Using Leakage Current Monitoring Instruments for Pollution Monitoring on Overhead Lines

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1. Background

Israel Electric is facing many special problems that make it different from most other utilities. While located in a sub-tropical as well as desert environment often associated with many developing countries, IE is expected to supply electricity which meet reliability indexes typical for most of the industrialized world. At the same time, while operating in a climate often associated with numerous problems which affect insulator performance, the utility needs to keep under tight control the maintenance costs, in the face of the high wages typical for a developed country.

Among the results of confronting these apparently contradictory goals was the strategic decision to switch to exclusive use of composite insulators for all the new overhead lines. As a result of this decision, already in 2003 the percentage of lines equipped with SR composite insulators was above 50% for 400 kV lines and 25% for 161 kV lines.

Another important step adopted for solving the above problems was to rationalize the maintenance of the ceramic insulators by introducing in use a pollution monitoring system based on the measurements of leakage currents on network porcelain insulators. The presentation of this system is the subject of the following paper.

2. Probability of line failure due to insulator pollution

As all the insulators of one phase of a line are connected in parallel,

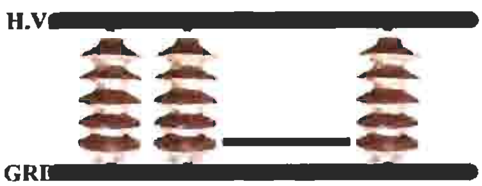


Fig. 1: The connection between the insulators of a line

a flashover on one insulator of any phase will produce a failure for the whole line (a transient failure, in most of the cases). Besides the transient failure on the line to which the insulator belongs, this transient power failure will be felt along the network as a voltage dip which might affect sensitive production processes, as in the glass or plastic industries, computer chip production, etc.

The probability of having a power failure due to a flashover of one of the insulators of the line – supposing that all of them have the same risk of flashover - is given by formula (1):

$$Q = 1 - (1 - q)^N \qquad (1)$$

where:

q – the probability of flashover of one insulator;
N – number of insulators on line;
Q – probability to have one flashover on the line.

Example: On a line of 80 km length, with 3 towers/km there are about 1,000 insulators. The relation between the probability of flashover on each insulator and the probability of a transient failure of the line for several situations, calculated with the above formula, is given on table 1:

Table 1: Relation between the reliability of insulators and the reliability of the whole line

Flashover probability for each insulator	Failure probability for the line
1%	0.99996
0.1%	0.632
0.05%	0.3935

3. **Maintenance of insulators**

3.1. Washing technique

The most common maintenance method used for reducing the risk of flashover is washing the insulators. The washing is performed from tracks or from helicopters. The aim of the washing is to remove the pollution from the insulators by using a high pressure stream of water. Usually, the washing procedure requires that the cleaning has to be done from only one direction of the water gun in report to the insulator. If the water pressure, or the distance between the nozzle and the insulator, or the nozzle diameter are not in the right range, the washing is inefficient and might be even dangerous, in case the pollution is moved by the water jet to the opposite side of the insulator, creating an area where the pollution is much more concentrated than it was before the washing. For an insulator to flashover a single conductive path is enough, and an insulator cleaned on 355^0 and very dirty on 5^0 might be much closer to flashover than an un-washed one (see fig. 2).

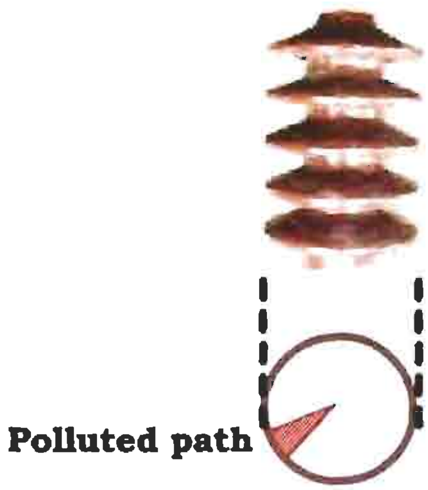


Fig. 2: The importance of pollution distribution on insulator surface

3.2. Planned maintenance

The planned maintenance of insulators is characterized by the existence of a fix timetable for washing. Common rules of planned maintenance are:

- All the insulators of the line are washed at the same rate;
- The rate at which the insulators of a line are washed is dictated by the most polluted segment of the line;
- There is no difference in the washing rate of insulators with different profiles, even if they might perform differently under pollution.

The main drawbacks of this approach are:

- It's very expensive (because it's excessive);
- It's inefficient, because too many towers have to be washed with too few washing tools (helicopters and trucks) and in a very short time interval;
- There is no tool to control the quality of the washing.

