Overhead Transmission Line Maintenance in Crete and Rhodes: 2016-2020

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Abstract-The Greek islands of Crete and Rhodes are equipped with 150kV isolated transmission systems that fall under the jurisdiction of the Islands Network Operation Department of HEDNO S. A., which carries out their operation and maintenance on behalf of PPC S. A. After 2016, the Transmission Line Operation and Maintenance Subsection of the Department, started to incorporate new approaches to improve the routine maintenance work. These include Unmanned Aerial Vehicle (UAV/drone) inspections, GIS/GPS software applications and project management/issue tracking tools such as Mantis Bug Tracker (or MantisBT). This paper provides an insight of the maintenance practices in combination with locality issues for the specific systems, along with an investigation of the MantisBT records from 2016 to 2020, in order to provide a view of the routine maintenance work of Overhead Transmission Lines in Crete and Rhodes. It should be noted that the majority of these issues are related to the Cretan transmission system and thus, this paper also provides a screenshot before the interconnection of Crete to the mainland Greece's transmission system, expected to initiate in 2021.

Keywords-overhead transmission line; maintenance; project management; issue tracking; UAV; thermal; MantisBT; inspection.

I. INTRODUCTION

Overhead Transmission Lines (OTLs) are used to connect High Voltage substations [1-2] and the term includes the conductors, supporting structures (e.g. towers, poles etc), insulators and all other equipment (overhead ground wires, transmission line arresters etc). OTLs are major constructions with long operational life expectancy, subjected to various environmental, mechanical and electrical stresses [1]. Thus, transmission Line maintenance is a key factor to secure safe and uninterrupted operation of the transmission system [1]. The term "OTL maintenance" usually includes the various tasks performed on OTL equipment under or in proximity of High Voltage but also several other works related to the towers' footings, vegetation management etc [1-6]. It should be noted that live maintenance of transmission lines is significantly more difficult (and costly) compared to distribution lines, due to the higher voltage levels and the resulting safety issues. Further, the route of OTLs is usually rather remote, meaning that they are frequently subjected to severe environmental stress (e.g. winds) and are located on difficult terrains, thus many of the live line requirements (e.g. use of helicopters and cranes [1, 7-8]) are not that easy to secure. On the other hand, turning off transmission lines is a complex issue that usually has a significant impact on the transmission system, with huge economical and operational impact and, thus, it is not a decision to be taken lightly. Especially in Crete and Rhodes, two Greek islands with growing economies, largely based on tourism, turning off transmission lines has become increasingly difficult over the years, especially during the tourist season [9-11]. Thus, the OTL Subsection responsible for maintenance has to maintain a system that keeps expanding [12] with very limited, and decreasing, personnel [13]. To cope with this, the Subsection has incorporated several new approaches, including a large insulator replacement project [14], drone inspections [15], using GIS/GPS software [12], and the use of MantisBT for issue tracking [16].

Mantis Bug Tracker (or MantisBT) is a free and open source issue tracker, mostly used for software debugging that can also be used as a generic issue tracking and project management tool [17]. In this case, MantisBT was used as a web-based tool for project management/issue tracking, aiming to optimize maintenance monitoring and scheduling and to offer fast on-site alternatives in case scheduled maintenance works could not be performed. The 2016-2020 MantisBT records are presented and discussed in this paper along with additional information regarding various local factors, in order to provide a further insight on OTL maintenance in Crete and Rhodes.

II. TRANSMISSION SYSTEMS OF CRETE AND RHODES

An actual representation of the 150 kV transmission systems of Crete and Rhodes on a map can be found in [12]. More detailed schematics are presented in Figures 1-3. These schematics were drawn using the geospatial information acquired through the procedure described in [12], combined with on-site inspections and cross-checking with official expropriation information in order to successfully link legal names and operational names of towers and lines, to identify towers that were never constructed, pin down the exact details of line merging, crossing over each other etc [6, 12]. Thus, these schematics provide additional information regarding the position of phases, the relative position of lines, the merging of single circuit lines to form double circuit lines, the use of

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double circuit towers in single circuit lines etc. Additional information is provided in Tables I-V. The dotted lines in Figures 1-3 denote underground cables (not considered in this paper) and the larger squares denote towers that support three circuits. The position and numbering of metal poles are stated using dotted text boxes and arrows. As explained in [12], towers obtain a legal name (used for expropriation and construction purposes) and an operational name given by the utility in charge of operation and maintenance. The operational name illustrates the actual role of the tower in the system, and thus may differ from the legal name [12]. Figures 1-3 show only the numbering part of the towers' names (the full name includes letters that usually denote the lines' ends). The legal numbering (when different from the operational) is shown within parentheses. A rather special case is the Linoperamata-Ierapetra line, since the middle part of this line uses towers that were part of an older line (Heraklion-Pachia Ammos) that is now out of service.

