Incorporating Open/Free GIS and GPS Software in Power Transmission Line Routine Work: The Case of Crete and Rhodes

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Abstract—**Geographical Information System (GIS) and Global Positioning System (GPS) software are widely gaining attention in power system planning and operation. Although commercial systems are increasingly being incorporated in power systems applications, they are yet to be fully incorporated in the routine work of utilities (and especially in the work of crews), due to several reasons such as cost, portability, connectivity, performance/speed, infrastructure etc. This paper focuses on incorporating certain open/free GIS and GPS software in routine transmission line work. The case study is the 150kV transmission systems of the Greek islands of Crete and Rhodes which show increased complexity due to certain localized factors such as Greek legislation, the diverse terrain/routes, the segmented design due to the network's growth over the years (regarding both voltage levels and routes) and the use of different Coordinate Reference Systems (or Geodetic Systems) from the Greek state. The main goals of this work was to incorporate open/free software that provided limitless online access points, offline navigation and a user friendly design that wouldn't require any additional training, programming etc. The basic scheme described in this paper can be followed to provide similar results in other applications.**

Keywords-power transmission system; GIS; GPS; offline navigation; free; open; software; geodetic systems; coordinate reference system.

I. INTRODUCTION

A power system can roughly be described as a network with three major discrete parts: generation, transmission and distribution, although further categorizing may be employed depending on the voltage level (e.g. subtransmission, ultra high voltage transmission etc), the type of current (AC/DC) and other characteristics [1]. The "transmission" term includes the long distance routes connecting high voltage substations, usually through overhead transmission lines (underground power cables may also be used). The basic structures of an overhead transmission line are the high voltage conductors and the towers (of various designs) used to support these conductors [1-2]. Line route design traditionally considers a variety of factors such as potential urban growth, location of cities, perpetual or actual location of substations, terrain, weather, legislation, costs etc (e.g. [2-4]) whereas recent developments include the use of advanced geographical representation systems (e.g. [5-7]).

A Geographical Information System (GIS) [8] is used to present and manipulate spatial or geographical data whereas a Global Positioning System (GPS) [9] is used to provide geolocations taken from satellite(s) to earth receivers (independently of telephonic/network connection). Such capabilities may be used in a variety of applications in power systems (e.g. [5-7, 10-15]) and various commercial software can be found that utilize GIS capabilities for power systems (e.g. [16-17]). The most familiar GIS system outside the power industry is undoubtedly Google Earth [18] which is provided free of charge by Google. In fact, Google has recently made its business version (Google Earth Pro [19]) also free [20]. Several other GIS software are also available (a slightly outdated list can be found in [21]) but Google Earth's popularity, user friendly design, speed and additional capabilities offered through other cooperating software, have made it difficult to ignore even in the electric power commercial software industry. Thus, commercial suites incorporate Google Earth (e.g. [22]) whereas the service of entering/depicting the data in Google Earth is also commercially available (e.g. [23]).

This paper focuses on the work done in 2016 to incorporate open/free GIS and GPS software in the routine work of the Transmission Lines Subsection of the Islands Network Operation Department of the Hellenic Electricity Distribution Network Operator (HEDNO), responsible for the operation and maintenance of the high voltage networks of the islands of Crete and Rhodes. Three were the major goals set: the first was to depict the transmission network in a free GIS software that could be used by all interested personnel with no limitations. The second was to migrate the data to a low cost portable device equipped with GPS that could offer free offline navigation. The third was that the scheme followed should require no programming of any kind and that it should be easy to use by all personnel including technicians. These goals were achieved with the use of additional (besides Google Earth) open/free software such as GE-Path [24] and Maps.ME (formerly known as Mapswithme) [25]. The latter works with free mapping data from OpenStreetMap [26] and accepts the import of Keyhole Markup Language (kml) [27] files acquired through Google Earth. A low-cost Android tablet was used as a GPS navigation device. In case of iOS devices, similar software (such as Galileo Offline Maps [28]) may be used. The offline capability of Google Maps [29] was also investigated. It should be noted that additional aid was needed to move through the different coordinate reference systems and although such a software is freely available [30] and widely used in Greece, the simpler approach of online bulk convention through a website [31] was followed in this case. The overall scheme is described step by step in the following sections.

