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On-Line Wireless PD Monitoring System for Contamination Detection on High Voltage Overhead Transmission Lines Insulators

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SUMMARY

In the age of Smart Grid, the use of new monitoring sensors in transmission networks, has become vital from a techno-economical perspective. Contaminated insulators in polluted areas may lead to flashovers and outages if they are not cleaned periodically. Resulting voltage sags and interruptions to the supply voltage, can cause considerable loss of capital to industry and penalties to electric utility companies, as there are numerous industries that depend upon the availability of an uninterrupted power supply. Leakage current measurements have been used in the past to predict flashovers over insulators, and Partial Discharge (PD) detection and measurements with corona day-light cameras are now in development and use. This paper evaluates the feasibility of using an online wireless PD sensing system and online wireless sensor network for predicting flashovers over insulator strings of high voltage transmission lines. The paper describes practical considerations concerning the installation, maintenance and functionality of wireless PD sensor systems, discusses the economical benefits of using such a system, and provides results from a field trial of monitoring ceramic isolator strings over 400kV and 161kV transmission lines.

KEYWORDS

Monitoring sensors in transmission networks, Techno-economical point of view, contaminated insulators, Partial Discharge (PD) detection and measurements, Assessment of the condition of line components, Improvement of tools and methods for assessment, Cost effective asset management.

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1. Introduction

The issues concerning determination of the level of contamination of power transmission lines have been studied in different research centers and energy systems for over 50 years. Due to concerns about severe environmental pollution, this issue is still of interest today. When the contamination of insulators is combined with other factors (the most important of which is the insulators' surface wetting), in some cases this may cause flashovers and thus short circuits on the lines. The physical effects which produce the short circuit have been well-studied, but to date no reliable and cost effective device for determining the risk of flashover due to contamination on existing transmission lines has been developed.

The leakage currents measurement method for determining the contamination level of insulators has several shortcomings, which prevent its widespread utilization on transmission lines:

- Leakage currents are correlated with the level of contamination only when the relative humidity exceeds 85%.
- An analysis of contamination requires installation and measurement of sensors on each insulator string.

The non-recurring measurement of contamination by corona method has low reliability and incurs considerable financial costs.

The hereby proposed method is based on the flashover risk due to the combination of contamination and other meteorological factors and not on determining contamination of insulators. In areas where intense and regular rain occurs, the insulation is cleaned by itself. In areas where rains are scarce and no self-cleaning occurs, insulators need to be washed. The developed method allows one to set up continuous monitoring of flashover level risk due to contamination, and to determine when washing is necessary.

2. Justification for the method

On overhead lines located near the sea insulation contamination, is caused by the presence of industrial by-products, agricultural activities, exhaust gases, sandstorms, fog, salty water droplets etc.. The contamination of insulators is not uniform: it depends on the shape of the insulators. At locations where the insulators have edges the contamination is maximal; on smooth surfaces it is minimal. When insulators become wet due to fog, rain or dew, the salts in the contaminator are dissolved, and the conductivity of the insulator surface rises sharply. The magnitude of the conductivity depends on the level of contamination, as well as on the wetting of the insulator. A current that passes along the surface of the wet and contaminated insulator reaches hundreds of mA. Since the insulator's surface area is not even due to edges presence along the string, the current density along the string is also not uniform. As a result, different areas of the insulator heat up differently. At locations where the current density is maximal, distinct patches around the circumference of the insulator become dry, and the resistance of these patches increases considerably. The voltage drop on such a patch increases, up to the value at which a breakdown of the air gap occurs. Thus, an electrical arc (discharge) is formed, shunting the dried insulator patch. Then the current passes along the surface of the insulators, drying the water drops, and the arc is extinguished. The dried surface becomes humid again and the process repeats itself. The resulting arc may develop on any area in the

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string, and it may cover one or several insulators, depending on the contamination level and the amount of wetting (moisture/humidity).