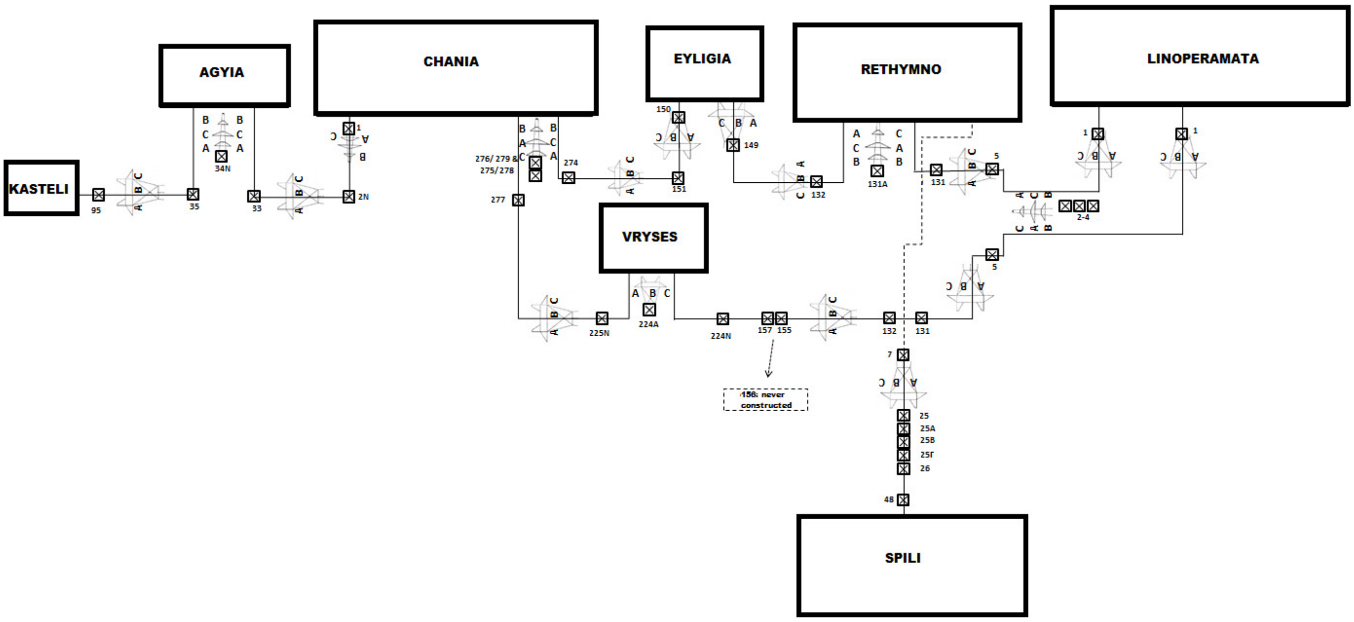

Fig. 1. Schematic of the Transmission System of Western Crete. Dotted lines depict undergound cables. Chania and Linoperamata are step-up substations. The Linoperamata-Rethymno-Eyligia-Chania line is referred to as Linoperamata-Chania I and the Linoperamata-Vryses-Chania line as Linoperamata-Chania II.

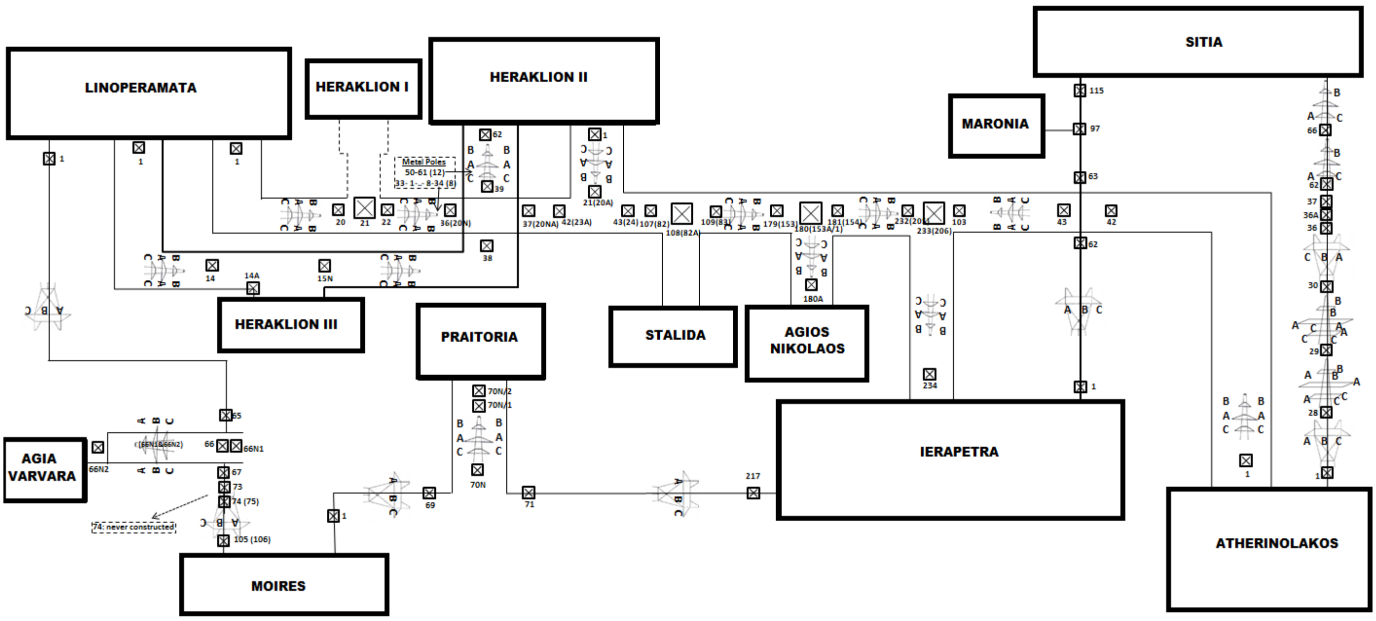

Fig. 2. Schematic of the Transmission System of Eastern Crete. Dotted lines depict undergound cables. Legal numbering of towers is given within parentheses when different from the operational numbering. Larger squares denote double circuit towers that support three circuits. Linoperamata and Atherinolakos are step up substations. The line connecting Heraklion II to the Linoperamata-Ierapetra line is referred to as System-Heraklion II.