II. THE CASE OF CRETE AND RHODES: BACKGROUND

The Greek power system was constructed, owned, operated and maintained by the Public Power Corporation (PPC) [32] until 2011. Following EU directives, PPC broke up and the new scheme was (roughly) that the distribution department formed the Hellenic Electricity Distribution Network Operator (HEDNO) [33] whereas the transmission department formed the Independent Power Transmission Operator (IPTO) [34]. However, the isolated high voltage transmission systems of the Greek islands of Crete and Rhodes remained under the responsibility of HEDNO after the break up and are operated and maintained by HEDNO's Islands Network Operation Department. The voltage level for both systems is 150kV today, but this is a result of a gradual upgrade from 66kV. In fact, Rhodes moved to 150kV in the current decade whereas although most of the Cretan network had been upgraded since the 70s, a small part was still functioning at 66kV in the 00s. As power demands grew, the system kept expanding through the years with new substations and line routes being added and single-circuit lines being upgraded to double-circuit lines. At the moment there are three major upgrade projects in progress: upgrading a single circuit part of the Cretan power system to double circuit, adding a stepdown substation in Crete and adding a power plant in Rhodes. The current and near future situations are depicted in Figures 1-2 and Table I.

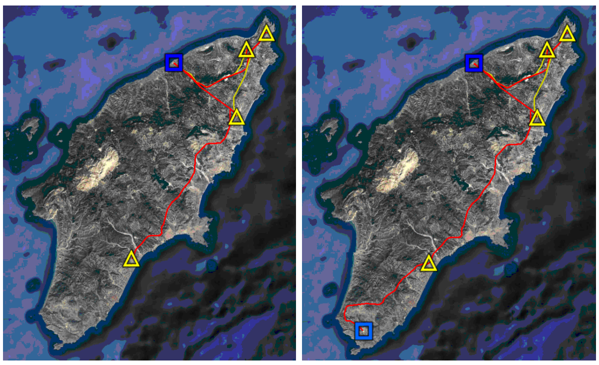

Fig. 1. The power system of Rhodes. Left: current scheme, Right: near future scheme. Squares denote power plants and triangles denote step down substations. Red line denotes a double circuit and yellow line denotes a single circuit. (Screenshots from Google Earth Pro, Map data: Google, Image LandSat, Data SIO, NOAA, U.S. Navy, NGA, GEBCO)

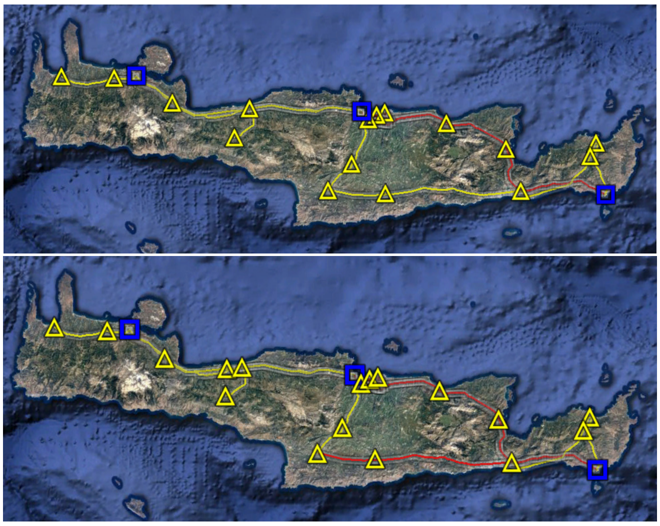

Fig. 2. The power system of Crete in 2016. Up: current scheme, Down: near future scheme. Squares denote power plants and triangles denote step down substations. Red line denotes a double circuit and yellow line denotes a single circuit. (Screenshots from Google Earth Pro, Map data: Google, Image LandSat, Data SIO, NOAA, U.S. Navy, NGA, GEBCO)

