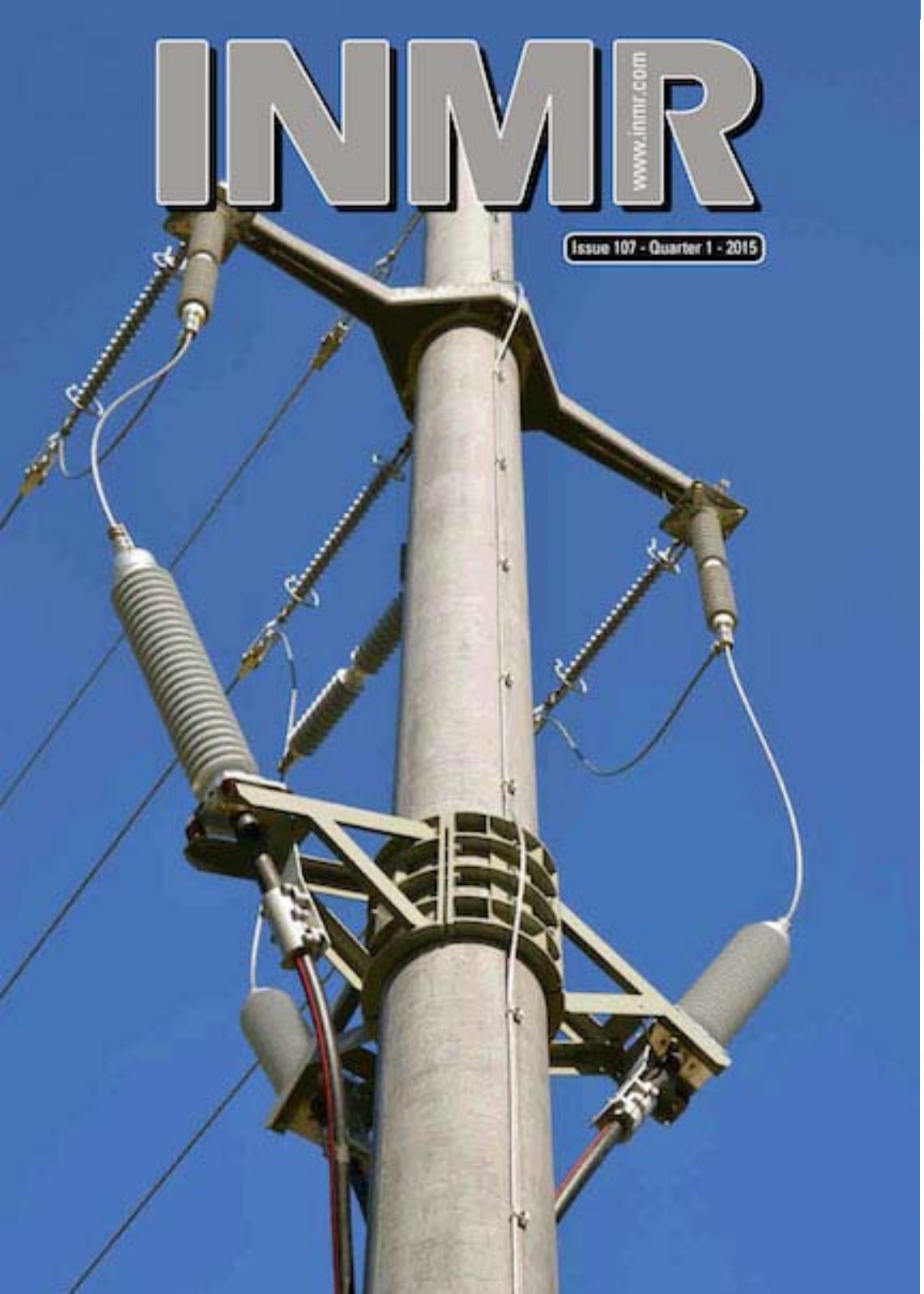
