Investigation of an Insulator Flashunder in an 150 kV OTL of the Power System of Crete

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Abstract—**Overhead Transmission Lines (OTLs) are used in Power Systems to carry High Voltage between substations, usually over long distances. Faults in OTLs are bound to happen and thus locating and coping with them is an important aspect of OTL's operation and maintenance. These faults may be of temporary or permanent nature, with certain types of faults progressing over time from the first category to the second. Local weather may also have a direct effect on the occurrence of faults resulting to puzzling events. A special category, often complex in nature, is insulator faults. Insulators are used in OTLs to support phase conductors while not allowing current to flow through the tower's body to the ground. Traditional ceramic insulators used materials such as porcelain and glass as insulation, but in the last decades composite insulators with two insulating parts (a glass core/rod and a rubber housing), have also known great use mainly due to their low weight and their capability to withstand pollution. However, they are subjected to certain faults unique to them, such as flashunders. Flashunder is a term commonly used lately to describe faults that are related to the rod/housing interface of composite insulators. Such faults are rather difficult to locate as the electrical discharge does not create an easily visible trace (as in the case of flashovers) or a permanent mechanical fault (as in the case of brittle fractures). Such a fault occurred for the first time in the Transmission System of Crete in 2019 and this paper follows and discusses the incident and the experience gained.**

Keywords- flashunder; overhead; transmission; line; insulator; power; high voltage; permanent; transient; fault

I. INTRODUCTION

Overhead Transmission Lines (OTLs) are major components of power systems, used in the Power Transmission part of the system to connect High Voltage Substations, usually over long distances. Their basic components are the conductors (used to carry the high voltage), the supporting structures (used to elevate the conductors at safe distances above the ground, the trees and all other structures), and the insulators that are used to provide electrical isolation and clearance (i.e. safe distance) obviously while also providing mechanical support. Overhead ground wires (or earth wires) are also commonly used, suspended above all other components, to provide lightning protection. The types, materials and designs for all these components (as well as for the voltage level used) vary [1-3]. Under various circumstances, and due to various causes, the electrical isolation between different conductors or, more commonly, between a conductor and the supporting structure may be bridged and in that case, a fault occurs [2-3]. Faults in OTLs may be of transient or permanent nature. When a fault occurs, it is detected by protection equipment and the line is powered off almost instantly [2-4]. To avoid needlessly powering off the line for large periods of time due to transient faults, protection schemes employ a re-energization (reclosing) strategy [2-4]. A transient line fault is by definition a fault cleared after a small interruption of power and it is the result of factors that are either temporary in nature (e.g. lightning, birds/twigs etc.) or are removed due to the stress induced by the power arc (e.g. a piece of string or wire) [2-4]. The term "permanent fault" on the other hand does not necessarily describe a fault related to a permanent damage. The term includes all faults that are not transient and a further categorization using the term "semi-permanent" is also occasionally used (e.g. in [5-6]).

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In this paper, just the basic separation in the two main categories is followed, which means that the term "permanent" is also used to describe faults that are sustained long enough to not allow reclosing but are removed in the long term. Such faults may be the result of factors that cease to exist after a longer period than the one set for reclosing (e.g. a passing fire [7], an air-borne item eventually carried away or burned out etc.). It should be noted, however, that a transient fault is not to be treated lightly as it may be an indication of an issue likely to re-appear causing new disturbances and/or that builds up and will eventually lead to a permanent fault. Also, a possible damage from the power arc and/or the fault's cause (e.g. a ground fire [7]) may have a direct impact on the lines' capability to operate correctly in the future. Thus, when a transient fault is recorded, the line maintenance crews are called to provide further insight. To that end, several factors are considered (time of fault, weather conditions etc.) to assess the importance of the event and inspections are scheduled. Powering off a transmission line may have a significant impact on the power system and huge economical costs (risks aside) and thus the usual first approach is to perform live inspections from the ground to check for any signs revealing the fault's cause and location as well as any fault-related damages. If nothing is found then the line is kept energized (or, in case of a permanent fault, re-energized). However, the number of events (along with other data) may be used in the long term to assess the necessity of further improvements in a certain transmission line (or parts of it). It should be noted that the exact location and cause of a line fault is often not easily identified. Thus, the faults' cause may often be misidentified or remain unidentified (e.g. some typical examples in [8]). It should also be noted that just the time needed to reach the indicated area (let alone complete the inspection) may be significant [9]. Thus, it is not unusual for operators to re-energize lines even when a non-conclusive inspection report is received. In the same context, it is not illogical for operators to sometimes try to re-energize a line even without an inspection report (e.g. in an emergency situation). Such approaches however may lead to a puzzling series of events in the case of insulator faults such as flashunders or pollution induced flashovers (which are generally rare compared to other fault causes [8]).