TABLE I. TRANSMISSION SYSTEM DATA

		Power Plants & Substations (S/S)	**Transmission Line Circuits (S/S to S/S)**	**Appr. Line Axes Length (Tower to Tower)**	**Number of Towers**
Today	**Crete**	19	22	581.5 km	1629
	Rhodes	5	8	120.2 km	361
Near Future	**Crete**	20	24	581.5 km	1629
	Rhodes	6	9	146.5 km	435

As shown, it is not easy to get a clear image of the system from Figures 1-2 and Table I. This is largely because of the segmented design and gradual upgrade of the system. In an effort to minimize costs, new substation have been connected to the system using existing routes by upgrading single circuit lines to double circuit lines and adding some new towers when necessary. It should be noted that when a transmission line is to be constructed, private property (the area needed for each tower) needs to be expropriated. Further, under Greek law, an area of certain width to the left and the right of the line needs to be partially expropriated in order to enforce building regulations/prohibitions. Therefore, whenever a new route is decided an announcement is posted in the Official Government Gazette (OGG) [35] which is published and maintained by the National Printing House [36]. For every route addition/change a new announcement in the OGG has to be posted. Today, there are announcements in over 60 different issues of the OGG regarding just the transmission lines of Crete currently in service with the first announcement dating back in the 60s. And since expropriation takes place, each tower has to be named in order to be legally referred to. The initial naming usually consists of numbers that increment throughout the line's route.

However, during the various stages of studying and construction, towers may be added or removed. This creates a problem as old towers cannot be renamed (in legal terms) and the problem becomes more intense as new routes and towers are added. Further, it is rather often that lines are constructed next to each other (in an attempt to follow the optimal route in the area). Thus, towers standing next to each other may have the same number in their respective OGG issues. This means that an additional notation is needed to safely discriminate them in the field. This notation usually comes from the first letters of the (initial) two ending points/substations. However, as single circuits are upgraded to double circuits and as parts of older lines are used for new ones, following a coherent and safe to interpret naming scheme throughout the network becomes impossible. Additionally, it is important to note that only one double circuit line (in Rhodes) connects the same two substations with its both circuits. This means that there are several "junctions" along the network (Figure 3). Further, there are also cases that single circuit lines coming from different directions meet at a certain tower and from there on continue their route together in a double circuit line (upper right image in Figure 3).

Fig. 3. Images from the power transmission system of Crete and Rhodes. (Screenshots from Google Earth Pro, Map data: Google, Upper Right image: (c) 2016 Digital Globe)

At this point one should add the additional difficulty of the terrain. The usual line route design tries to make the most of mountains in an effort to minimize costs and keep the lines away from urban areas. This means that getting to a certain tower or from one tower to the next may prove tricky as different mountain roads/paths need to be followed. In fact, a significant part of the training of new linemen has to focus in familiarizing with the different routes needed to be followed to reach each tower.

III. COORDINATE REFERENCE SYSTEMS

Geodetic systems (or Coordinate Reference Systems) are coordinate systems used to map the location of places on Earth [37]. However, moving from a three dimensional object (of imperfect shape) to two dimensional maps becomes tricky. Each geodetic system refers to a base point (or "anchor"). As the distance of mapping from the base point decreases, the accuracy increases. Therefore, although there is a universal geodetic system (the World Geodetic System usually referred to as WGS84) [38], countries also maintain their own geodetic systems for a variety of reasons (historical, accuracy, independence from the US provided WGS84 etc). In the case of Greece, things are slightly more complicated as historically there have been various different geodetic systems used by various public services (with different base points and representation/calculation forms) [39]. Thus, the transmission line construction files may include coordinates in various reference systems (although detailed coordinates for each tower may not be documented in case of older lines, which are not few). Further, queries from state services (or citizens) may also refer to different coordinates systems. Today, the Hellenic Geodetic Reference System 1987 (HGRS87) (or Greek Geodetic Reference System 1987–GGRS87 or EGSA87 using the Greek acronym) [40] has been accepted by most involved parties as a common reference. However, the official goal is to migrate to the Hellenic Terrestrial Reference System 2007 (HTRS07) [41]. It should be noted that moving from one coordinate system to another is bound to insert some deviance, for example moving from GGRS87 to HTRS07 will insert a difference of 8 cm or less throughout the country whereas moving from HTRS07 to WGS84 inserts an average difference of less than 1 m [41].