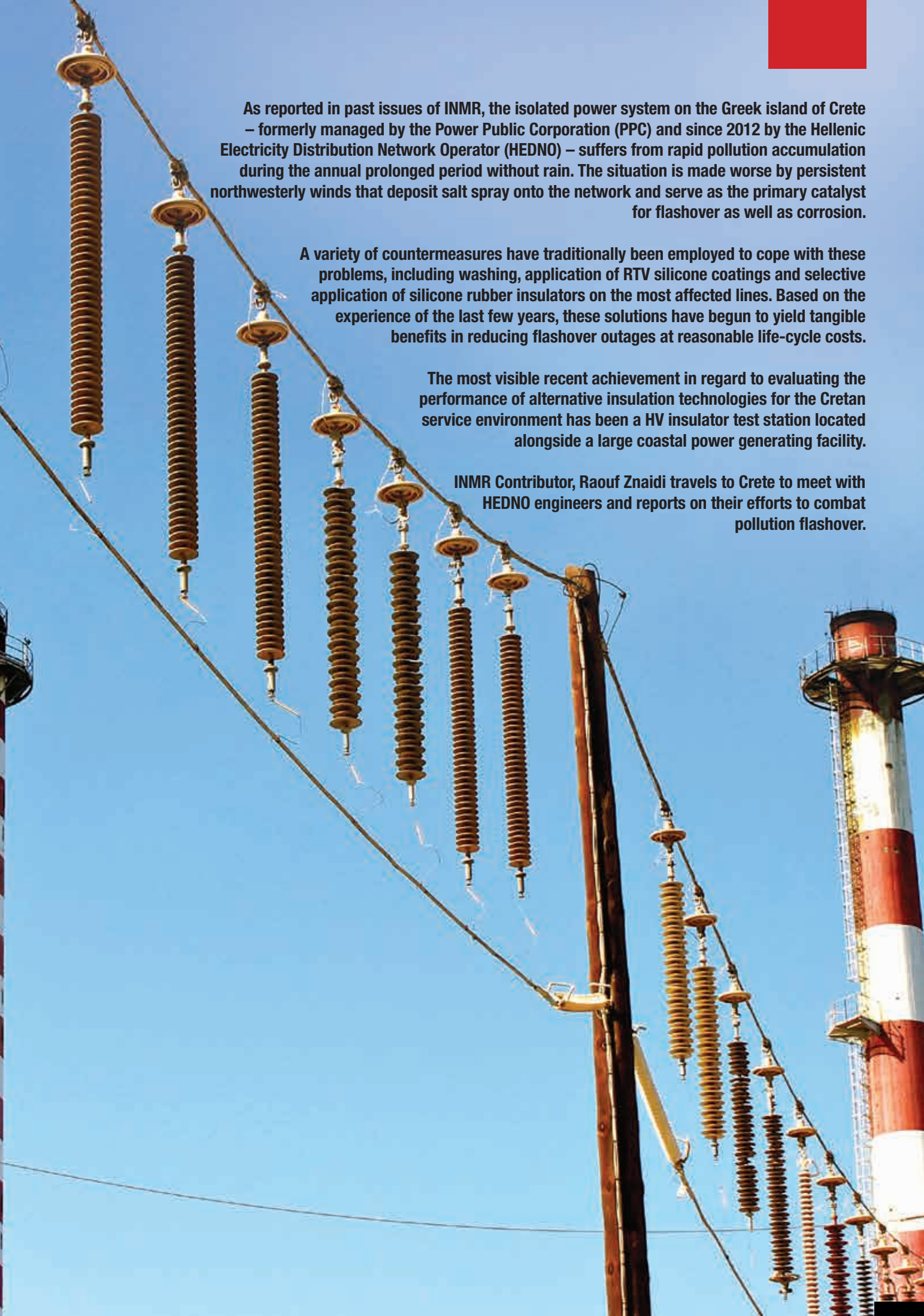