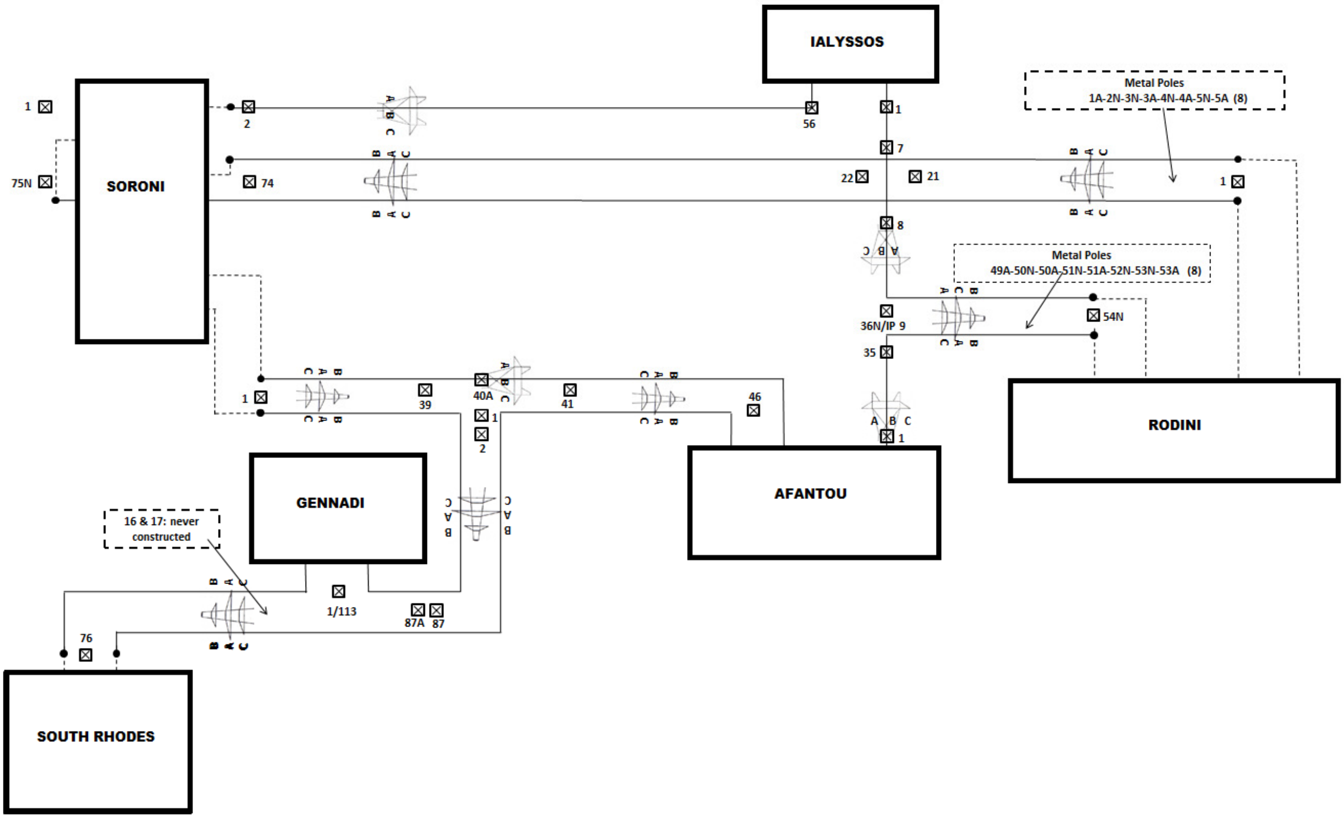

Fig. 3. Schematic of the Transmission System of Rhodes. Dotted lines depict undergound cables. South Rodes and Soroni are step-up substations.

III. MAINTENANCE AND LOCALITY ISSUES

A. Maintenance periods

There are several factors to be considered in case of OTL maintenance, especially in these two particular systems. First of all, live line maintenance in Greece is not conducted in transmission systems, although it is gradually incorporated in some distribution system maintenance works. The standard practice is that a part of the transmission system (e.g. a transmission line's circuit) is to be isolated and grounded at all ends before a worker/lineman is allowed to work on it. Secondly, Crete and Rhodes are two Greek islands with economies largely based on tourism and thus most circuits can not be turned off for maintenance during the tourist season which, especially for Crete, may span from May to October. Turning both circuits off in case of crucial double circuit lines (as the ones connecting step-up substations) is also avoided throughout the whole year.

B. Marine pollution and insulator washing

Marine pollution is significant due to the coastal development of the islands and of their transmission systems. This issue has been largely resolved with the replacement of ceramic insulators with composite ones in most lines [14]. Currently, only two lines are still equipped with ceramic insulators in Crete: the Chania-Kasteli and the Moires-Ierapetra lines. The Chania-Kasteli line faces minimal pollution issues due to natural washing [14, 18-20]. The Moires-Ierapetra line on the other hand, has to be washed once a year (Figure 4). The line is to be refurbished in the near future however, and the refurbished line is to be equipped with composite insulators.

Fig. 4. Dead washing of the Moires-Ierapetra line. The water is carried with trucks and pumped-up to the lineman that performs the washing. The line is to be refurbished and the new footings and base are visible.

C. Wind influence

Another significant issue related to the local climate is the influence of winds. The OTLs in Crete experience more severe wind stress compared to the ones in Rhodes due to the island's shape, local weather patterns, the existence of mountains and gores in proximity to line routes etc [20]. The problem is fiercer near Atherinolakos. This was a known issue and additional weights were installed in most towers of the OTLs in the area, as well as silicone coated ceramic insulator strings in the jumper parts of tensions towers (two such strings in certain towers). This suppressed the effect of wind in order to avoid clearance issues (as the ones shown in Figure 5), but the constant swinging motion has had a great effect on mechanical parts (shackles, clevises, bolts, pins, v-hangers etc) (Figures 6 and 7).

Fig. 5. A car tipped-over by the wind near Atherinolakos (left). Wind lift-off of conductors and/or jumper parts on lines not equipped with additional weights and/or ceramic insulators at jumper parts (right).

Fig. 6. A jumper part of a tension tower suspended by two coated glass strings (to avoid wind lift-offs). The last insulator of the right string was found unbuckled during inspection. As shown in the right picture, the insulator's cap was found misfigured.

D. Recent OTLs going uninspected

The two double circuit lines connecting Atherinolakos and South Rhodes with the Crete and Rhodes systems respectively, are lengthy lines that were only recently commissioned (2004 and 2017 respectively). Thus, it was considered that they would not require much inspection and maintenance during their first years of operation. This however proved erroneous especially for the Atherinolakos-Ierapetra line that suffered intense stress due to the winds in the area. In fact, a metal fitting replacement program had to be issued in early 2020 for most towers, in order to replace metal parts/fittings that supported the conductors (Figure 7). An additional issue was related to the overhead ground wire of the double circuit towers of this line. The wind effect had caused significant damage to suspension clamps (grips) and to the shield wires (Figure 8). Thus, it was decided to replace such clamps with yoke plates and dead-end tension clamps, effectually making suspension towers similar to tension towers (in terms of shield wire arrangement) while avoiding any contact with near angles (a problem faced in the past with single circuit towers) (Figure 9).

Fig. 7. A collection of pictures with various metal parts/fittings (shackles, clevises, bolts, pins, v-hangers etc) as removed from service.

Fig. 8. Overhead ground wire issues: a damaged suspension clamp (left) and broken strands (right)

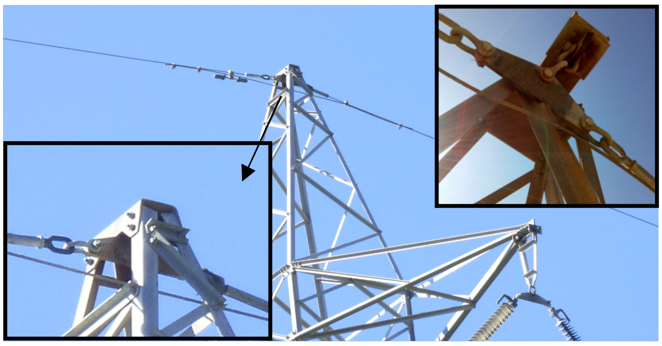

Fig. 9. An overhead shield wire arrangement on a double circuit suspension tower using a yoke plate and dead-end tension clamps to replace the initial suspension clamp, making the arrangement effectively similar to that of a tension tower. Down and left image: a zoom-in of the arrangement. Up and right image: A similar approach on a single circuit suspension tower proved problematic.