There are several websites that offer an online transformation capability, but most of them offer just a single point transformation capability (e.g. [42]). However, since a list of some coordinates in GGRS87 was available, a bulk transformation service was needed. A freeware software [30] that conducts most transformations (from one system to the next) is widely used in Greece (especially in the private sector), however a simpler approach through the website of a private company [31] that offers free bulk transformation between four systems (WGS84, EGSA87, HRTS07 and HATT) was followed in this case. It should be noted that several sites of public agencies may be used for random cross-checking (e.g. the National Cadastral Agency offers the ability to put points on the Greek map using aerial photos taken in 2007-2009 [43]).

IV. WORKING WITH BULK DATA

The next step would be to import the data in Google Earth. This can be done easily via two ways: the first is to use a website that offer free conversion of the coordinates data file to a Keyhole Markup Language (kml) file that can be simply drugged and dropped in Google Earth. For example such a service (that accepts both xls and cvs file types) is available at [44]. The second way is to switch to the free business version of Google Earth (Google Earth Pro [19]) and use the provided import function. However, Google Earth Pro accepts only csv files and this inserts an additional issue for the Greek user. In Greece, the comma is used as a decimal separator and the point (fullstop) is used as the thousand separator. This inserts an obvious problem when working with Comma Separated Values (CSV) files that use the comma as a delimiter symbol and the point as a decimal symbol. Although, MS office offers the ability to use custom symbols (independently from system settings) this ability seems to be rather buggy when working with csv files and other software. To avoid any issues, system settings should be set in the manner followed by csv files. These settings should be maintained also when exporting kml data to a csv format. It should be noted that in order to maintain the name of each point (placemark) through the import process, the user has to use a template for all placemarks, or else all names will be set to null [45]. Keeping the description is slightly more complicated. In this particular case, the online transformation from csv to kml through [46] has been employed, which also provides additional capabilities.

V. WORKING WITH GOOGLE EARTH PRO AND GEPATH

Some fine adjustment may be needed for placemark location for an optimal viewing result, which should be fairly easy as most towers are clearly visible in Google Earth (Figure 4). This deviation could be generated through transformation accuracy errors (from GGRS87 to WGS84) or through the inaccuracy inhibited when low cost GPS devices have been used by the line crew to note the coordinates of placmearks in cases that official coordinates do not exist. The next stage is to add a placemark to each side of double circuit towers (on the end of the longest visible cross arm) in order to later depict circuit routes (Figure 4). Then, GEpath [24] can be used to automatically connect the cross arms placemarks and also calculate distances (e.g. from both ends and/or the previous and next placemark in each group) (Figure 4). It should be noted that if a tower is not visible in Google Earth (e.g. due to a cloud) the user may refer to older satellite images. However, a previously undocumented bug should be reported here: if the user moves back in time and then returns to the current date, an overall displacement of the satellite images seems to take place which may throw the whole project off track.