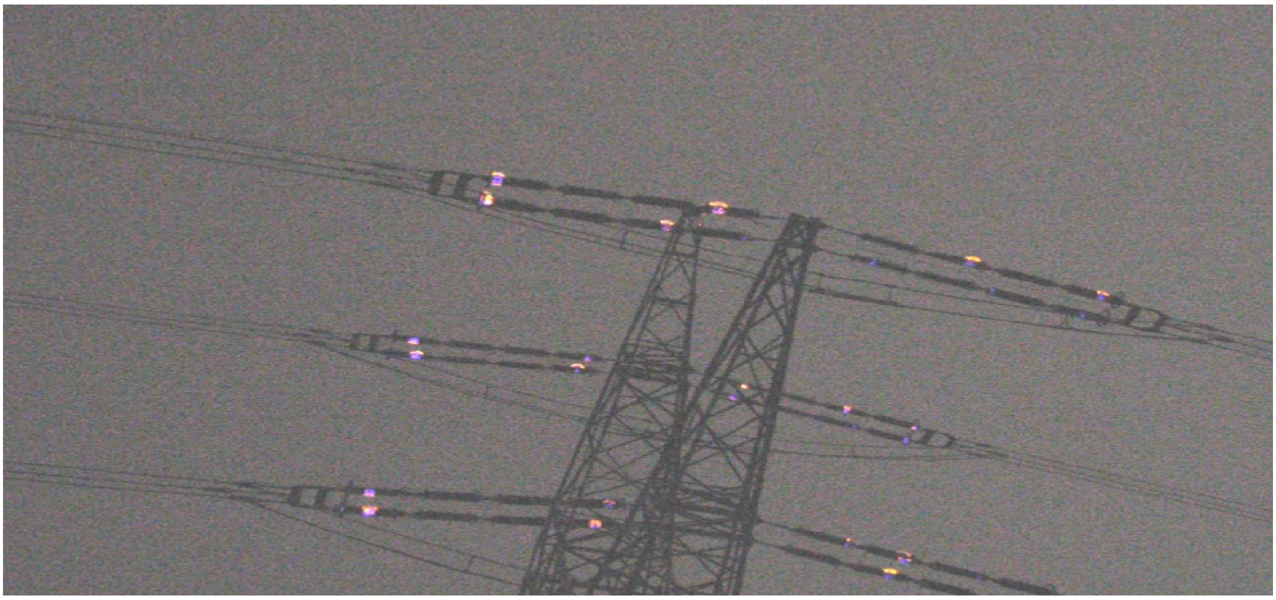

Fig. 1. Discharge on polluted insulators of a 400 kV line.

Fig. 2. Discharge on polluted insulators of a 160 kV line.

Figures 1 and 2 show such discharge over 400 kV and 160 kV insulators. Such discharge does not interrupt the normal operation of the power transmission line. In cases of severe contamination of the insulator, in the presence of high air humidity, the arcs start to cover considerable parts of the insulator surface (Fig. 3).

In this process the leakage current on the surface of the insulator increases and the resistance of the arcs decreases. This causes a further increase in current and eventually may cause an insulator flashover.

The arc lengths may vary from a few mm to tens of cm. The speed of the arc head progression is 50 m/sec and higher. This results in pulses with amplitudes that reach tens of kV, with a front of between tens of nanoseconds to several microseconds. The consequence of these pulses is acoustic noise, visible light and electric interference in a spectrum of up to hundreds

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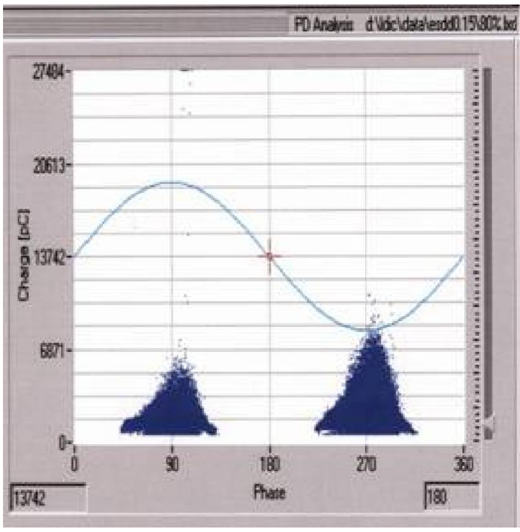
of MHz. The quantitative parameters of each of these effects depend on the combination of many factors: the contamination of the insulators, air humidity, the wind force and direction, the temperature gradient, etc.

Fig. 3.