This paper focuses on a flashunder fault experienced earlier this year in the transmission system of Crete. It took more than 20 days for the fault to be identified and located. During this time, the fault kept appearing and disappearing creating a confusing profile. The series of events related with the fault (and the attempts to locate it) are thoroughly discussed in this paper, from the OTLs Subsection's point of view, aiming to add to worldwide experience.

II. FLASHING OVER AND UNDER

A special category of OTL faults is the one related to insulators. Although insulator faults are easy to deal with in terms of the immediate actions needed to remedy the situation (a simple insulator replacement is usually enough), actually locating the faulted insulator tends to be much more complex. Locating was not much of an issue when dealing with traditional ceramic insulators (using glass or porcelain as an insulating material) as a power arc usually meant some broken glass insulators or some clearly visible signs on porcelain insulators in the string. The most complex and well known issue related to traditional ceramic insulators is the accumulation of pollution on their surface that, in the presence of a wetting agent, creates a conductive film [2-3, 10-11]. This procedure may lead to a flashover [2-3, 10-11] but arcing counteracts it and thus an inconsistence performance may be recorded.

The ability to suppress the pollution phenomenon along with several other advantages (e.g. low weight) has led to wide installations of the relative new, for OTL time frames, composite insulators. Composite insulators have two different insulating parts, a core and a housing, and have proved to be able to cope with the pollution phenomenon due to their hydrophobic surface properties [2-3, 10-11]. They still experience flashovers however, mainly caused by other factors (e.g. bird activity, ground fires etc.) [3, 8, 10-11]. They also suffer from another type of fault whose root cause is located in the rod/housing interface, as internal tracking along the core may occur due to moisture ingress [12]. It should be noted that internal defects may also cause tracking through the core [12]. Initially, such faults were more frequent due to design imperfections (e.g. filling the rod/housing interface with grease, improper rod material etc. [3, 11]) or mishandling [2-3, 11]. As more experience was gained from manufacturers and linemen, such issues are now considered solved [3] but their traces are still evident in transmission lines already equipped with such insulators (as replacing older insulators precautionally is usually not an option) or in past fault recordings. Thus, such faults are still found to be among the top fault causes for composite insulators (a sum up of major surveys can be found in [3, 11-12]). It should be noted however that there are several issues regarding the classification between different organizations, countries and time frames as a result of the absence of strict definitions and also due to the fact that one type of failure may lead to another [3, 11-13].

"Flashunder" has surfaced as a term commonly used to describe a bridging discharge conducted under the housing (in contrast to "flashover") and along or within the core [12]. Internal tracking grows in or on the rod until a critical distance is bridged and a flashunder occurs [12]. A flashunder is visibly spotted when traces are ultimately created on the sheath, but the location and size of these traces makes them difficult to spot. On the contrary, a flashover is much more easily spotted as the power arc leaves easily visible traces on the sheds. Typical images from worldwide experience can be found in [3, 11-14] whereas additional images from flashed-over and flashed-under insulators removed from service from the Transmission System of Crete are shown in Figure 1. It should also be noted that, similar to the effect arcing has on recessing the pollution flashover process, a flashunder power arc may dry out the moisture from the rod/housing interface thus allowing the line to be re-energized, only to fail again after time or renewed wetting [12].