Expanded Test Station Helps Greek Power System Operator Assess Insulator Design & Performance



As reported in past issues of INMR, the isolated power system on the Greek island of Crete – formerly managed by the Power Public Corporation (PPC) and since 2012 by the Hellenic Electricity Distribution Network Operator (HEDNO) – suffers from rapid pollution accumulation during the annual prolonged period without rain. The situation is made worse by persistent northwesterly winds that deposit salt spray onto the network and serve as the primary catalyst for flashover as well as corrosion.

A variety of countermeasures have traditionally been employed to cope with these problems, including washing, application of RTV silicone coatings and selective application of silicone rubber insulators on the most affected lines. Based on the experience of the last few years, these solutions have begun to yield tangible benefits in reducing flashover outages at reasonable life-cycle costs.

The most visible recent achievement in regard to evaluating the performance of alternative insulation technologies for the Cretan service environment has been a HV insulator test station located alongside a large coastal power generating facility.

INMR Contributor, Raouf Znaidi travels to Crete to meet with HEDNO engineers and reports on their efforts to combat pollution flashover.

Fig. 1: Typical distances from the coast of power infrastructure on Crete.

The HEDNO power system on Crete is the largest fully autonomous system in Greece, comprised of some 585 km of 150 kV lines as well as 18 substations. Most of this system runs close to the coast due to the geography of the island, which is 260 km long but never more than 60 km wide.

The annual dry season starts in April and lasts until the end of October. Over these months, there is steady accumulation of pollution – mostly salt mixed with industrial and agricultural pollutants – that deposit onto insulators and become wetted by high humidity, dew and salt spray from the surrounding Mediterranean. The combination of contamination build-up and rapid onset of wetting often result in pollution flashovers on the most exposed lines. For example, some of the worst years, such as 1985, saw up to 25 outages recorded per 100 km/year – a level that dealt a serious blow to the island's important tourist industry. Table 1 shows the number of outages due to flashover of contaminated insulators and highlights the especially severe pollution affecting northern Crete, where one key line – Linoperamata to Agios Nikolaos to Ierapetra – alone experienced a total of 117 flashover outages since 1994.

HEDNO consultant, Dionisios Pylarinos, has been investigating this problem for years and reports that the unusually high level of outages on the line running from Linoperamata to Ierapetra is due to severe pollution along the route made worse by the fact that it is also the island's longest double circuit 150 kV line. Says Pylarinos, "the eastern portion of Crete is more affected by flashover outages due to the impact of salt spray depositing on insulation and this line runs especially close to the sea". Fig. 1 illustrates typical distances between the Cretan transmission network and the coast.

Another problem related to the continuous salt spray as well as frequent wetting from high summertime humidity is corrosion that affects a range of vulnerable components and structures, from

Table 1: Outages Affecting Key Lines on Crete 1994 to 2013

Chania-Kasteli	2
Linoperamata-Chania	41
Linoperamata-Agios Nikolaos-Ierapetra	117
Linoperamata-Mires-Ierapetra	72
Linoperamata-Iraklion 2	31
Ierapetra-Atherinolakos-Sitia	44

Examples of pollution and corrosion affecting porcelain cap & pin insulators on Crete.

Views of Linoperamata Power Plant show insulators coated with RTV silicone and also impact of corrosion on equipment. Transformer at right in process of being sprayed with special anti-corrosion coating.

cap & pin insulators to transformer enclosures. These require HEDNO to implement a costly maintenance program where external contractors are brought in to treat HV transformers and other substation apparatus with special anti-corrosion coatings.

Historical Solutions to Reduce Pollution Flashover

Emmanuel Thalassinakis is Assistant Director at HEDNO's Islands Network Operation Department and this role puts him in charge of the power system not only on Crete but also on the island of Rhodes to the north. Referring to the long history of flashover problems dating back to the 1980s, he recalls that transmission lines in those days were insulated using standard anti-fog cap & pin glass or porcelain strings. The poor performance of these insulators, however, eventually made Crete one of the first places in Europe to experiment with first generation composite insulators with Teflon housings. In fact, Crete was also one of the first places in the world to experience the phenomenon of brittle fracture, subsequently traced to poor design of wedge type end fittings on these first generation composite insulators.

Thalassinakis explains that coping with the severe maritime pollution affecting Crete's lines and substations has been accomplished in a step-by-step process involving applying different solutions as well as predictive countermeasures. For example, costly dead washing of insulators during the 1970s was eventually replaced with live washing by ground crews (circa 1985) and then by more efficient washing using helicopters (1995). Another countermeasure was to increase specific creepage distance of insulators from 32 to 39 mm/kV.

More recently, HEDNO has been implementing an external insulation strategy based on assessing the comparative performance of different RTV silicone coatings as well as silicone composite insulators. For example, three different RTV

material formulations have now been evaluated over a decade at the large Linoperamata Substation as well as on problematic lines insulated with traditional cap & pin glass or porcelain insulators. At the same time, HEDNO has come to rely more and more on composite line insulators to reduce pollution flashovers and also maintenance costs. “We have been working since 2004,” reports Thalassinakis, “on a strategic program to selectively replace glass and porcelain string insulators with silicone composite types”.