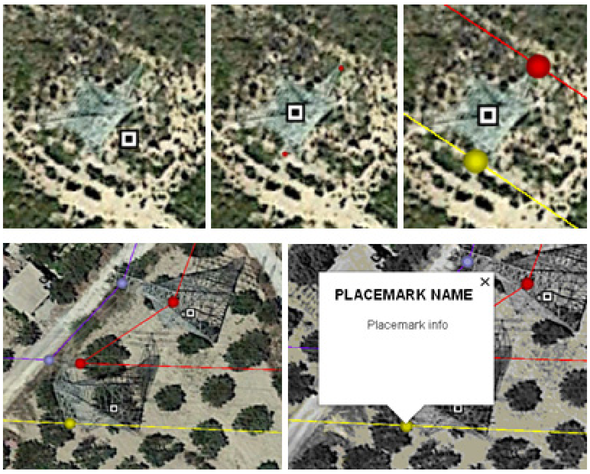

Fig. 4. Upper pictures: Working in Google Earth: left: tower placemarks may need fine adjustments, middle: adding cross arms placemarks, right: adding circuits using GEpath. Bottom pictures: screenshots from the final result (line axes have been deselected for viewing in this case). A click on each placemark (square or dot) will show its name/info. An example is shown in the bottom right picture (for the yellow cross arm placemark). The actual info have been removed to portary the generic scheme. (Screenshots from Google Earth Pro, Map data: Google)

It is also important to note that the desired formatting of lines (width, color) can be set in GEpath but also in Google Earth. Additional placemarks may be used for substations (Figures 1 and 2) and GEpath can also be used to draw the area limits of each substation. Finally, the user can now organize the data in Google Earth in the way that makes most sense to him. The tree-like organization of data in Google Earth allows for the user to have branches (and sub-branches) so that the needed information at a given time can easily be selected for viewing. However, as explained in the following section, data may have to be tighter organized in order to be ported to other software/devices.

VI. OFFLINE NAVIGATION

The next step is to use the data to facilitate offline navigation. On-line navigation was not considered as this would require a certain cost and would also mean a dependency on connectivity (which could be a major issue when following line routes through mountainous areas). It should be noted that usual low-cost GPS navigation devices are insufficient for this purpose as most of them do not offer a bulk import function and those that do, usually have a limit on the number of placemarks that may be imported (2,000 placemarks is the usual limit, which is rather lower than the needed in this case). Thus, it was decided to purchase a low-cost tablet that could be equipped with free software that offers off-line navigation. The Maps.ME software (previously named Mapswithme) [25] was chosen as it provided offline mapping, navigation, map editing, kml import function and worked on low cost Anroid tablets. The software gets the map data from OpenStreetMap (OSM) [26]. It should be noted that Galileo [28] seems to be a software of similar function for iOS. It should be stressed that each individual segment of data has to be imported as an individual kml file in Maps.ME in order to be selectable for viewing as Maps.ME does not support tree-like schemes for kml data. By "clicking" each placemark, its name and attributes/information appear. Thus, the cross arms placemarks have to be maintained (circuit line routes are not clickable) in order for the user to be able to get each circuit's name (usually referring to the two ending points) and info. Different colors may be used for each circuit route.

The data can be organized in various ways to provide better usability, keeping in mind that the Maps.ME software does not provide a tree-like organization of kml files. The approach followed in this case was to have people working with a small number of kml data files so that selecting and deselecting items for viewing would be easy. One kml file is used for tower placemarks, one for line axes (a line connecting tower placemarks), one for cross arms placemarks, one for the actual circuit lines and one for the placemarks and area limits related to substations. The followed scheme is shown in Figure 5. However, other approaches can also be followed (individual files for each line/circuit, a file for phase position, a file for insulator types, a file for tower design etc). In the approach followed in this paper, the crossarms placemarks' names include the name of the tower and the two connecting ends (stating both substations and the name of the isolators/disconnectors/switches). Each placemark's info may refer to distance (from ends or from next/previous placemark), tower design/type, insulators, position of phases etc. Screenshots from the final result (Maps.ME software equipped with all data and used in our low cost tablet) are shown in Figures 6-11.

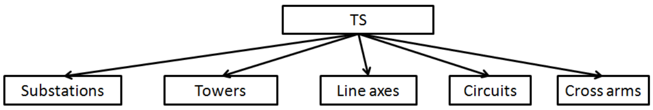

Fig. 5. The tree-like scheme followed for the organization of data..