E. Maintenance of crucial double circuit lines

An additional factor to be considered is that crucial double circuit lines, such as the two lines mentioned in the previous paragraph, cannot have both their circuits turned off simultaneously. Due to this, the OTL subsection has adopted the practice to work on one of the circuits while the other is live, a practice that, although permitted under certain requirements, is rather unusual for linemen in Greece. However, the direction of wind has to be considered at all times, as ropes and pulleys are used to lift tools and equipment to the maintenance spot (Figure 10). This factor is rather important for locations that are subjected to strong winds and/or winds that swiftly change direction, especially when working on the shield wire (i.e. closer to the live circuit).

Fig. 10. Maintenance works on double circuit towers with only one of the circuits turned off. Extra care and consideration should be given to the direction of the wind as ropes and pulleys are used to lift tools and equipment to the maintenance spot.

F. Inspections

Traditionally, inspections were carried out either from the ground (with the use of binoculars) or by climbing. However, the position of the sun and the actual position of the various parts that needs to be checked, makes ground inspections highly unreliable for anything more than spotting arc traces, checking for nests or materials carried by the wind (Figure 11). Climbing inspections, on the other hand, are rather reliable but require de-energizing for lengthy time periods. The use of Unmanned Aerial Vehicles (UAVs) provided a better solution. Such drone inspections can be carried with the circuits live and, with proper equipment, from a safe distance (Figure 12). In addition, when using a drone, viewing angles can be altered on site in order to safely assess the severity of issues. Adding an experienced lineman in any drone inspection team offers the ability of on-the-spot assessment of issues, significantly reducing the inspection times (compared to the later assessment of tens of pictures per tower). Climbing inspections still remain necessary as some parts of the tower (e.g. the upper fitting of the yoke plate in the down and left image of Figure 9) can only be inspected from a close distance. A comparative view of images taken through different inspection approaches is provided in Figure 13.

Fig. 11. Views of ground inspections, taken with an 60x optical zoom camera. Left image: A transient arc caused by a bird carrying a string. The arc traces are visible on the arcing horn of the right insulator along with a piece of string. Middle image: a potentially dangerous object on a conductor midway of the span, as seen from near one of the towers (natural and zoomed in view). Right image: a nest right above of an insulator.

Fig. 12. Climbing and drone inspection. Up: Climbing inspections. Down: drone inspections. Note that a no-zoom drone has to approach to a very close distance (left image) but a suitably equiped drone can perform inspections from a safe distance (right image).

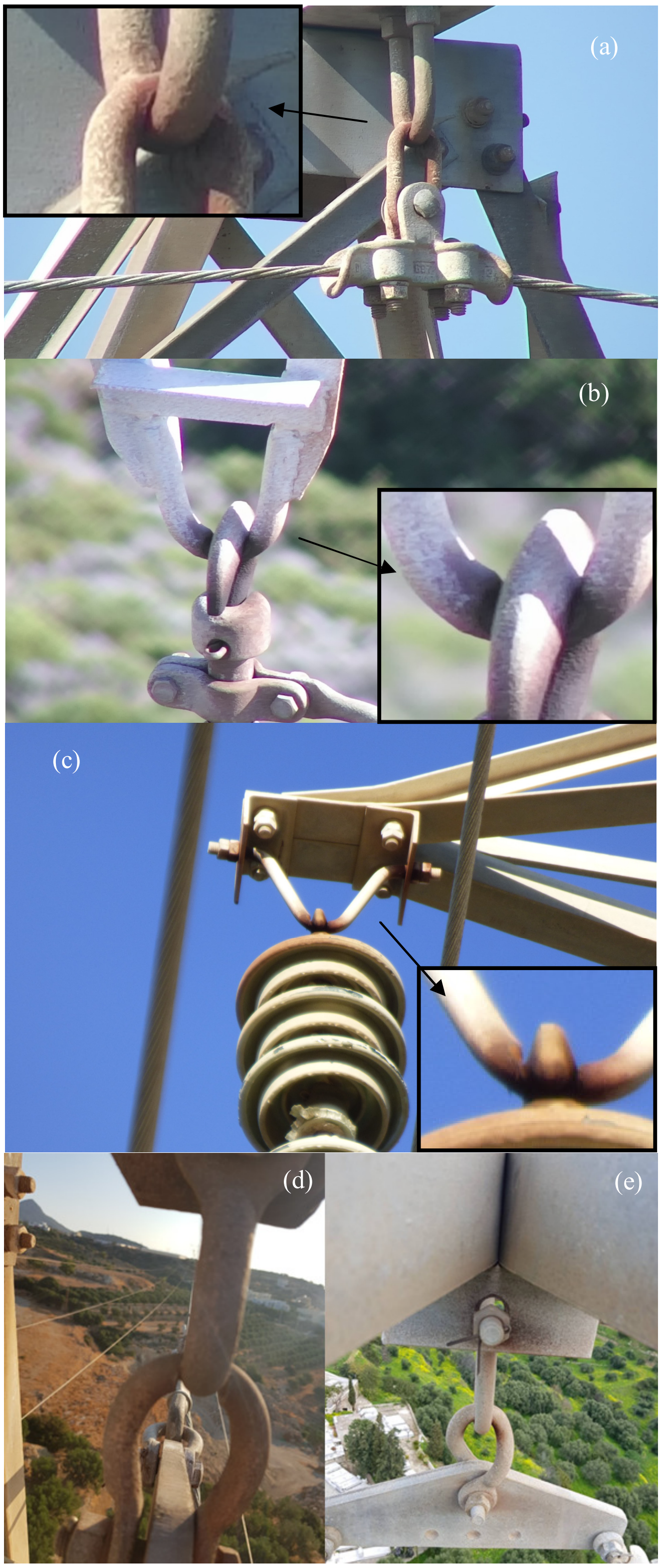

Fig. 13. Inspection photos. (a) and (b): drone photos, (c): photos taken from the ground, using a 60x zoom camera. (d) and (e): climbing inspection views. Pictures within pictures in (a)-(c) are zoomed in details of the larger respective pictures.Notice that even when the viewing angle from the ground allows to spot an issue, the secerity of the issue can not be safely assessed.

G. Vegetation, roads, footings etc

OTL maintenance also includes works such as vegetation management and tree trimming [4-6], road maintenance, buried ground conductor issues and general maintenance of tower bases/bodies/footings etc. Regarding vegetation management, utilities in Greece are required by law to trim dangerous trees each year in order to maintain a safe distance and also to fully clear the vegetation near or under connection points i.e. tension towers. Such issues are thoroughly discussed in [4-6] and will not be further discussed here. Other issues that require attention is exposed ground conductors, impassable roads due to land and rock slides, missing bolts or angles from the bodies of towers etc (Figure 14). Corrosion is also a well-known issue regarding OTL towers (e.g. [21-24]). In Crete and Rhodes corrosion issues are mainly observed on the towers' footings as shown in Figure 15. Strangely enough, the issue seems to be more severe in recent lines such as the Atherinolakos-Ierapetra and the South Rhodes-Gennadi lines. Apart from vegetation management, the severity (and thus the prioritization) of other issues is judged on a case by case basis and such works are usually performed when other works of higher priority cannot be conducted or when the crew is in the area and the weather interferes with scheduled tasks of higher priority.