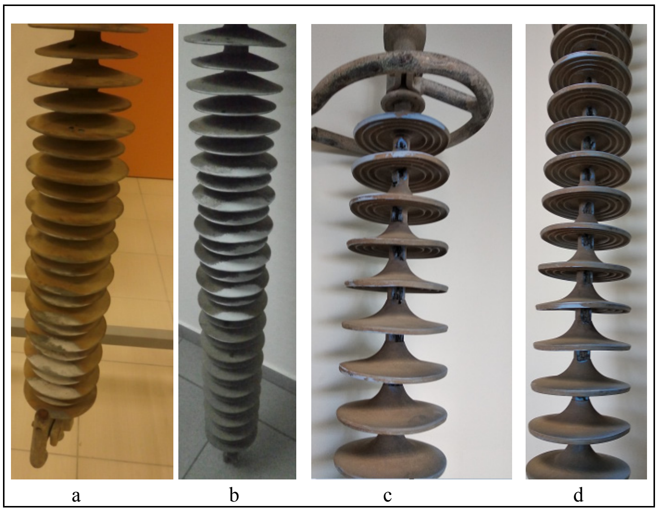

Fig. 1. Visible traces of flashover (discolored sheds) in a-b and flashunder (damaged sheath) in c-d. Photos a and b from past faults. Photos c and d from the insulator of the incident analyzed in this paper.

III. THE TRANSMISSION SYSTEM OF CRETE

The Transmission System of Crete operates at a 150kV nominal voltage and it is consisted of 20 substations (three of them attached to powerplants) and the lines that connect them, as shown in Figure 2. Historically, the coastal growth of the network along with the experienced weather and microclimate, resulted to increased pollution issues, especially to the eastern side of the island (eastern of Heraklion) [15-17]. A major program to replace ceramic insulators with composite ones with silicone rubber (SIR) housing has been launched in 2004 in order to cope with the problem, with rather satisfying results [15]. It should be noted however that originally, back in the 80s, a prior attempt to use polytetrafluoroethylene (PTFE) composite insulators proved to be a failure due to brittle fracture issues, attributed to poor design of end fittings [16]. This bad experience held back the further installation of composite insulators for a number of years [16]. The first installation of non PTFE composite insulators started in 1993, in a trial basis. As results were encouraging (no problems reported), large scale installation was initiated in 2004, on the longest line of the eastern side and other lines gradually followed [15]. Today almost all OTLs in Crete have been equipped with SIR composite insulators (with the exception of the far west line connecting Chania and Kasteli that does not face pollution problems and the line connecting Moires and Ierapetra which is under refurbishment). The gradual progress, a necessity derived from operational needs, means that insulators from different generations and manufacturers have been installed in the system. They are collectively referred to as SIR insulators in this paper, even though variation approaches in design and material (e.g. [11, 18]) may exist.

Fig. 2. The Transmission System of Crete (screenshot from Google Earth. Map data: Image LandSat/Copernicus) (yellow triangles: step-down substations, blue squares: step-up substations attached to power plants).

The length of all transmission lines in Crete today (considering the axes) is approximately 583.5 km (approximately 151 of them are lines carrying two circuits), supported by 1629 towers (mostly lattice ones, with the exception of 20 steel poles). The OTL Subsection currently employees four linemen, stationed in Heraklion, to cover the scheduled inspection and maintenance of the transmission system and also to tend to faults. The same crew also has to tend to the needs of the transmission system of Rhodes, another island in Eastern Greece [9]. The morphology of Crete is an added burden as moving from Heraklion to the west or the east end of the system means roughly a three hour drive (a six hour drive from one end to the other). These drive times are achieved by following pavement roads and highways and not line routes. Actually reaching the towers (or moving from one tower to the next) requires much more relocating time [9] which should be added to the time needed to perform the actual work.

IV. TRANSMISSION LINE DETAILS

The Transmission Line of interest is the one connecting Atherinolakos and Sitia substations at the far east side of the island of Crete as shown in Figure 3. It is a single circuit transmission line, approximately 23.24 km long supported by 67 lattice towers (numbered incrementally from south to north). The installation of SIR composite insulators in this line started in 2006 [15]. A roughly 3 hour drive from Heraklion is needed in order to reach either substation. It should be noted that inspecting thisd line is a tedious task as the line moves over gores and mountainous locations and is subjected to frequent and strong winds. In fact, it is not unusual for the line crew to have to lie down when performing ground inspections in order to be able to maintain a steady view through their binoculars/cameras.