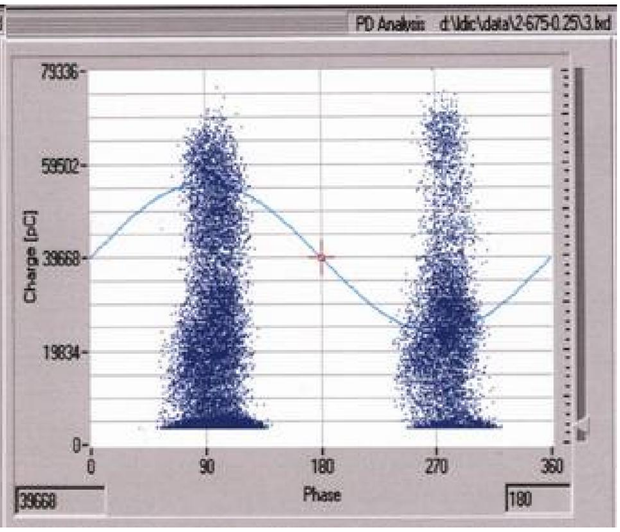


Fig. 4. ESDD 0.05 H=80%

Fig. 5. ESDD 0.15 H=80%

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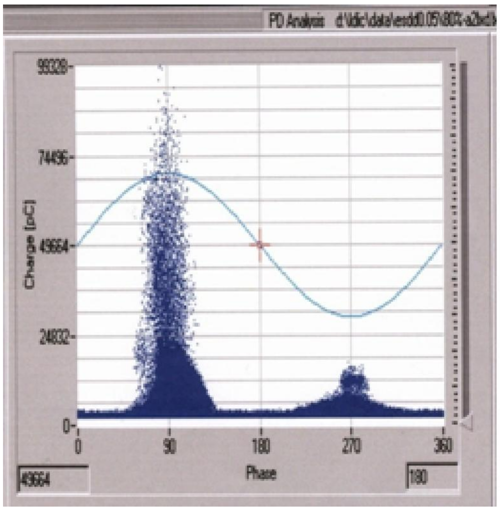

Fig. 6. ESDD 0.25 H=80%

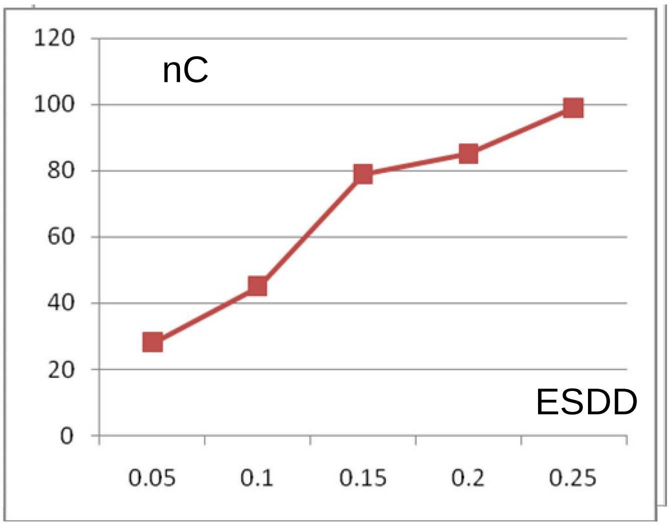

Fig.7. H=const=80%

Figures 4, 5, 6 show the results of measurements of partial discharge on the surface of ceramic insulators. These measurements were conducted in a special chamber, where air wetting was automatically maintained at a given level of 70 to 100%. More than 100 tests were conducted under these conditions, with ceramic and non-ceramic insulators (NCI), with polluted insulators removed from 160 kV and 400 kV OH transmission lines in the presence of artificial contamination. In all the tests, synchronic measurements were made for the following parameters:

- Humidity of the ambient environment: it was maintained constant during the test;
- Temperature of the ambient environment;
- Atmospheric pressure;
- Leakage currents along the insulator's surface: a current transformer with a frequency band of 0-100000 Hz was used for this purpose;
- Partial Discharges (pC);
- Pulse Amplitude: special sensors with a frequency range of 0.01-100 MHz were used;
- Number of pulses with different amplitudes during a pre-set period of time;
- Lengths of insulator segments, which are covered by partial discharge pulses: special photography was used.