Fig. 14. Maintenance works on the ground: an exposed ground conductor, impassable roads and a hanging angle in a tower's body (noted with an arrow).

Fig. 15. Typical images from footing corrosion in South Rhodes-Gennadi and Atherinolakos-Ierapetra OTLs

H. Thermal imaging

Thermal imaging is an inspection procedure that can easily spot poor connections and other potential hazards. Thermal imaging can be conducted either by properly equipped drones or from the ground with hand held thermal cameras (equipped with a proper lens, capable of sufficient zoom). Up to now, thermal imaging inspections in Crete and Rhodes are conducted yearly at all connection points (tension towers, junctions etc). The most usual findings are poor connections of jumpers at tension towers (Figures 16 and 17). The inspection is conducted during summer time, with hand held cameras from the base of each tension towers and the crew at the same time re-checks vegetation management works, including tree trimming. The condition of roads is also checked during these inspections along with the tower's body, footings etc.

I. Extra jumpers

Poor connections may result to hot spots that may ultimately result to melted bolts and to a generally poor state of the whole connection, as shown in Figure 17. To further compensate this, additional jumpers may be used to connect the initial jumper and the conductor as shown in the bottom left picture of Figure 17 and in Figure 18. This is an approach largely followed in Crete and Rhodes and it has proven a valuable precaution not only against hot spots but also as an added safety measure.

J. Bolts, nuts, cotter pins, broken strands etc

The linemen performing OTL inspections also check for missing or loose bolts, nuts, cotter pins etc. Such findings are not that rare and should be attributed mostly to vibrations, although other factors (e.g. under-tightening) may also play a role. Figure 19 shows instances from cotter pin and bolts about to fall off and a suspension clamp with three missing nuts out of a total of four. Such issues may not be easily spotted during ground inspections due to their nature and also the effect of the sun (a sepia filter had to be used in order to get the first two pictures of Figure 19). Such issues were usually dealt with upon their discovery in case of climbing inspections and thus, especially in the past when climbing inspections were the cannon, were under-recorded, as they were considered minor issues that are dealt with during inspection. Broken conductor strands are also an issue, and may be the result of vandalism (Figure 20) or of conductor swinging/vibrations (Figure 21). The latter is specifically important in case of junctions as the ones found in various locations in Crete, in combination with the effect of wind (Figure 21).

Fig. 16. A typical image acquired by a thermal camera from the ground showing a typical issue (a hot spot in the jumper connection).

Fig. 17. Views of a severe hot spot.

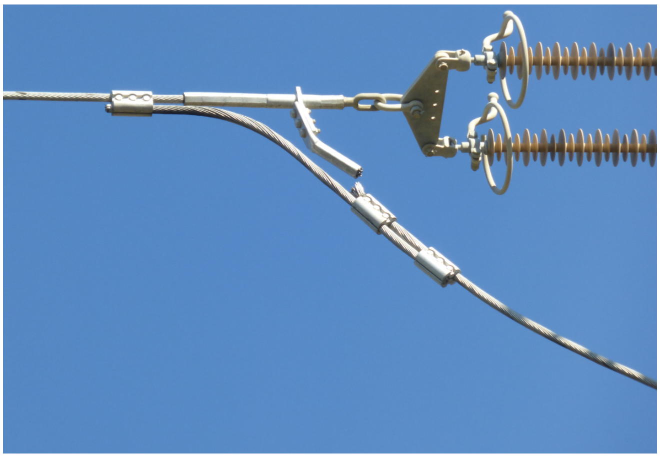

Fig. 18. An additional jumper saving the day.

Fig. 19. Missing and loosened cotter pins, bolts and nuts.

Fig. 20. Broken conductor strands due to vandalism.

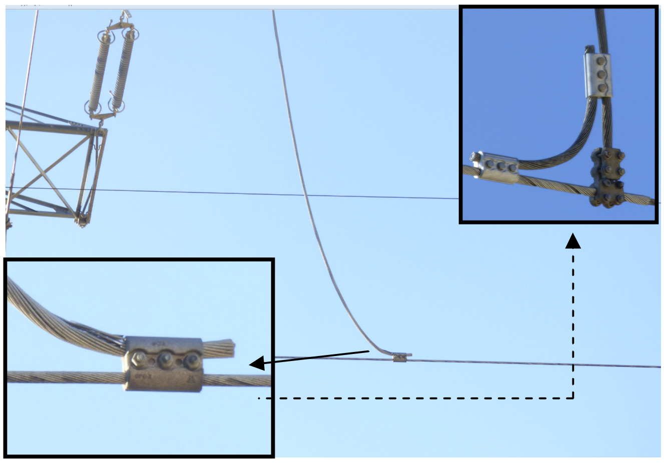

Fig. 21. Broken conductor strands and the improved arrangement at the junction outside the Agia Varvara Substation (the station was constructed as a connection point of a wind farm, an obvious hint that the location is subjected to strong and frequent winds).

K. Special works

Apart from regular maintenance works, the line crew occasionally has to deal with special works. A recent example was the construction of a temporarily connection of the Vryses-Chania and the Chania-Kasteli circuits (in the span between the second and third tower of the Chania-Kasteli line) using wooden structures as shown in Figure 22. This allowed the Chania-Kasteli circuit to be powered by the Vryses-Chania circuit for four days, during which the part of the Chania-Kasteli line, up to the second tower, had to be turned off for necessary works related to the upcoming interconnection of Crete to the mainland. Other such past examples of special works are related to a fallen tower due to landslides [6], a flashunder [13], works on the overhead high voltage conductors inside open-air substation etc.

Fig. 22. An overview of the temporary connection of the Vryses-Chania and the Chania-Kasteli circuits using wooden structures, near the Chania Substation and the adjacent power plant.