Assessing Site Pollution Severity

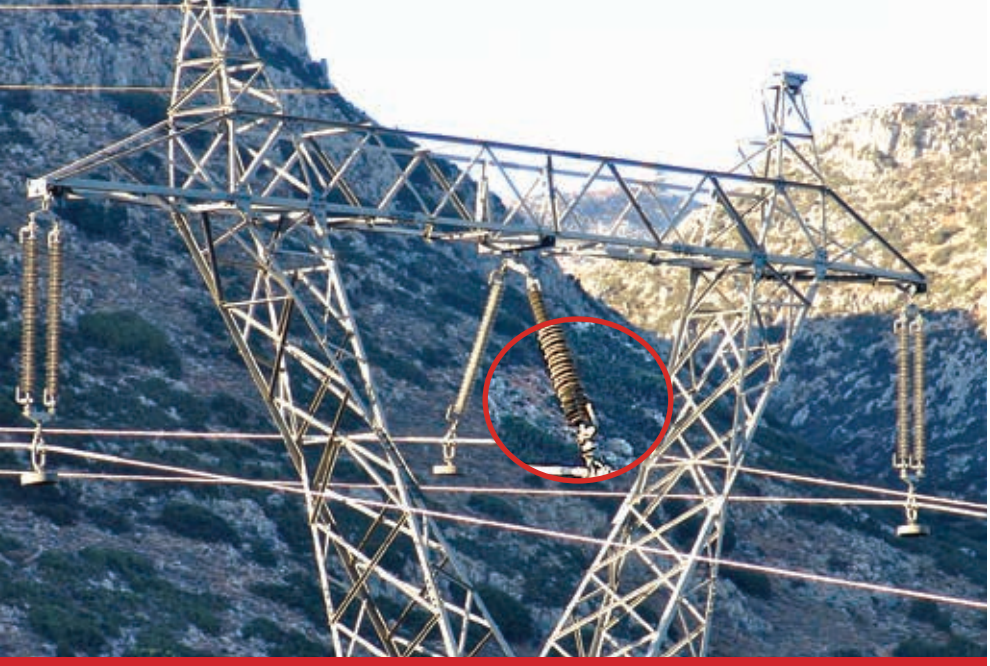
Over the last three years Pylarinos has been involved in assessing site pollution severity on Crete based on ESDD & NSDD measurements taken before the onset of the first autumn rains. Conducted in cooperation with HEDNO line crews, data has been gathered using non-energized porcelain cap & pin insulators hung on 33 HV towers scattered across the island. These locations have been selected so as to cover most of the different service conditions and local microclimates.

Data collected on site pollution severity has then been used to construct a pollution map of the Cretan power system, providing engineers with an indication of the maximum pollution that collects on insulators operating in different parts of the island. Not surprisingly, it was confirmed that much of the Cretan power system suffers from heavy marine pollution. The only exception proved to be a line that runs from Chania to Kasteli that was classified as exposed to only Medium Pollution

Fracture failure of Teflon insulator once used on Cretan power network.

Alternative formulations of RTV silicone coatings have been applied to line and substation insulators to establish which perform best.

Non-energized string on selected towers used to collect ESDD and NSDD measurements.



Line in heavily polluted northeast Crete insulated with silicone insulators. Note that one unit installed on middle phase has blackened near live end at time of photo (2008).

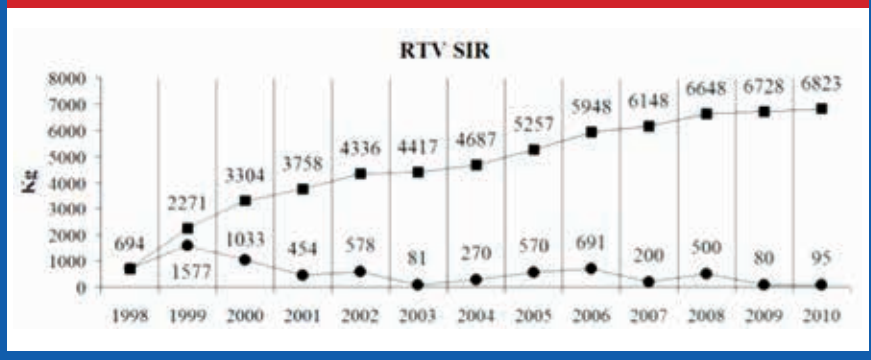
Fig. 2: Estimated site pollution severity at different locations on Crete.