During this work, two software versions were used: one available through SlideME (version 4.4.3, Figures 6-8) and one available through Google Play (version 6.5.2, Figures 9-11). A multiple placemarks representation with no line axes is shown in detail in Figure 7 whereas the tower and line axes representation (with no circuit lines and cross arms placemarks) along with the navigation interface is shown in Figure 8 (from the 4.4.3 version). It should be noted that, in general, different colors should be assigned to axes and circuit lines to avoid confusion. A significant advantage of this software is its steady zooming function during navigation, which suits better this particular task since it can provide a wider view of the area which allows the crew team to identify distant towers during navigation (Figure 9). Further, newer software versions (such as the 6.5.2 version) provide additional/improved functions (easy-to-use map editing, calculating routes from starting points different to the user's location, calculating hiking and bike routes, improved searching etc), increased map detail and significantly more preset placemarks with some of them, strangely enough, corresponding to towers (marked as "Power Towers"). However, increased zoom is needed to make these preset placemarks visible (as dots) and their positioning should not be considered as accurate since the placemark data are probably offered by other users through the map editing capabilities provided (Figure 10). In general, the latest version should be used but older versions (such as the 4.4.3 tested in this case) are also sufficient for the task.

Fig. 6. The transmission System of Crete (left) and Rhodes (right) ready for offline navigation (screenshots from Mapswithme/Maps.ME version 4.4.3, Map data from OpenStreetMap)

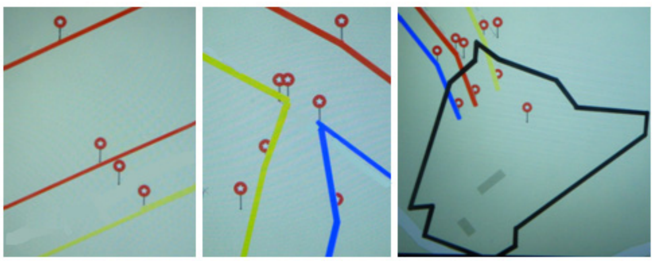

Fig. 7. Multiple placemark representation with the line axes deselected for viewing. Left: a single circuit line (up) and a double circuit line (down). Middle: the "junction" depicted in the lower left image of Figure 3. Right: entering a substation (an extra placemark is used for the substation and the area limits are drawn in black) (screenshots from Mapswithme/Maps.ME version 4.4.3, Map data from OpenStreetMap)

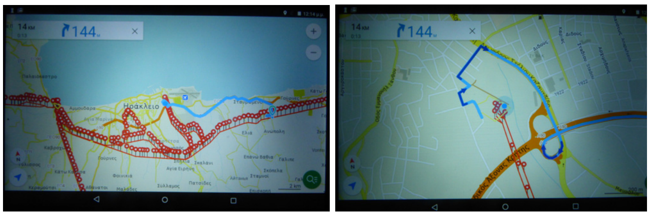

Fig. 8. Offline navigation using the Mapswithme software and following a single placemark represenation (only tower placemarks and line axes selected for viewing): zooming out (left) and in (right) (screenshots from Mapswithme/Maps.ME version 4.4.3, Map data from OpenStreetMap)

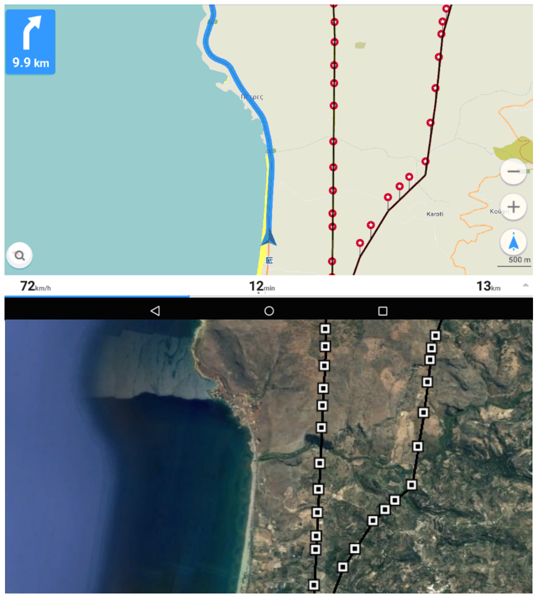

Fig. 9. Upper image: Navigation with tower and axes placemarks on (Screenshot from Mapswithme/Maps.ME version 6.5.2, Map data from OpenStreetMap). Lower image: The same area as shown in Google Earth Pro (Screenshot from Google Earth Pro, Map data: Data SIO, NOAA, U.S. Navy, NGA, GEBCO)