Fig. 3. The considered transmission line and the location of the fault at Tower 29 (screenshot from Google Earth. Image © 2019 CNES/Airbus, Map data: Data SIO, NOAA, U.S. Navy, GEBCO).

V. INCIDENT ANALYSIS

The first fault was recorded on February 16, 2019 (14:20). It was a transient fault (Phase C to Earth). Two linemen were sent to perform ground inspections but nothing was found. At the time, the fault was attributed to bad weather/lightning and was considered a run-of-the-mill fault of this type. However, a new transient fault was recorded a day later (February 17, 05:37) and then again half an hour after that (February 17, 06:07). A new fault occured again 35 minutes later (February 17, 06:42) and this time it was permanent. The readings from the distance relay were consistent that they all were Phase C to earth faults with a relatively steady distance around 12.3 km from Sitia (roughly in the span between Towers 32 and 33). This was a rather unusual and puzzling series of events. A third lineman was added to the crew and the crew performed close range visual inspection (i.e. climbing inspections). The inspections proved fruitless and thus an attempt was made to re-energize the line (February 17, 13:27) but failed. As a response, the line crew foreman (a lineman with over 25 years of experience) was also sent to the location. A climbing inspection was performed again at the next day, but still nothing was found. At this point, suspicions emerged that the fault was not related to the power line at all, but was originated from some other piece of network equipment (e.g. within the GIS structure of Atherinolakos) or a protection equipment malfunction. To make matters worse, the line protection scheme at Atherinolakos suffered from a communication error at the time and thus the possible fault location wasn't easy to be confirmed or narrowed down. Fear of a possible flashunder also emerged. However, the spotless record of composite insulators installed in Crete advocated for the opposite. Nevertheless the possibility was brought to the attention of the crew and specific instructions to pay extra care to the sheaths were given. In an attempt to acquire more information, the line was divided in two parts by removing the bridging parts in Tower 37 (February 18, 11:38). Then, the northern part was energized without an issue. The northern part was then taken offline and the bridging parts were reinstalled at Tower 37 and removed from another tension tower (Tower 24) closer to Atherinolakos. The northern part (that this time included Tower 29, the actual location of the fault) was again energized without an issue (February 18, 13:58). The part was de-energized, the bridging parts were reinstalled and the line was re-energized without an issue an hour later (February 18, 14:57). At this time, the linecrew had performed several ground and climbing inspections and had found nothing. The behavior of the fault did not suite any of the usual profiles of line related faults experienced by the team and the line had been successfully re-energized. Thus, a decision was made to relocate the crew on the western side of the island for scheduled inspection and maintenance works. It should be noted that during that time, a transient fault was recorded on a line at the western side connecting Chania to Rethymno (February 25, 13:11).

However, a new transient fault was recording at the Atherinolakos-Sitia line on February 26, 08:49. At this time, the line had been energized without issues for more than a week since the previous fault. The fault kept being recorded between the same phase and the earth and roughly at the same distance. Still no verification on the distance and thus the location of the fault could be provided from Atherinolakos. While the Division was still puzzled by the event, yet another fault was recorded almost two hours later (February 26, 10:20) and this time it was a permanent one. It was rapidly decided to relocate the crew to the eastern side. At the same time, a protection crew also prepared to be relocated to Atherinolakos to attend to the communication issues and thus provide some additional information. For the two following days (February 27 and 28) the line stayed de-energized while the linecrew did thorough climbing inspections on all towers. Photos of insulators that have flashed-under found in the literature (most notably the one in [14]), were handed out to the crew in an attempt to help them visualize the sought traces. Again nothing was found. The line was re-energized on March 1, 12:40 without any issues. The following day, it was decided to overload the line and perform an IR inspection, focusing on insulators in an attempt to spot activity and heating under the housing [3, 12, 19]. Again, nothing was found. However, a new permanent fault occurred later that night (March 2, 22:10). The next morning an attempt to re-energize the line proved futile (March 3, 08:21). At this point a decision was made to remove again the bridging parts at Tower 24 and leave the two parts energized (March 03, 11:06) hoping that soon a new fault would provide a more solid confirmation on the location of the fault (and eliminate the possibility of a malfunction/ protection/substation fault in Atherinolakos). Some switching was tried in March 04 hoping to re-create the fault but unfortunately, nothing happened for the following 5 days. During this time, the readings from the distance relay in Atherinolakos came in and seemed to confirm the readings from Sitia, although they expanded the possible location of the fault by approximately 2 km. Thus, it was decided to reinstall the bridging parts on Tower 24. However, prior to that, the crew conducted yet another climbing inspection on the line. During that inspection, a crew member noticed arc traces on the arcing rings (Figures 4-5) of an insulator installed in Tower 29 and the fault was finally located (March 08, 13:10). A sum up of the timestamps of the different events and actions is shown in Table I.

