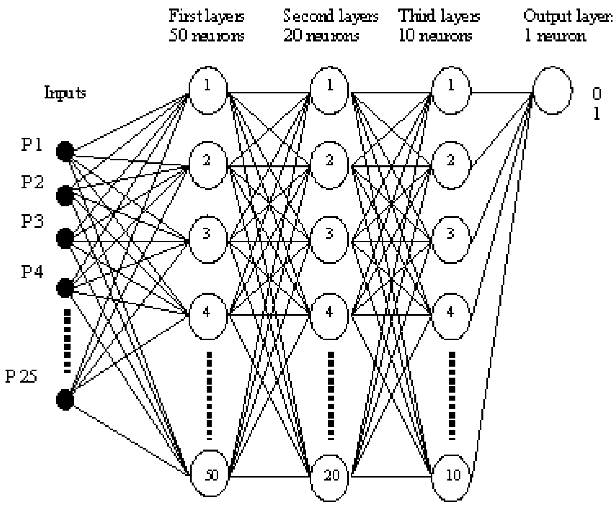


Fig. 6-b Structure of the second network (ANN2)

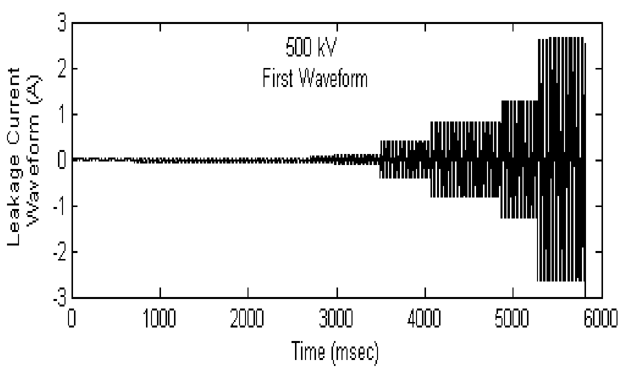


Fig. 7 Leakage current in Ampere against time in mille seconds records for the polluted insulators 500 kV, 25 µS conductivity

Each waveform gives a complete description of the external condition of the insulator surface from the instant of the voltage application to a complete polluted surface till complete flashover occurrence. The dry band formation and discharging activity levels are clearly appeared in the shape of each cycle. Spectral analysis to Figs 7 and 8 came up with the following deduction [١], which summarizes the severity of discharging into four groups:

1. Sinusoidal and small nonlinear deformed pattern in which the value of odd harmonics content is less than 20 %.
2. Highly nonlinear deformed pattern in which the value of odd harmonics content is between 20 % and 30 %.
3. Heavy (severe) discharges with transients leakage current pattern in which the value of odd harmonics content is greater than 30 % and the value of even harmonics content is greater than 5 %.
4. Heavy (severe) discharges with non-transients leakage current pattern whenever the value of odd harmonics content is greater than 30 % and the value of even harmonics content is less than 5%. Hence, the condition of the insulator surface can be asset by knowing the harmonics content in the leakage current cycles or its shape.

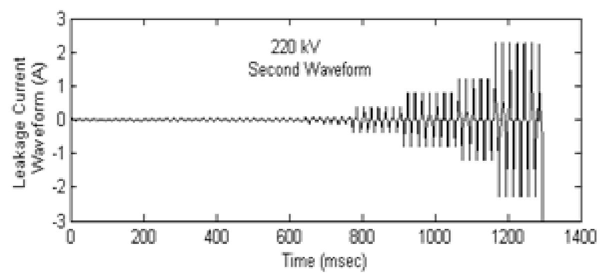


Fig. 8 Leakage current in Ampere against time in mille seconds for the polluted insulators 220 kV, 20 µS conductivity

B. Environmental Effects:

Adverse weather is one of the main factors that cause multiple trips in transmission lines especially near coasts. Surface flashover of insulators plays the main role in most of these trips since pollutants accumulation rate on the insulator surfaces accelerate during these conditions. Sometimes these trips extended to become a whole power outage event on the whole region, which is concerned with the transmitted power. Fig. 9 gives data profile for desert weather from the spring period in Egypt [١]. Table 3 gives the targets category and their significance for the artificial neural networks (ANN1 and ANN2) of the suggested monitor. As it is noticed in this table the combination of out puts of (ANN1 + ANN2) determines the final signal of monitoring alarm. An alarm signal in case of (2+1 or 3+1) will be sent to the maintenance team and will be recorded by PC unit. Monitor output (1+1) means stand by for insulator strings washing, while in monitor outputs (0+1, 2, 3) there is no alarm.

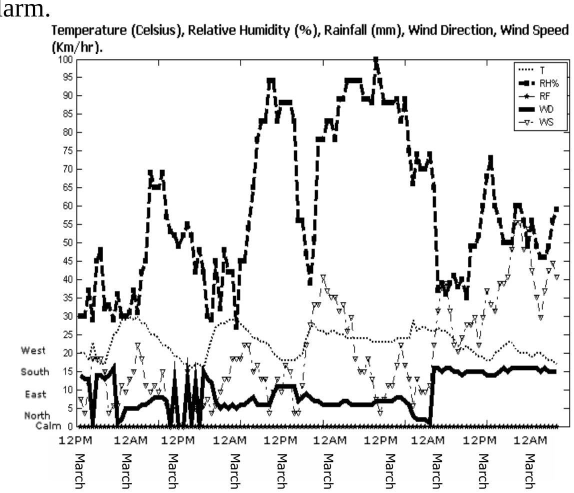


Fig. 9 Data profile for desert weather from the spring period in Egypt

VII. CONCLUSIONS

New monitor is presented in this paper to asset the condition of the polluted insulators of high voltage transmission lines and to predict flashover events earlier before being developed into a fault and sensed by protective relays. The online monitor builds its results on leakage current patterns and weather records. The artificial neural networks used in this monitor is constructed, trained and tested to leakage current patterns. The monitor shows a mean square error of 0.246 during testing. Modification of the online monitor is needed for future work achievements to be wireless system.

TABLE 2 TARGETS CATEGORY AND THEIR SIGNIFICANCE FOR THE METHOD

Outputs ANN 1	Outputs ANN 2	Significance	Alarm
1	0	Sinusoidal / Small nonlinear Normal weather	No
2	0	Highly nonlinear Normal weather	No
3	0	Severe discharges Normal weather (No approaching flashover)	No
1	1	Sinusoidal/Small nonlinear Bad weather	Standby
2	1	Highly nonlinear Bad weather	Yes

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