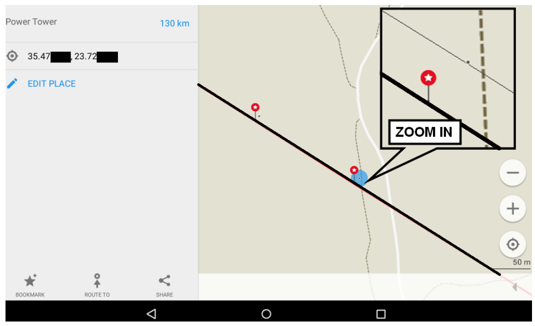

Fig. 10. Several preset placemarks are provided by Maps.ME for "Power Towers". Increased zoom is needed to make these preset placemarks visible (as dots) and their location is not always accurate. In this image two screenshots have been merged: the background screenshot shows a dot placemark selected and its description to the left reads "Power Tower" (the last four coordinate digits have been deliberately blackened). The exact position of the tower migrated through the scheme described in this paper is noted with the red star placemark. The foreground screenshot shows a zoom-in of the area. (Screenshot from Mapswithme/Maps.ME version 6.5.2, Map data from OpenStreetMap)

It should be stressed that the representation in Google Earth is made from a certain angle whereas Maps.ME uses a fully vertical representation, so it is obvious that data files that look perfect in one software will not look that perfect in the other (e.g. both cross arms placemarks may appear on the same side of a tower or the tower placemark may appear closer to one of the two cross arms placemarks). This is a minor issue and the user can either ignore it or create different files specially designed for viewing in each software. The approach followed in this case is to aim for a perfect visual result in Google Earth as this representation is using actual photographs instead of maps. The navigation on the other hand, is usually conducted using only the towers/axes kml files whereas cross arms and circuit line data are used only in special cases (e.g. to discriminate between the two circuits after reaching a certain tower) and thus such issues were considered as minor problems that could be ignored (Figure 11).

It should be mentioned that an offline function is also provided through Google Maps [29] however the map data should be periodically downloaded and both Google Maps and Google Earth seem to hang up in our low-cost tablet. However, these are interesting alternatives as they would provide actual satellite images instead of maps and some mountain roads may not be visible in maps. There is a possible workaround for that issue however when using Maps.ME and OpenStreetMap as they provide a map editing function and also custom routes may be drawn in Google Earth and then be ported as kml files. Finally, it should be noted that other devices (e.g. private smartphones of employees) may also be equipped with the software and data and be used for navigation.

VII. Additional Potential Uses

The main objective of this work was to provide the capability of free mapping and navigation of the transmission systems of Crete and Rhodes, mainly to aid the work of the Transmission Lines Subsection of the Transmission System Operation Section of the Islands Network Operations Department of the HEDNO S.A. Besides the basic uses described previously in this paper, there are other potential uses that could be mentioned. For example, the kml files may also be given to employees working on other sections in order to help them get a more representative image of the system and possibly help them in their work (e.g. Dispatching Centers may use it to assess potential hazards such as ongoing fires). An additional use is related to Greek legislation that, as explained earlier, enforces restriction on construction/building activities in proximity of high voltage lines. The restriction may be e.g. a full prohibition of any building construction. However, the exact restriction is not the same for each line nor throughout each line's length, and field inspections and topographical measurements may be required. Therefore, placing a certain property on the same navigation device with the transmission system can be of use. Further, as line crews are equipped with this low cost system and use it as a navigation device, it is easy for them to note placemarks of interest during inspections or other regular work throughout the system (e.g. a tree that needs to be cut). The cumulative distance calculation function provided through GEpath may also be used to assist fault location. The data can also be used for public display. The easiest way to do this is to use the Google Maps embedding function [47]. An example for Crete is shown at [48]. In this case, certain data (names, exact position of towers etc) have been removed (a similar policy has been followed throughout this paper) and only tower placemarks and line axes are depicted.