Fig. 4. The flashed under insulator with visible arc traces on rings. Sheath damage barely visible from this angle and distance.

Fig. 5. A direct view of the flashed under insulator (red arrow). Some conductor parts used for phase transposition are also visible (green arrows).

VI. DISCUSSION

The fault was found in one of the two insulators in a double tension string in Tower 29, located 13.73 km away from Sitia. Towers 28 and 29 are double circuit tension towers with the extra circuit endings being used in a way that facilitates a phase transposition (Figure 5), the only one in the Cretan Transmission System. These towers, known to suffer from strong winds and intense humidity in early mornings, are located at the top of a steep hill (Figures 6-7). For all these reasons, and even though the distances recorded from the fault locator in Sitia was steadily around 12.3 km (approximately 1.5 km short), extra focus was given to these specific towers as possible fault locations. They were inspected multiple times, by different linemen, from the ground and in close range and also using an IR camera while the line was overloaded. However, the fault could not be spotted. A breakdown of the several reasons for that is provided below.

TABLE I. TIMESTAMPS OF EVENTS/ACTIONS

Date, time	Switches	Comment
Feb 16, 14:20	A: O-C B: O-C	Transient fault. Two linemen sent for ground inspection (no findings)
Feb 17, 05:37	A: O-C B: O-C	Transient fault.
Feb17, 06:07	A: O-C B: O-C	Transient fault.
Feb 17, 06:42	A: O B: O-C-O	Permanent fault. Add third lineman for climbing inspection.
Feb 17, 13:27	B: C-O	Inspection ended (no findings). Failed attempt to close the CB at B. Linecrew foreman added to the crew.
Feb 17, 13:27 - Feb 18, 11:38	A:O (remain) B: O (remain)	Climbing inspection. No findings. Bridges at Tower 37 removed.
Feb 18, 11:46	A:O (remain) B: C	Part (Tower 37-B) energized.
Feb 18, 12:26-13:43	A:O (remain) B: O	Reinstall bridges at Tower 37 and remove bridges at Tower 24.
Feb 18, 13:58	A:O (remain) B: C	Part (Tower 24-B) energized.
Feb 18, 14:15-14:38	A:O B: O	Bridges at Tower 24 reinstalled.
Feb 18, 14:57	A: C B: C	Line re-energized.
Feb 19-25	A: C (remain) B: C (remain)	Line crew relocated to the west side of the island.
Feb 26, 08:49	A: O-C B: O-C	Transient fault.
Feb 26, 10:20	A: O-C-O B: O-C-O	Permanent fault. Line crew relocated to the east side. Protection crew sent to Atherinolakos
Feb 27-28	A: O (remain) B: O (remain)	Climbing inspection. No findings.
Mar 1, 12:40	A: C B: C	Line re-energized.
Mar 2, 8:36-13:00	A: C (remain) B: C (remain)	Line overloaded. IR inspection. No findings.
Mar 2, 22:10	A: O-C-O B: O-C-O	Permanent fault.
Mar 3, 8:21	B: C-O	Failed attempt to re-energize.
Mar 3, 9:14-10:30	A: O (remain) B: O (remain)	Bridges at Tower 24 removed.
Mar 3, 11:06	A: C B: C	Part (A-Tower 24) energized from A. Part (Tower 24-B) energized from B.
Mar 8, 08:25 - Mar 8, 13:10	A: O B: O	Climbing inspection.
Mar 8, 13:10	A: O (remain) B: O (remain)	Fault located at Tower 29.
Mar 8, 13:10 – Mar 9, 10:50	A: O (remain) B: O (remain)	Bridges at Tower 24 reinstalled. Insulator at Tower 29 replaced.
Mar 9, 11:00	A: C B: C	Line re-energized.
A=Atherinolakos, B=Sitia, O=Open, C=Close		