The results after data processing show that all the measured values (leakage currents, pulse amplitudes, partial discharges, number of pulses and the length of the flashed-over insulator segment) behave similarly to the graphs in Fig. 7. These values increase with the air humidity or with the increase of insulator contamination, under constant humidity conditions.
However, the reproducibility of the contamination tests was low. Determination of insulator contamination level based on accurate measurement of leakage currents, partial discharge pulses, acoustic noises or corona brightness, seems not to be practical even under laboratory conditions. Carrying this out on actual transmission lines could not be realistically possible.

From a practical aspect, there isn't much significance to the level of contamination *per se* – a flash-over risk cannot be predicted according to this abstract notion. What is significant is the flashover risk due to this contamination. The insulator flashover risk level may be determined by measuring the amplitude of partial discharge pulses on the insulators surfaces and observing which part of the string is flashed-over. When 20% of the insulator length is

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flashed-over, under any random effect, a flash-over of the entire insulator is possible. The maximal value of pulse amplitude for the superficial partial discharges (considering humidity and other external factors) is correlated with the insulator contamination, starting from 75-80% of ambient humidity level.

Due to the large number of factors affecting the measurement results for existing transmission lines, reliable data can only be obtained after statistical processing of long-term measurements. It is important to note that the amplitude of pulses which governs the level of flashover risk would be different for lines of different voltage ratings and even for lines of the same class with different types of insulators.

The insulators surface pulses generate electromagnetic pulses which propagate - by various means through the ambient space. Current pulses in phase conductors, in overhead ground conductor and in overhead transmission lines supports, are generated. The dependence between the amplitude of the current pulse in lightning arresters and the amplitude of the current developed on the insulators is practically constant in time. Therefore, by measuring the pulses in the lightning arresters and at the same time, observing which part of the insulator is flashed-over by the partial discharge arcs, one may determine the amplitude of the pulses in the lightning arrester for which insulator flashover is possible.

3. Method of measurement

The sensor that measures the amplitude of the pulses is set on the shield wire, as shown in Figure 8. The frequency range of the sensor is 0.1-100 MHz.

Fig. 8. Installation of the Sensor on the Shield wire

The signal from the sensor, enters a specially designed data acquisition unit, filtered by band path filters, analyzed, and transmitted through a modem to the O&M center, where the information is processed by statistical methods. The measurement takes place 8 times a day.

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The sampling and analysis duration of each session is 5 minutes. During this period, 300 samples are taken and the maximal pulse amplitude in each second is measured. The dynamic range of the measurements is divided into 32 equal levels from 0.7 to 32.7 V. Thus, from the measurements we obtain a set of pulses with amplitude that corresponds to the level in which they were measured.

4. Field deployment and results

IEC and Metrycom joined efforts to develop a new monitoring system based on detecting (measuring) electrical signals from partial discharges on insulators and transferring the data to a collecting system and analyzing them to determine the pollution condition of the insulators. Maintenance-free wireless sensor-units were developed for installation on the grid's pylons. The sensor units make the measurements, and send the data to a control server. The information is then transmitted to the maintenance departments responsible for flushing insulator chains, assisting them to perform the insulator cleaning operations at the right time and at the required quality.

The objectives of the system are as follows:

1. To provide the maintenance teams real-time information about transmission line segments that are at high risk to develop flashovers.
2. To considerably reduce short-circuits and power sags resulting from contamination over insulators, and consequently reduce related losses to industry.
3. To reduce insulator-washing costs, by optimizing the cleaning times and the choice of transmission-line segments to be cleaned
4. To provide direct online status of insulator contamination, including immediate feedback about the affectivity of each washing operation.

Figure 9 illustrates the block diagram of the system:

Sensor units are located on the transmission towers for measuring high frequency signals generated by partial discharges (PD) over contaminated insulator strings. The power consumption of the sensor units is extremely low, allowing them to operate for 10 to 20 years without needing to change batteries. Each sensor unit includes a low-power wireless modem, which can communicate with multiple adjacent sensor units, thus creating a mesh IP sensor network. Data measured by any sensor unit is routed from sensor to sensor along the transmission line until it reaches the gateway, which is usually located at the substation. The network is self-healing, and if a sensor unit is destroyed, the other sensor units find new routing, e.g. through a more distant neighboring sensor unit.