Table 2: Trend in Number of Outages/100km on Crete 1980 to 2010

	1980-1989	1990-1999	2000-2010
Outages/100 km	75	51	24

Table 3: Growth in Volume of RTV Silicone Coatings Applied on Cretan Power System

(Cumulative & Year-to-Year)



Class due to natural washing from heavy rains on the western side of the island. By contrast, based not only ESDD and NSDD measurements but also on historic outages, the line ranked as most exposed to Heavy Class Pollution was Linoperamata to Agios Nikolaos to Atherinolakos. This line was therefore given highest priority to be entirely equipped with silicone rubber insulators.

According to Thalassinakis, application of proven pollution countermeasures as well as use of predictive maintenance in place of 'hit or miss' responses to problems as they occur have together led to noticeable improvements. For example, over the past decade alone there has been a 50% reduction not only in number of outages/100 km but also in the maintenance costs needed to achieve this.

Experience with RTV Silicone Coatings & Silicone Insulators

HEDNO has more than a decade of experience assessing different RTV silicone coating brands and also related optimal application techniques. In fact, Thalassinakis considers Linoperamata, near Crete's capital of Iraklion, as a model of a 100% coated substation. Based on years of inspecting these coatings, he concludes that all coatings tested have performed relatively well and in fact exceeded initial expectations given the harsh marine environment.

A related issue has involved application of these coatings. Because of the heavy reliance on RTV silicone material applied to porcelain and glass insulators on Crete, HEDNO has decided to develop internal know-how in their application. Maintenance staff and linemen have therefore been provided with targeted training programs, followed by direct practice applying coatings in the field. "Now," says Thalassinakis, "our personnel have sufficient experience to ensure that coatings are always properly applied. For example, for our type of pollution environment we have found that the optimum thickness for a coating falls in the

Newly coated CT at Linoperamata. Condition of coatings on cap & pin insulators periodically removed from service.

range of 0.3 to 0.5 mm, applied in two or at most three layers".

The use of RTV silicone material has also been extended to line insulators, especially those where intense discharge activity has been noted. In fact, this type of maintenance activity is now considered a routine operation within HEDNO.

Impact on Maintenance Costs

Looked at over the past decade, Thalassinakis calculates that reducing the incidence of pollution flashover outages on Crete has been achieved with diminishing investments in maintenance. "From the perspective of a cost-benefits analysis," he notes, "gains have far outweighed incremental costs. For example, the annual cost of helicopter washing, while lower than traditional ground based techniques, was still found to be more than 20% of the estimated cost to replace ceramic insulators with silicone composite types. That meant that the payback period of what we invested in purchasing and installing these insulators was less than 5 years."

Maintenance cost reduction has also been achieved at substations. For example, in the case of the fully coated Linoperamata S/S, application of different RTV silicone coatings over the past decade were estimated to have saved 40,000 Euros in the first year and approximately 240,000 Euros in each subsequent year.

On top of these gains, there have been all the economic benefits related to the significant reduction in outages. Together, these factors have encouraged HEDNO to continue and even accelerate its strategic program to selectively install silicone rubber insulators on the system's most problematic lines (see Table 4). In fact, it is planned that by 2015 virtually the entire 150 kV overhead transmission network on Crete will be equipped with silicone insulators. The only exception will be the Chania to Kasteli line which will remain insulated with porcelain due to its lower pollution exposure.

Notwithstanding these achievements, Thalassinakis strikes a cautious note. "All our past work and field investigations on different insulator designs and materials, including RTV coatings, still need refinement," he observes. "Therefore, we are now involved in targeted field and also laboratory tests to better understand the ageing mechanisms of silicone insulators with a view to assessing expected service life. At the same time, we need to optimize our line inspection program so that we can identify and replace any defective unit before there is a failure."