IV. ISSUE TRACKING AND PROJECT MANAGEMENT

MantisBT was introduced for OTL maintenance routine work in Crete and Rhodes in 2016 [16]. The basic organization scheme/tree used within MantisBT is shown in Figure 23. Issues were categorized in two basic categories (projects) depending on whether they required de-energizing a circuit or not (will be referred to as Type-1 and Type-2 from now on). Then, they were further divided depending on the transmission system (Crete or Rhodes) and finally categorized in circuits (in case of Type-1 issues) or transmission lines (in case of Type-2 issues). The actual circuits and transmission lines are stated in Tables I to IV along with some additional data (length, number of towers). MantisBT was customized so that each issue had seven basic attributes: status (new, assigned, closed etc), name of circuit or transmission line, tower or span, description, report date, resolved date and attachments. The status and name of circuit/line were given though drop down menu choices that included additional information such as towers' sequence, the relative position of circuits on double circuit lines (left or right) etc. Basic functions (e.g. search and ordering by column) were also provided and the user could also limit the viewing or searching on issues depending on their status (e.g. view the closed issues or not). This way, the user had fast and easy access to issues regarding a certain circuit/line or in a certain area as well as historical data regarding past works.

It should be noted that, initially, MantisBT was installed in the subsection's local server with local access only, as the initial approach was that it would mostly be used to provide better tracking of conducted works. However, it soon became evident that such a system would be put in better use if moved to a web server so that issues could be viewed, reported and edited on site. This way, the system could now further optimize the scheduling of works. To better understand this, one should consider the specific characteristics of the two systems and of the maintenance work. First of all, issues should be grouped together considering their location. This way, the line crew could be stationed for some days in Rhodes or in the western (or eastern) part of Crete and attend several different issues in that general area. It is also important to group all issues related to the same circuit so that the crew is able to conduct as much work as possible on a circuit while it is taken off service. It should also be noted that scheduled works on a certain circuit or tower may be impossible to be performed on a certain day due to the weather in the area or because of other works conducted in the system. In such cases, MantisBT was used to easily provide a wide selection of alternative works in the area. This is a relatively usual problem especially in the eastern area of Crete due to the effect of the terrain (mountains, gores etc) and of the microclimate [20] and such decisions often have to be taken on site.

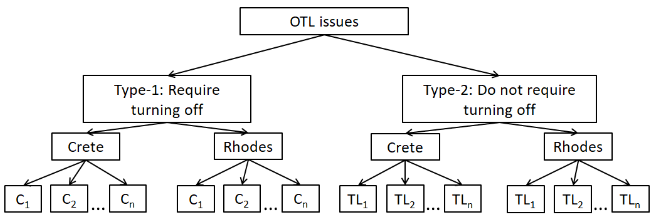

Fig. 23. The basic organiztaion scheme inside MantisBT.

V. ISSUES PER LINE AND CIRCUIT

A breakdown of the recorded issues from 2016 to 2020 is shown in Tables I to V. It should be noted that a circuit may be supported by different OTLs (or parts of them). Thus, Tables I-V refer to different data (length, number of towers) depending on whether the issue refers to a circuit (Type-1) or a transmission line (Type-2). The issues shown in Table I to V do not include a) vegetation management issues that are part of the regular work of contractors [4-5] and issues related to easement and right-of-way cases [6]. On the other hand, they do include issues related to tree trimming or tower base cleaning as these works are generally performed by the subsection's personnel [4-5]. It should also be noted that special issues that were monitored separately either because of their significance or due to their nature may also not be included in the MantisBT records.

The number of issues reported in Tables I to V should be considered as an indication but not a strict measure of the amount of work per circuit or line. This is because reporting, grouping, editing etc of issues was conducted in a way that suited the maintenance needs and did not aim to provide accurate statistical results. For example, a climbing inspection of a whole circuit may be recorded as a single issue if conducted on consequent days but in different issues if conducted in different seasons/years. Identical works conducted to a number of different towers of the same line/circuit may be recorded as a single issue if they are considered as part of a project with a specific schedule. On the other hand, if such works are considered individual, they are recorded as different issues. Works on the same tower are recorded as a single issue if spotted during the same inspection. Regarding the commissioning year stated in the tables, this is an approximate value that may not be accurate for a specific part of a line or circuit (as the system evolved through time and also considering that circuits are often supported by different lines). Thus, the commissioning year illustrates the year that the largest part of the line or circuit was commissioned.

TABLE I. TYPE-1 ISSUES (CRETE)

Circuit	Commisioning Year (Appr.)	Appr. Length (km)	Towers/ Poles	MantisBT Issues	Issue/ km	Issue/ Towers
Atherinolakos-Ierapetra	2004	37.54	105	62	1.65	0.59
Ierapetra-Maronia-Sitia	1977	42.46	115	59	1.39	0.51
Atherinolakos-Heraklion II	2003	115.78	212	99	0.86	0.47
Agios Nikolaos-Ierapetra	2003	20.98	56	26	1.24	0.46
Linoperamata-Heraklion III	1975	4.78	15	5	1.05	0.33
Linoperamata-Heraklion II	1975	19.2	63	20	1.04	0.32
Agyia-Kasteli	1973	23.01	62	15	0.65	0.24
Heraklion III-Heraklion II	1975	14.36	48	11	0.77	0.23
Linoperamata-Stalida	2003	39.31	108	22	0.56	0.2
Praitoria-Ierapetra	1978	56.96	149	30	0.53	0.2
Linoperamata-Agia Varvara-Moires	1974	38.77	107	18	0.46	0.17
Atherinolakos-Sitia	2006	23.25	67	11	0.47	0.16
Linoperamata-Rethymno	1972	46.68	132	19	0.41	0.14
Rethymno-Eyligia-Chania	1972	52.65	146	19	0.36	0.13
Vryses-Chania	1994	19.11	56	7	0.37	0.13
Stalida-Agios Nikolaos	2003	28.81	82	8	0.28	0.1
Chania-Agyia	1973	9.78	34	3	0.31	0.09
Heraklion I-Heraklion II	2003	16.65	51	4	0.24	0.08
Linoperamata-Vryses	1994	80.76	224	13	0.16	0.06
Moires-Praitoria	1978	24.29	72	4	0.16	0.06
Rethymno-Spili	2013	16.71	45	1	0.06	0.02
Linoperamata-Heraklion I	2003	10.15	21	0	0	0
Average	1988	33.73	89.55	20.73	0.59	0.21
Total	-	741.99	1970	456	0.61	0.23

TABLE II. TYPE-2 ISSUES (CRETE)

Transmission Line	Commisioning Year (Appr.)	Appr. Length (km)	Towers/ Poles	MantisBT Issues	Issue/ km	Issue/ Towers
Atherinolakos-Ierapetra	2004	37.16	103	27	0.73	0.26
Linoperamata-Ierapetra	2003	88.81	243	31	0.35	0.13
Linoperamata-Heraklion II	1975	19.2	63	8	0.42	0.13
Linoperamata-Moires	1974	38.77	107	14	0.36	0.13
Chania-Kasteli	1973	32.79	95	11	0.34	0.12
Ierapetra-Sitia	1977	42.46	115	13	0.31	0.11
Linoperamata-Chania I	1972	99.33	277	31	0.31	0.11
System-Heraklion II	2003	5.89	21	2	0.34	0.1
Atherinolakos-Sitia	2006	23.24	67	7	0.3	0.1
Linoperamata-Chania II	1994	99.87	279	22	0.22	0.08
Moires-Ierapetra	1978	80.76	219	10	0.12	0.05
Rethymno-Spili	2013	15.27	45	1	0.07	0.02
Average	1989	48.63	136.17	14.75	0.32	0.11
Total	-	583.55	1634-5=1629*	177	0.3	0.11