The gateway then sends the data which was received from the sensor units to a control server, which stores all the data, converts it to information in a comprehensible format, and sends the information to all users of the system.

The information is sent to the regional/geographic maintenance department responsible for flushing insulator chains.

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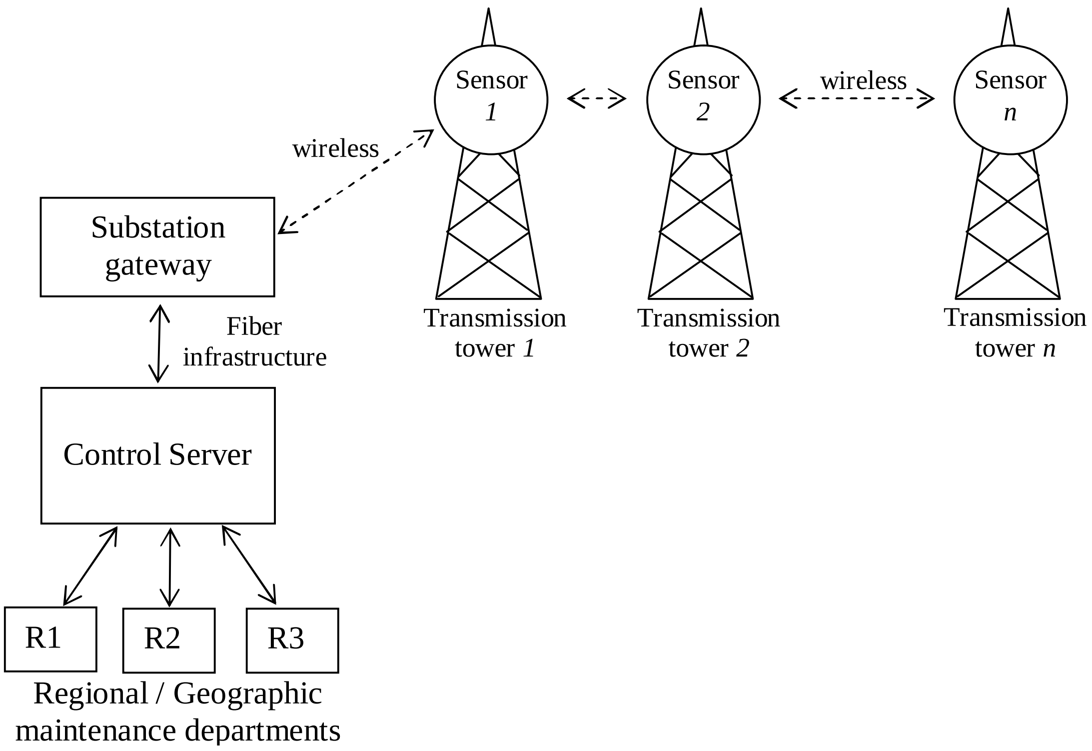

Figure 9 : A block diagram of the monitoring system

The wireless sensor units use IP mesh-radio protocols which are based on new internet standards (6LoWPAN [2], RPL [3]). Implementing internet protocols on sensors, meters and other smart objects extends the internet to billions of new wireless instrumentation devices, creating the concept “the internet of things”.

5. Results:

The system was deployed on selected 160kV and 400kV lines in Israel. An example of measurements conducted on one 160 kV line in the Israeli Power Network in the south of Israel (near Beer-Sheva) is shown in Fig. 10. From the results of preliminary measurements, it was found that for pulse amplitudes which exceed 3.5 V, considerable insulator contamination is present, and for pulse amplitudes exceeding 6.5 V, flashover of the insulation is possible. In this case, it is recommended to wash the insulators. The figures show that in September 2011 the insulators were severely contaminated, but it was not necessary to wash them. In mid December 2011, after rain fell, the insulators were naturally washed, and impulse level dropped almost to zero (not shown in figure 10. The periodic changes in the measurements were due to the day-night cycle (3 measurements made at night, where PD pulses were maximal due to the high humidity, and 4 measurements during the day, where PD was almost zero because of the low humidity). Since the system provides online daily information, the user can get a complete picture of the level of the PD pulses under different humidity conditions, based on many days’ measurements.