Talos Insulator Test Station

The Talos HV Insulator Test Station in Iraklion is the result of years of investment and development by HEDNO and PPC engineers as well as local specialists. Named after the mythic giant, Talos, who protected Crete against invaders, the test station has three test bays

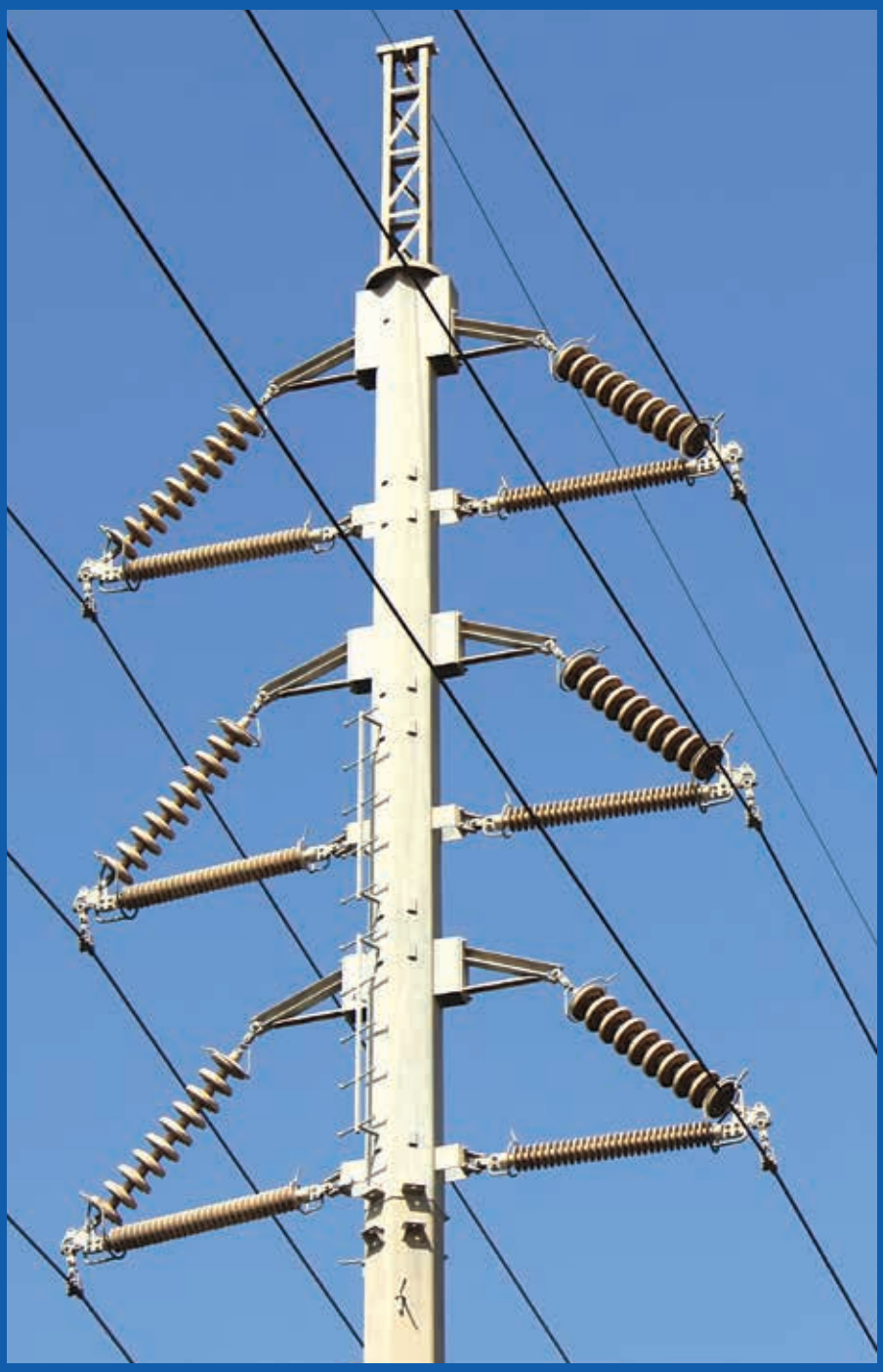
situated only meters from the sea and sandwiched between the shore and the chimneys of the adjoining Linoperamata Power Plant. Here, a variety of suspension and post insulators for 21 kV and 150 kV are exposed to continuous combinations of heavy marine and industrial pollution. Each insulator being tested is connected to a leakage current monitoring system while an on-site weather station tracks key meteorological parameters such as humidity, temperature, UV, rainfall and wind speed. A high current generator at the site is used for clamp testing.