3.3. Predictive maintenance

The principle of the predictive maintenance is to perform the maintenance only **when** and **if** the need is detected. There are several arguments for adopting such a method for the maintenance of the insulators:

- The big expenses done for washing periodically the insulators are often obliterated by flashovers and usually it's difficult to evaluate if the cause was an un-efficient washing or a sudden and massive depositing of pollution;
- The pollution level on insulators is most influenced by climatic factors, which can vary a lot from region to region and by the profile of the insulators, which can also be different along the lines;
- The risk of flashover – which is a factor different and more important for maintenance than the pollution level – vary from one type of insulator to another, under the same pollution conditions.

The implementing of this kind of maintenance implies the use of a method for on-line monitoring of the risk of flashover and this method can be used in the same time as a tool for controlling the quality of washing.

This monitoring tool is the Leakage Current Monitoring System. It was developed for Israel Electric and after an experimental stage, it became operational this year.

4. LCM equipment

4.1. Pre-requisite requirements and their solutions

Continuous measurements of leakage current can became a reliable indication about the risk of flashover if 3 main conditions are fulfilled:

- There is enough humidity in the air during many days of the year, in order to permit the detection in time of pollution built-up process through measurements of leakage currents on insulators;
- The measuring equipment is reliable enough to permit continuous and independent functioning when installed on network tower lines;
- The communication equipment and software of the monitoring system keeps all the instruments reliably linked with the central unit.

4.1.1. Humidity of the air

As a result of several years of experience with the LCM System, it was found that in order for the pollution to become conductive, a minimum level of the relative humidity is needed. This minimum level – for most types of pollution – is 75%. If the pollution is very soluble or very conductive, lower values of RH are needed for making it conductive. In fig. 3 it can be seen that the leakage current measured in an agricultural area increases substantially only when the relative humidity equals or exceeds the level of 75%. From the checking of the situation in other areas of Israel, it was found that in most of them the RH by night rises frequently to values in the range 70-85%. This finding was crucial for deciding to use continuous measurements of leakage current as indicator of pollution level and more specifically, as indicators of flashover risk.

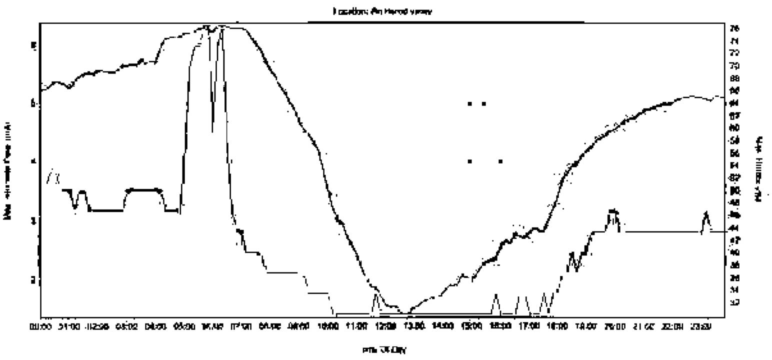


Fig.3: RH and leakage current recordings, as measured in September 2005, in Ein Harod (inland, agricultural area)

4.1.2. Reliability of the LCM equipment

The LCM system installed in Israel Electric network is composed of 12 operational instruments (see their components in fig.4, 5). Most of these instruments are installed on towers of HV and EHV lines and are powered from batteries charged by solar panels. The batteries are exchanged once in two years and the solar panels have to be cleaned once a year. The data transfer is made through cellular modems; once a day the central computer addresses automatically each instrument and downloads from it a file of about 30KB. The outdoor temperature is close to the maximum working temperature of the instruments (about 50°C) and in order to cope with this problem, on each instrument was installed a fan for circulating the air warmed by the electronic circuit.

The main reliability problems encountered were:

- Theft of batteries and solar panels;
- Power supply shortages due to the dust which covered the solar panels or the batteries end of life.

Fig.4: The components of a LCM test station (1)