Fig. 6. A view of the location of Towers 28 and 29

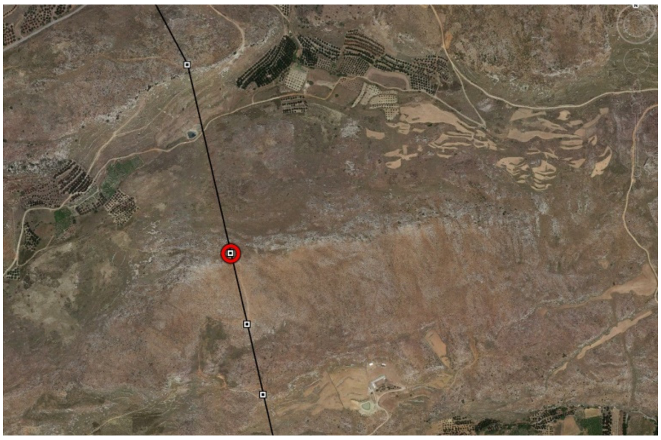

Fig. 7. The location of Tower 29 (red circle) on top of a steep hill (screenshot from Google Earth, Map data: Google Earth)

A. Lack of Signs/Traces

The first and most important reason is the very nature of the fault. Considering the mechanism of a flashunder, it is safe to assume that there were probably no visible signs prior to the fault. Even after the first fault(s), the visible traces could be minimal. It probably have taken multiple power arcs to achieve the state shown in Figure 1 and Figures 8-10. It should be noted that, besides periodical visual inspections, yearly IR inspections (during the summer) were also performed on that tower and although it have been proposed that IR inspection could locate internal tracking and activity under the housing [3, 12, 19], this approach also proved futile in this case. Even when IR inspections were performed on March 2 with the line overloaded and with special attention given to any sign of such activity, nothing was found.

B. Insulator Type/Design and Installation

The insulator that suffered the fault was an even shed insulator, installed in a double tensions string. Thus, the sheds' shadows obscured the view of the sheath at most times and angles (Figures 8-10).

C. Location of Visible Damage on the Insulator

The location of the sheath damage was on the "outer" side of the insulator, i.e. facing away from the tower, making it difficult to spot from any angle accessible from the tower or the ground (Figures 8-10).

Fig. 8. Even from a small distance, the damage is not visible due to the sheds overshadowing the seath

Fig. 9. The damage visible from close distance and correct angle.

Fig. 10. Views of the flashed under insulator before its removal

D. Weather Data

The area around Tower 29 is not inhabited. Thus, at the time of the incidents, the information regarding the weather came from the cities of Sitia and Ierapetra (along with inspection information). The location of these cities, next to the substations with the same names, and their relation to the fault location can be seen in Figure 3. The weather information did not seem to advocate for the possibility of a weather related fault. This can be more understood when examining the recordings from the closest automatic weather stations of the National Observatory of Athens network which are located in Sitia and Ierapetra [20]. Their monthly data are easily available through [21] and the rain and wind recordings are depicted in Figure 11. Fault occurrence could not be correlated with any specific weather condition (e.g. strong wind or heavy rain). The first fault was recorded on Feb 16, a day with minor winds that had followed a series of days with much stronger winds. No correlation with rainfall, a factor that may play a role in the flashunder process, could also be established, as faults were recorded on days with no rain in Sitia (Feb 17, Feb 26, Mar 2) or Ierapetra (Feb 16, Mar 2) and Feb 25 was faultless although intense rain fell on both cities.

The micro-climate at Tower 29, and especially values with a strong locality factor such as relative humidity (RH), can not accurately be described by the recordings in either Ierapetra or Sitia (thus the RH measurements are not shown in Figure 11). It was known that Tower 29, being located at a top of a steep hill, was subjected to intense humidity (fog/mist) in early mornings. The same could be hypothesized for late afternoons. However, even when a possible flashunder was brought to the table as a strong possibility, the time of faults would not back a correlation with high RH values either. The first fault was recorded at midday of Feb 16 (at 14:20), the line was re-energized on Feb 18 and the next fault was recorded on Feb 26 at 08:49. Thus, no safe correlation with morning and afternoon fog/humidity could be established.