The main purpose of the test facility has been to assess the behavior of different insulator types and geometries and also of alternative RTV coating formulations. Thalassinakis explains that one bay focuses on special applications and tests of 150 kV post insulators, a second on 150 kV suspension insulators while the third is devoted to 21 kV post and suspension insulators. "Our ultimate goal," he says "is to use results from Talos to improve reliability and availability through selection of only the most suitable insulator designs for our network. At the same time, we hope to better understand any relevant ageing mechanisms so that we can be in a better position to assess risk of external insulation problems before these evolve into unplanned outages."

Presently, more than 60 different insulator specimens are under test at Talos. These include new as well as naturally aged 150 kV suspension insulators of silicone, coated and uncoated ceramic discs of standard and anti-fog profile as well as coated and uncoated ceramic and composite post insulators. Traditional 21 kV glass and porcelain as well as composite post insulators are installed in a vertical orientation to simulate real service conditions. All 150 kV suspension insulators being tested are isolated from earth by stand-off coated glass insulators and energized at test voltage through a dual explosive fuse system that protects the samples and also the

Table 4: Program to Replace Ceramic Insulators on Crete 2004 to 2015

Transmission Line	Insulator Type	Year of Changeover
Linoperamata-Agios Nikolaos-Atherinolakos	HTV SIR	2004
Atherinolakos-Sitia	HTV SIR	2006
Ierapetra-Sitia	HTV SIR	2010
Iraklion-Mires	HTV SIR	2013
Iraklion-Chania	HTV SIR	2013
Mires-Ierapetra	HTV SIR	2015
Chania-Kasteli	Porcelain	Unchanged



Insulators on 150 kV tower near downtown Iraklion coated to control discharge activity and noise.

Talos Insulator Test Station recently expanded to 150 kV.

150 kV test bay at Talos devoted to post insulators.

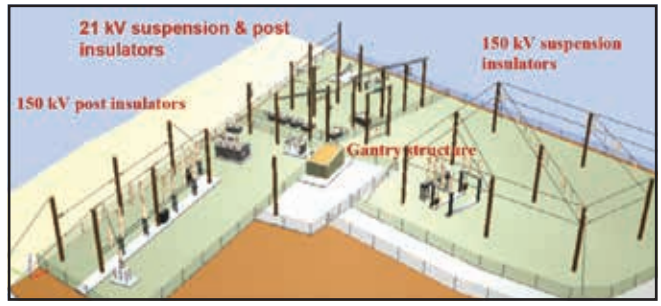


Fig. 3: Schematic of Talos Test Station.

high voltage supply source against possible overcurrent or flashover.

Current impulses flowing over the surfaces of a contaminated insulator are widely recognized as the most important alarm indicator before onset of the flashover mechanism. These are monitored using 16 current sensors and all data are correlated against relevant weather parameters. At the time of the visit by INMR, specialized contractors were in the process of installing and testing yet additional such sensors dedicated to measuring leakage current in real time on incoming new test sample insulators.

Apart from its three test bays, the Talos Test Station is also equipped with a locally designed power-driven gantry structure. Here, a variety of different types and geometries of non-energized insulators are hung at different heights to allow comparing pollution accumulation as well as measuring contact ESDD and hydrophobicity. The automatic up and down control on the structure allows for easy visual inspection of all test insulators, including the condition of RTV coatings, distribution of pollution along surfaces, ageing, etc.