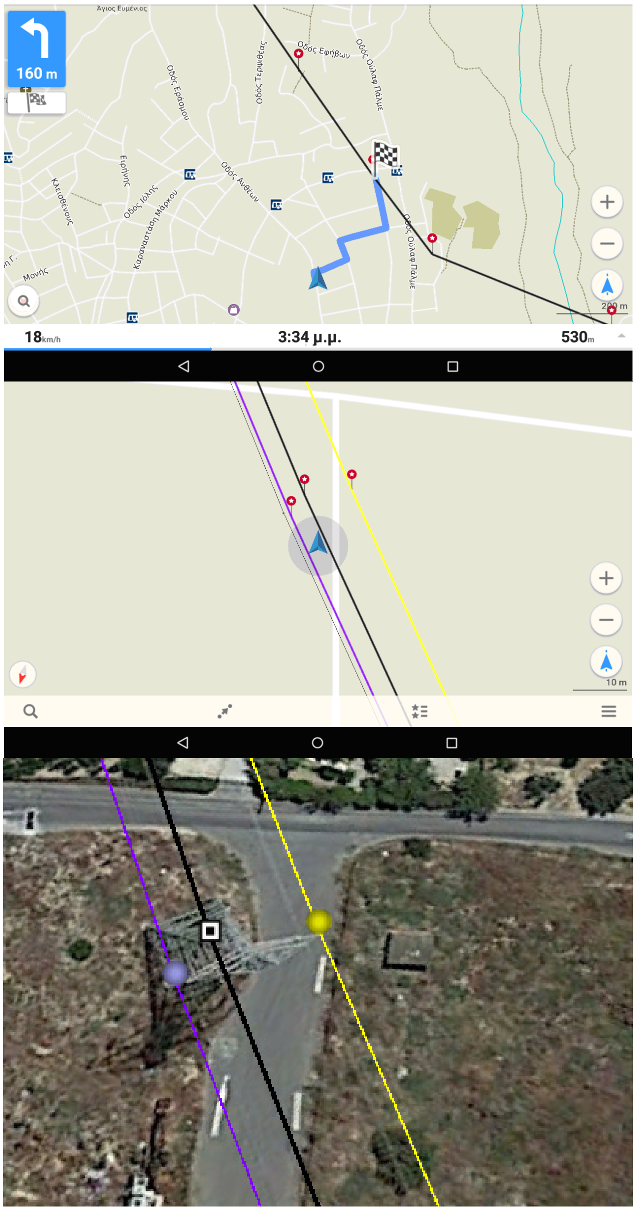

Fig. 11. Upper image: navigating to a certain tower (only tower and axes shown). Middle image: reaching the tower (turning on all placemarks). (Screenshots from Mapswithme/Maps.ME version 6.5.2, Map data from OpenStreetMap). Lower image: View of the tower in Google Earth Pro (Screesnshot for Google Earth Pro, Map data: Google).

VIII. Conclusion

Incorporating GIS and GPS technology may significantly assist the work of any geographically spread out organization/service and, obviously, power transmission systems. The focus of this paper is on incorporating open/free GIS and GPS software to assist the routine work of the Crete-Rhodes Transmission System Operation Section and especially of the Transmission Lines Subsection. The isolated transmission systems of these two Greek islands demonstrate several peculiarities that strengthen the need and increase the positive effect of such tools. The characteristics of these systems are discussed and a detailed step by step guide throughout the overall project is provided. The basic goal accomplished was to provide a free and user friendly scheme that would provide unlimited online access and offline navigation. The scheme described in this paper is currently used by the Transmission Lines Subsection of the Islands Network Operation Department of the Hellenic Electricity Distribution Network Operator. However, the basic scheme can also be used as a low cost alternative for other tasks inside or outside the power sector.

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