*5 common towers in Linoperamata-Chania I and Linoperamata-Chania II lines

TABLE III. TYPE-1 ISSUES (RHODES)

Circuit	Commisioning Year (Appr.)	Appr. Length (km)	Towers/ Poles	MantisBT Issues	Issue/ km	Issue/ Towers
Ialyssos-Rodini	1998	7.9	31	3	0.38	0.1
Afantou-Rodini	1991	18.3	58	5	0.27	0.09
Gennadi-Soroni	2008	53	154	13	0.25	0.08
South Rhodes-Afantou	2017	65	194	10	0.15	0.05
Rodini-Soroni I	1974	25.2	74	3	0.12	0.04
Rodini-Soroni II	1974	25.2	74	2	0.08	0.03
Gennadi-South Rhodes	2017	26.4	74	1	0.04	0.01
Soroni-Ialyssos	1998	19.6	56	0	0	0
Soroni-Afantou	1988	16.2	46	0	0	0
Average	1996	30.08	89.38	4.63	0.16	0.05
Total	-	256.8	761	37	0.14	0.05

TABLE IV. TYPE-2 ISSUES (RHODES)

Transmission Line	Commisioning Year (Appr.)	Appr. Length (km)	Towers/ Poles	MantisBT Issues	Issue/ km	Issue/ Towers
Gennadi-Soroni/Afantou	2008	38.6	114	2	0.05	0.14
Ialyssos-Rodini (up to junction)	1998	2.4	9	1	0.42	0.11
Rodini-Soroni	1974	25.2	79	8	0.32	0.1
Afantou-Rodini	1991	18.3	58	5	0.27	0.09
Soroni-Ialyssos	1998	19.6	56	3	0.15	0.05
Gennadi-South Rhodes	2017	26.4	74	4	0.15	0.05
Soroni-Afantou	1988	16.2	46	2	0.12	0.04
Average	1996	20.96	62.29	3.57	0.21	0.08
Total	-	146.7	436	25	0.17	0.06

TABLE V. OVERALL RESULTS

Crete and Rhodes	Appr. Length (km)	Towers/ Poles	MantisBT Issues	Issue/ km	Issue/ Towers
Circuits (Crete)	741.99	1970	456	0.61	0.23
Lines (Crete)	583.55	1629	177	0.3	0.11
Total* (Crete)	583.55	1629	633	1.08	0.39
Circuits (Rhodes)	256.8	761	37	0.14	0.05
Lines (Rhodes)	146.7	436	25	0.17	0.06
Total* (Rhodes)	146.7	436	62	0.42	014
Circuits (Crete and Rhodes)	998.79	2731	493	0.49	0.18
Transmission Lines (Crete and Rhodes)	730.25	2065	202	0.28	0.1
Total* (Crete and Rhodes)	730.25	2065	695	0.95	0.34

*considers the length and number of towers of lines (not circuits) but all issues for both lines and circuits

Some basic conclusions that can be drawn are:

- The transmission system of Crete has required more maintenance (per km/tower) in 2016-2020 compared to Rhodes which is only logical considering that a) the latter is a generally newer system that was also only recently refurbished/upgraded system (from 66 kV) and b) the fact that the local environmental conditions in Rhodes are more

"OTL friendly" (with the exception of the frequency of lightning strikes).

- The main maintenance works conducted are Type-1 issues (Crete: 456 Type-1 issues over 177 Type-2 issues and Rhodes: 37 Type-1 issues over 25 Type-2 issues). This is indicative of the maintenance approach as Type-1 issues are considered of higher importance and priority.
- The Atherinolakos-Heraklion II circuit shows the maximum number of issues but this has to be attributed to its length, as it is also the longest circuit. If one considers the issues per km (or tower), it is obvious that the Atherinolakos-Ierapetra circuit faces the most issues, followed by the Ierapetra-Sitia circuit. This has to be attributed to the effect of wind (Atherinolakos-Sitia also connects the Maronia wind farm to the system) but also to a minimalistic maintenance approach over a number of years prior to 2016, as the Atherinolakos-Ierapetra circuit was rather recent and the Atherinolakos-Maronia-Sitia circuit was not taken off service easily due to the presence of the Maronia windfarm. However, it gradually became evident after 2016 that significant maintenance of these lines was required and this has resulted to the large number of issues shown in the Tables.
- The years of service should not be considered a decisive factor for the scheduled maintenance works of a line/circuit. As derived from the Tables, there is no direct connection between years of service and maintenance needs. Local factors such as the environmental stress seem to be significantly more decisive.
- The issues trend shown in Figure 24 shows the number of reported, resolved and open issues through time, as acquired by the Mantis Graphs 2.11.1 plugin [21]. The relatively steady number of open issues through time is a result of the existence of low-priority issues that remain unsolved (up to a more convenient time) but also of the fact that new issues are steadily being reported (and solved).

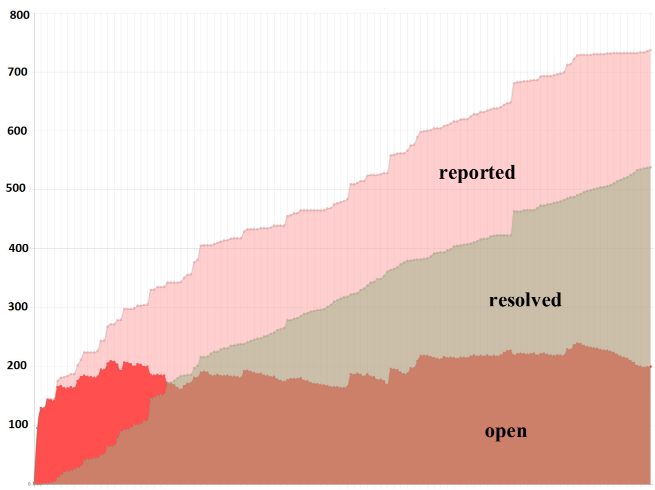

Fig. 24. Issue trends as provided by Mantis Graphs 2.11.1 plugin (all issues)

VI. CONCLUSION

Overhead Transmission Lines are key components of Transmission systems, spanning over large distances and, usually, remote locations, enduring a variety of stresses through their life time. Although, they are often considered a maintenance free piece of equipment by the public, this is often far from reality. This paper provides an insight of the maintenance works of OTLs in Crete and Rhodes from 2016 to 2020. Both these Greek islands are equipped with isolated 150kV Transmission Systems. The records from MantisBT, a project management and issue tracking software, used to optimize maintenance scheduling are considered. Maintenance approaches are discussed in combination with locality issues for both systems.