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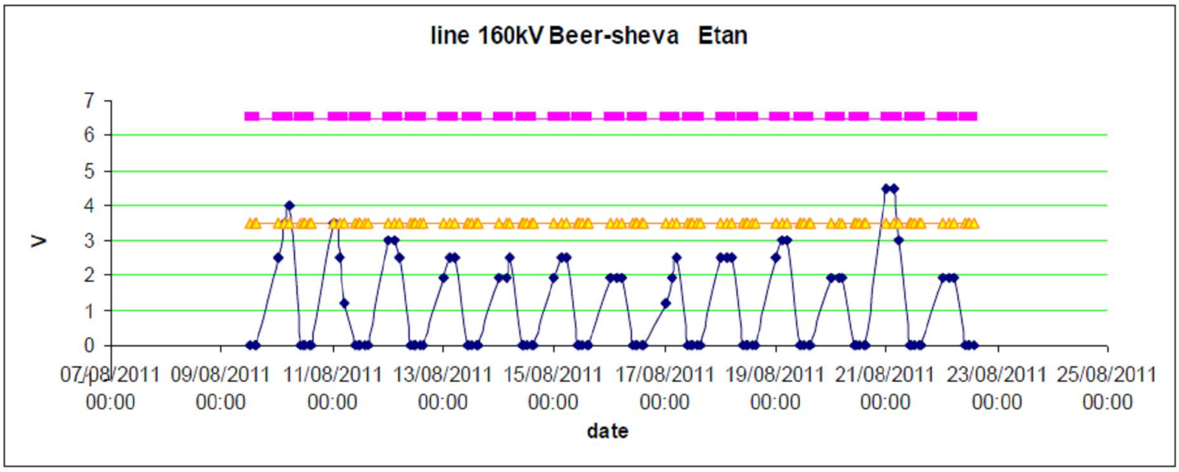

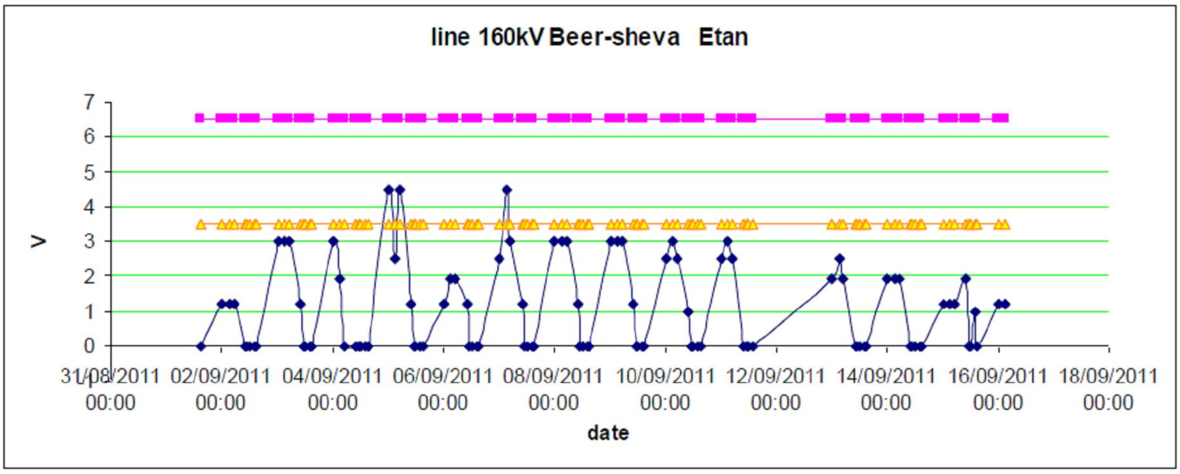

Fig. 10: Beer-Sheva Sensor results in August and September. The insulators were polluted, but the measurements were in the “Green” and “yellow” level, but did not cross the “red” level. Washing was therefore not required**.**

6. Conclusion

From analysis of the measurement results it is possible to determine the washing necessity of insulators. Spectral analysis of the pulses allows the determination of the short circuit risk level using a single sensor. This sensor can monitor several adjacent supports.

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