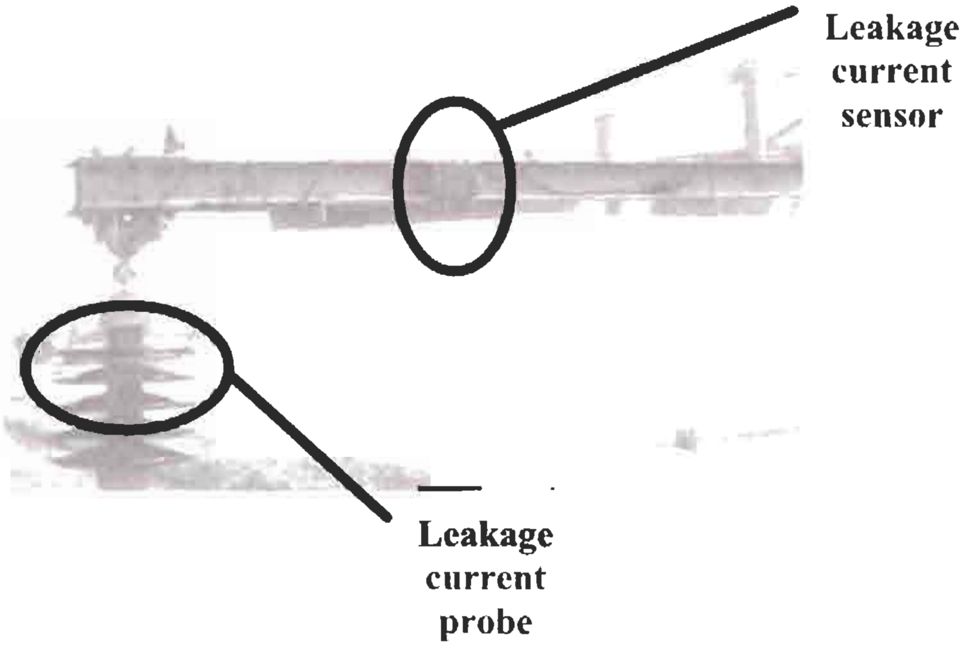


Fig.5: The components of a LCM test station (2)

5. Pollution monitoring reports

The process of gathering information about the leakage currents and meteorological parameters in specific locations in the network evolved at IE for the last 4 years. In the first stage, the measurements were done mainly for learning about the correlation between leakage currents, relative humidity and risk of flashover evolution depending on season and geographical area. As a result of this work, a first set of reference values was defined, see table no.2.

Table 2: Reference values for defining the risk of flashover on porcelain insulators

Warning level	Risk of flashover	RH [%]	Leakage current [mA]	Recommendation for washing
Green	Light	50-70	< 25	No need
Yellow	Medium	≤ 75	25 - 150	Wash, but not urgent
Orange	Heavy	Doesn't matter	150 - 300	Wash in a week
Red	Immediate risk of flashover	Doesn't matter	> 300	Maybe it's too late

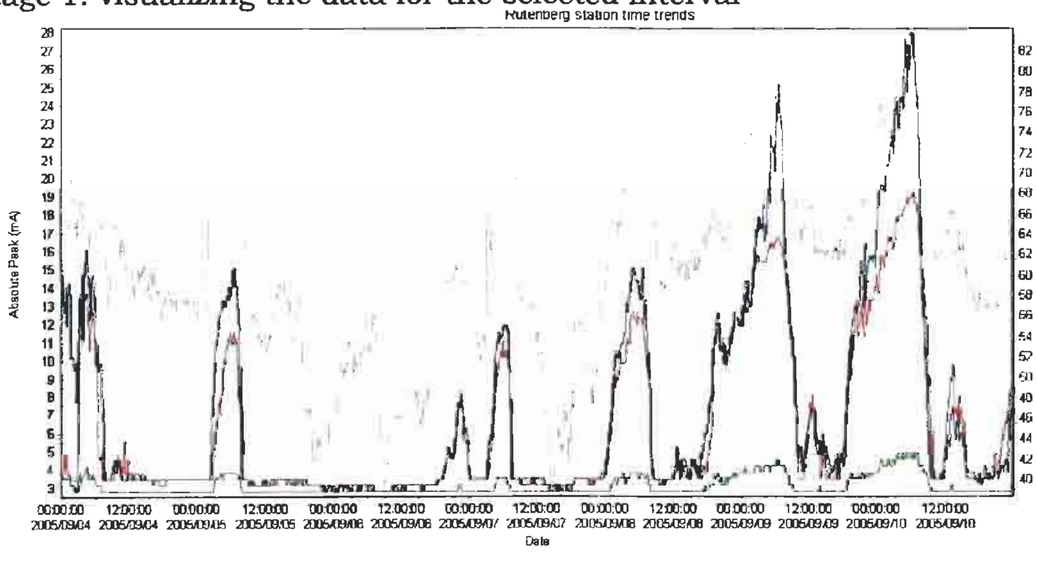
Note: The values in this table do not cover all the situations which can be met in reality. The classification of different situations has to be done taking into consideration supplementary information, see explanations further on.

Beginning this year, the online measurements are used for issuing weekly reports for the regional maintenance departments with information about the estimated risk of flashover, recommendation about the need to wash the insulators and the limits of the area for which these reports are representative.

A summary presentation of the stages of preparing a weekly report for one location – Rutenberg test station, is presented bellow.