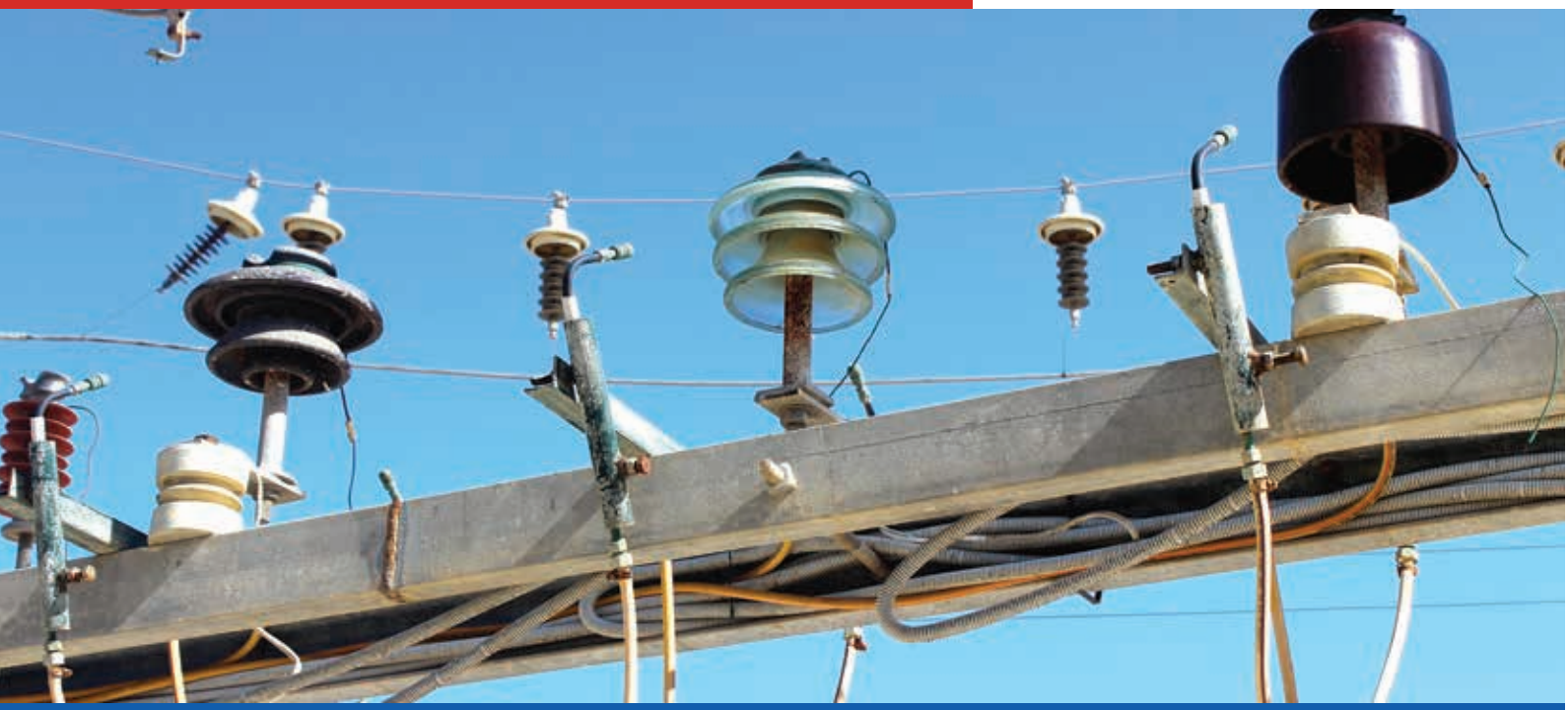
Pylarinos explains that the first series of comparative ESDD and NSDD measurements were conducted in collaboration with Democritus University in Thrace this past spring. The work looked at five different insulators installed on the gantry, including a composite type made from Teflon, a glass fog type disc, a coated glass fog type disc, a standard profile glass disc and a composite insulator made from HTV silicone rubber. Results are now being processed and are expected to provide an insight into comparative pollution accumulation on different types of insulators installed in the same location and under the same conditions.

Another feature at Talos, notes Thalassinakis, is that video cameras have been installed at strategic locations around the test station. Their goal is to monitor any surface discharge behavior and allow an observer in the nearby main control room to record their evolution. The facility is also equipped with a spray installation offering adjustable levels of salinity. For example, nozzles are directed toward the bodies of 21 kV and 150 kV post insulators and observation identifies the formation of hot spots on test insulators under normal service voltage or under accelerated testing with added salt spray.

Device to allow comparative measurements of ESDD and hydrophobicity on non-energized test insulators.

"The aim," explains Pylarinos, "is to assess different post and suspension insulators under conditions of severe salt spray. This will permit more rapid detection of any hidden defects, poor design or premature ageing – especially in the case of composite insulators and RTV-coated insulators."

Thalassinakis remarks that the Talos Test Station has the capacity to handle even more insulators for testing since it is equipped with extra stand-off insulators ready to support up to 20 additional specimens for pollution performance assessment. He regards the facility, which is the culmination of years of work, as an ideal platform to assess insulator performance under severe marine and industrial pollution and also to monitor ageing phenomena under such contamination exposure. "We are also open," he says, "to develop any kind of co-operation or technical assistance either with insulator manufacturers or with other power system operators who face similar difficult environmental conditions to those here on Crete." ☒



Spray nozzles directed toward specimen insulators permit accelerated testing to detect surface discharges and hot spots.