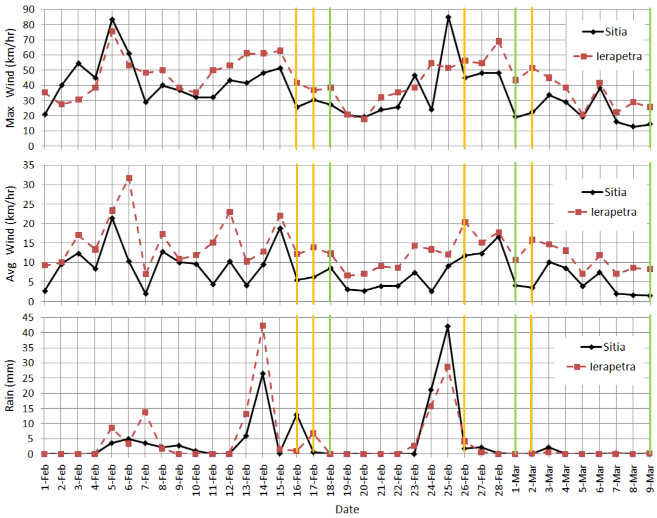

Fig. 11. Weather data from weather stations in the National Observatory of Athens network located in Sitia and Ierapetra. Yellow vertical lines indicate the occurrence of fault(s). Green lines indicate the re-energization of the line.

E. Similarity to Run-of-the-mill Incidents

One should keep in mind that transient faults are rather usual in a transmission system and not being able to locate a fault or its cause is also usual. An initial analysis of the 307 faults recorded in the transmission lines of Crete from 1994 to 2013 is available in [22]. Although, both record keeping and analysis suffer from much of the issues described in [8] (i.e. non uniform record keeping, cause: "unknown", cause: "under investigation", misclassification, changes in line configuration etc.) some basic info can be deducted with safety: first of all, faults are mainly transient. Only 29 of the 307 faults, less than 10%, were permanent/semi-permanent. The two months where most faults are recorded historically are February and March (Figure 12), exactly as in the considered case. Faults recorded with causes such as "bad weather", "rain", "storm", "lightning", "under investigation" and "unknown" are the vast majority of the data. In the particular line in question, only 6 faults had been recorded: two attributed to lightning, three to bad weather and one of unknown origin. In other words, the basic initial profile of this specific fault did not hinted to anything out of the ordinary and certainly did not justify any special action.

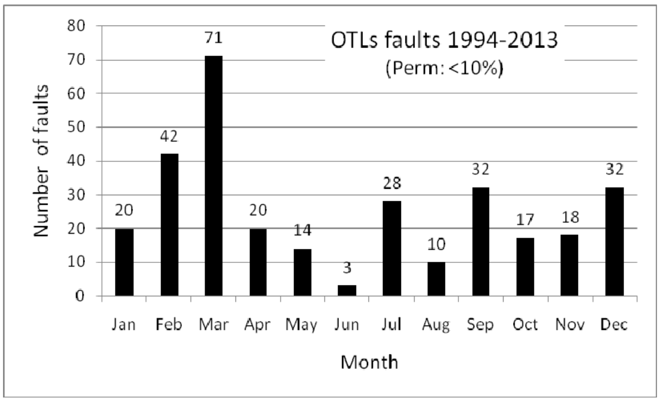

Fig. 12. Faults per month as recorded in Transmission Lines of Crete from 1994 to 2013.