REFERENCES

[1] K. O. Papailiou (editor), *Overhead lines*, CIGRE Green Books, Springer, 2017.

[2] L. L. Grigsby (editor), *The electric power engineering handbook: electric power generation, transmission and distribution,* CRCPress - Taylor and Francis Group, 2012.

[3] CIGRE JWG C3/B1/B2.13, *Environmental issues of high voltage transmission lines in urban and rural areas*, Technical Brochure 748, 2018.

[4] D. Pylarinos, "Vegetation Rules for Greek Utilities," *Transmission & Distribution World, Vegetation Management Supplement*, pp. 18-22, Jun. 2020.

[5] D. Pylarinos, "Overhead power transmission lines and forests: an ill-regulated relationship?," NatureVolve, vol. 5, pp. 8-10, 2020.

[6] D. Pylarinos, "Overhead Transmission Line Easement and Right-of-Way Cases in Crete, Greece: A Statistical Analysis of 1220 Cases from 1974 to 2019," *Engineering, Technology & Applied Science Research*, vol. 10, no. 3, pp. 5581-5589, Jun. 2020, https://doi.org/10.48084/etasr.3591.

[7] R. Al-Aqeeli and I. Habiballah, "Live Line Maintenance of Transmission Lines: A Review," *International Journal of Engineering Research & Technology*, vol. 9, no. 11, pp. 234-238, Nov. 2020.

[8] H.A.Badgujar,"Live Line Maintenance Of Transmission Lines In Indian Perspective-A Review," *International Journal of Engineering Applied Sciences and Technology*, vol. 4, no. 3, pp. 157-160, Jul. 2019.

[9] K. Fiorentzis, A. Tsikalakis, E. Karapidakis,Y. Katsigiannis,and G. Stavrakakis,"Improving Reliability Indices of the Autonomous Power System of Crete Island Utilizing Extended Photovoltaic Installations," *Energies*, vol. 13, no. 1, Jan. 2020, Art. no. 64, https://doi.org/10.3390/en13010064.

[10] E. S. Karapidakis, Y. A. Katsigiannis, A. G. Tsikalakis, and E. Maravelakis, "Current status and future prospects of Crete's power system," in *2014 International Symposium on Fundamentals of Electrical Engineering (ISFEE)*, Bucharest, Romania, 28-29 Nov. 2014, https://doi.org/10.1109/ISFEE.2014.7050600.

[11] D. Katsaprakakis, N. Papadakis, D. Christakis, and A. Zervos, "On the wind power rejection in the islands of Crete and Rhodes," *Wind Energy*, vol. 10, no. 5, pp. 415-434, Sept./Oct. 2007, https://doi.org/10.1002/we.229.

[12] D. Pylarinos and I. Pellas, "Incorporating Open/Free GIS and GPS Software in Power Transmission Line Routine Work: The Case of Crete and Rhodes," *Engineering, Technology & Applied Science Research*, vol. 7, no. 1, pp. 1316-1322, Feb. 2017, https://doi.org/10.48084/etasr.1182.

[13] D. Pylarinos and I. Pellas, "Investigation of an Insulator Flashunder in an 150 kV OTL of the Power System of Crete," *Engineering, Technology & Applied Science Research*, vol. 9, no. 5, pp. 4851-4858, Oct. 2019, https://doi.org/10.48084/etasr.3198.

[14] D. Pylarinos, K. Siderakis, E. Koudoumas, and E. Thalassinakis, "Polymer Insulators and Coatings in the Cretan Power System. The

Transmission Line Case," presented at the *9th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion (MEDPOWER 2014)*, Athens, Greece, Nov. 2-5, 2014.

[15] N. Mavrikakis, K. Siderakis, D. Pylarinos, I. Pellas, and E. Thalassinakis, "Diagnostic techniques for assessing the condition of composite insulators: The case of the transmission system of Crete," (in Greek), *30th CIGRE Greece National Conference "e-Session 2020"*, CIGRE Greek National Committee, Athens, Nov. 26, 2020.

[16] D. Pylarinos and I. Pellas, "Open/Free Software in Overhead Transmission Line Operation and Maintenance: The Case of Crete and Rhodes," (in Greek), *e-Journal of Science & Technology*, vol. 13, no. 2, pp. 71-86, 2018.

[17] Wikipedia, "*Mantis Bug Tracker*," available at: https://en.wikipedia.org/wiki/Mantis_Bug_Tracker.

[18] M. Dimitropoulou, D. Pylarinos, K. Siderakis, E. Thalassinakis and M. Danikas, "Insulation coordination and pollution measurements in the island of Crete," *ICPADM International Conference on the Properties and Applications of Dielectric Materials*, Sydney, Australia, Jul. 19-22, 2015.

[19] D. Pylarinos, K. Siderakis, N. Mavrikakis, E. Thalassinakis, "Mapping HV Insulators' Pollution in the Mediterranean Island of Crete," *DEMSEE 9th International Conference on Deregulated Electricity Market Issues in South Eastern Europe*, Nicosia, Cyprus, Sept. 25-26, 2014.

[20] J. Stefanakis, E. Thalassinakis, K. Siderakis, D. Agoris and E. Dialynas, "Fighting pollution in the Cretan transmission system. 25 years experience," *Contamination Issues on High Voltage Installations*, Heraklion, Greece, 2001.

[21] W. J. Piper and J. D. Piper, "Tower Footing Corrosion," *Corrosion*, vol. 7, no. 4, pp. 134-140, 1951, https://doi.org/10.5006/0010-9312-7.4.134.

[22] C. S. Johnson and G. S. Thirugnanam, "Experimental study on corrosion of transmission line tower foundation and its rehabilitation," *International Journal of Civil & Structural Engineering*, vol. 1, no. 1, pp. 27-34, 2010.

[23] E. V. Liapunov, "Protection of metal towers of overhead lines from corrosion: non-destructive diagnostic methods and recommendations for additional security," *Cigre*, 2018, Art. no. Art. no. B2-211_2018.

[24] D. A. Da Silva and S. A. Asto Soto, "Maintenance strategies of transmission towers on the peruvian coast affected by salt pollution," *The 20th International Symposium on High Voltage Engineering*, Buenos Aires, Argentina, Aug.–Sep. 2017.