Rutenberg test station, 4-10.09.05

Stage 1: visualizing the data for the selected interval



Stage 2: issuing a draft detailed 7 days report

Date	4.9.05	5.9.05	6.9.05	7.9.05	8.9.05	9.9.05	10.9.05
I_{max} [mA]	16	15	8	12	15	25	28
RH [%]	65	73	63	72	69	83	83
Time	Always by night, between 22:30 – 6:30						

Stage 3: issuing the weekly report

I_{max} [mA]	**RH** corresponding to I_{max} **[%]**	**Area represented**	**Warning level and washing recommendation**
28	83	4 km width seashore area, between power stations Rutenberg and Eshkol	No need of wash in the foreseeable future

The definition of the alarm levels and washing recommendations for cases not covered in the reference Table 2 is done taking into consideration an array of factors:

- The correlated values of I_{max} and RH recorded during critical pollution intervals in the location of the monitoring station;
- The type of pollution in the monitored area;
- The profile of insulators on which the monitoring was done;
- Other types of insulators used in the same monitored area;
- Local climatic patterns;
- Time needed for the maintenance teams to react to a warning.

The factors influencing the comportment of insulators are numerous and moderate changes in only one or two of them are sometimes enough for bringing it close to flashover. The time needed for the insulators to change their risk of flashover situation depends of local climatic conditions and on their geometry. One practical example is the case of 3 monitoring stations installed along a 400kV line. In fig.6 are presented the maximum values of RH, as recorded by each of these stations during one summer month. It can be seen that the highest values are represented by the violet line, which shows the measurements recorded by test station Rutenberg. As this location is closed to the sea, the pollution here is mainly salt, which is highly conductive and very soluble. These considerations determined us to define this station as the most sensible for this line and in certain conditions dangerous levels of leakage currents recorded here can trigger an alarm for washing larger portions of the line.

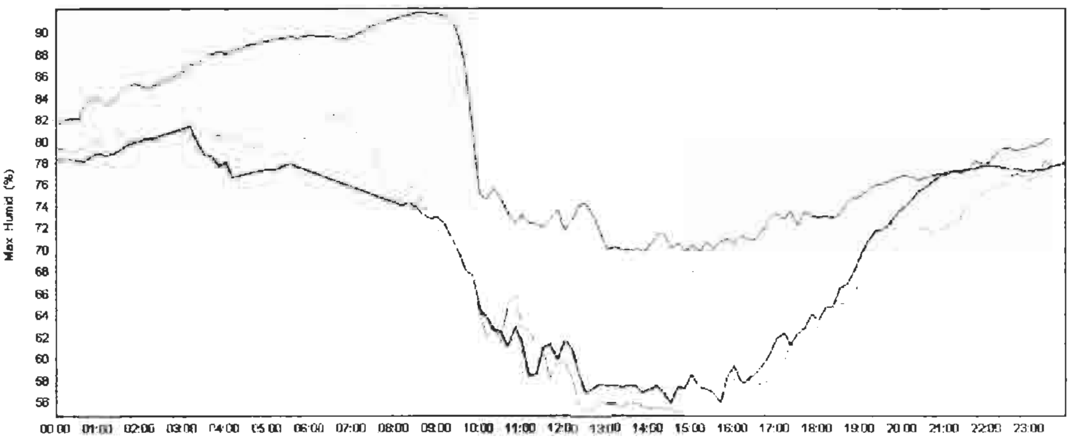


Fig. 6: relative humidity, max. values, daily trends for one month, as recorded by 3 monitoring stations located along a 400 kV line

6. Evaluation of the reports

The evaluation of the above reports can be done by quantifying the following factors:

- The cost of the monitoring equipment and it's maintenance;
- The yearly reduction achieved in the number of flashovers recorded;
- The yearly reduction achieved in the cost of washings.

In the LCM system in use at IE, each monitoring station covers an area in which there are 40 up to 150 double circuit HV and EHV towers. The number of insulator strings on these towers is between 320 and 1200.
Considering the typical maintenance costs for using helicopters, it can be easily concluded that by saving one washing yearly and by not increasing the number of flashovers, the cost of the LCM system is returned in not more than two years.

7. Conclusions

1. The task of keeping the lines crossing polluted areas free of flashover by washing the insulators is difficult to accomplish. IE experience shows that the use of Silicone Rubber insulators proved to be a better solution, at least for sub-tropical and desert environments.
2. The success in using leakage current monitoring instruments for receiving on-line information about the insulator's risk of flashover is dependent on the existence of frequent high levels of air humidity.
3. The LCM system can be used also as a tool for checking the efficiency of insulator washing.
4. Based on the information supplied by the LCM system and also on information about insulator's parameters and climatic parameters, a scale of flashover risk levels was defined.
5. Preliminary calculations shows that if the use of LCM system succeeds in eliminating one washing per year in the surveyed area, the investment with this equipment is returned in not more than 2 years.