F. Typical Inspection Procedure not Suitted for Flashunders

The run-of-the-mill inspection procedure proved to have weaknesses in spotting a flashunder. This is however rather logical, as the procedure has been designed (and adjusted) to the faults and issues historically experienced in this particular system, always aiming to achieve the optimum trade off between result/productivity and time/cost. Thus, thorough sheath inspection had never been incorporated in inspections. The usual inspections in Crete are performed either from the ground using binoculars or by climbing and inspecting from the tower's body (an IR inspection is also performed annually on tension towers). Checking the sheath from all angles (e.g. using mirrors as shown in [14], ladders, cranes etc.) would mean a significant decrease of productivity (and increase in costs) and would have brought zero results for the past 15 years. So, such approaches have justifiably not been incorporated in the inspection procedure. This however means that even if any signs of the problem (e.g. minor sheath damage) were visible prior to the fault (which is rather doubtful), they couldn't have been spotted. This also means that the infrastructure, experience and tendency for such an approach were missing. In short, it can be assumed that the long successive experience of following a specific walkthrough resulted to a weakness when an unpresented case presented itself.

G. Practical Issues

The limited personnel combined with the size of the system and relocation times means that each inspection and each maintenance has to be carefully planned and crew relocating is conducted only when strictly necessary. For example, as mentioned earlier, during the time that the flashunder induced faults appeared in the east, a transient fault also appeared in the west and a line inspection was scheduled to take place also in the west. This means that the OTL Subsection rarely has the luxury of dedicating extra time and manpower to investigate any single incident further than needed to assure the system's operation. Even more so in case of an incident that originally appeared as a run-of-the-mill transient fault and its profile kept not fitting to any of the "more serious" fault types. It should also be noted that de-energizing this line does not have a direct effect on the system (outages, cutting off wind farms etc.) so faults in this specific line are generally considered of lower priority.

Besides the OTL Subsection, similar conditions exist for all other subsections and thus several actions that could offer more information were judged not necessary at the beginning, adding to the overall delay in locating the fault. For example, HEDNO substation personnel (two persons at the considered period, working on different shifts) were regularly located only in Sitia. This means that for one of them to visit the other end of the line (Atherinolakos) (even just to read the readings of the distance relay) will mean that both substations have to be left unattended for two hours (as the single-way travel time is approximately one hour) or that the second person has to be called in for overtimes, which is also a decision not to be taken lightly in the current economical context. In addition, when the communication issue with the distance relay in Atherinolakos surfaced, all the personnel from the Protection, Metering & Telecom Systems Section of the Division was stationed elsewhere and the relocation of a crew to Atherinolakos took some additional faults (and days).

H. Psychological Aspect

Although earlier PTFE insulators have performed poorly suffering from brittle fracture [16] and flashover [17] faults, the next generation SIR composite insulators had an almost spotless record in the Cretan power system. The only, rather rare, faults were caused by bird activity (Figures 1a and 1b) [15, 23]. This had caused an increased confidence to the personnel regarding the performance and the reliability of the SIR insulators. The linemen performing the inspection had never experienced any such phenomenon (i.e. a flashunder that induced line faults without causing brittle fracture). It is also possible that the brittle fracture issues on older PTFE insulators more than 35 years ago [16] had created an erroneous notion that moisture ingress under the sheath would lead straight to brittle fracture faults. Even though the possibility of a flashunder that wouldn't lead to a brittle fracture was communicated to the linemen, it is logical to assume that, subconsciously, they never fully accepted that possibility and thus they were not that prone, in an subconscious level, to perform an as thorough as needed inspection on sheaths. Not having solid information on fault location from both distance relays, at least for the first few days, contributed to that by increasing the load of work and also creating doubts about the correctness of the information. The ill-correlation with weather data also contributed as the behavior of the fault didn't seem to fit any scenario (including a flashunder).

VII. CONCLUSION

Moisture ingress in the rod/housing interface of composite insulators, widely used in Transmission Lines, may lead to a flashunder, a bridging discharge taking place under the housing and along the core. The discharge may dry the moisture causing a temporary recess while leaving minimal traces on the insulator. This procedure along with the general operating principles of Transmission Systems may cause a rather difficult to interpret series of events as the fault may keep appearing and disappearing. Locating such a fault may prove rather challenging for the OTL sections bearing the responsibility to inspect, locate and remedy OTL faults. This paper discusses the experience gained from a flashunder incident that occurred in the Transmission System of Crete in February/March 2019, mainly by following the point of view of OTL personnel. The actions taken and the various scenarios considered up until the identification of the fault and the replacement of the faulted insulator are discussed. Additional pieces of information, such as historical and weather data, are also considered in order to provide an, as complete as possible, image of the various factors involved in the process.

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