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SC A3 - Transmission & Distribution Equipment
PS 2 / Decarbonisation of T&D equipment
Life cycle management and the impact on the design of T&D

UAV usage for Asset Condition Assessment

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SUMMARY

Israel Electric Corporation ltd. and an Israeli highly experienced UAV technology company developed and implemented a unique method for “Unmanned Airborne Vehicle (UAV) usage to Asset Condition Assessment of Switchgear and Substation's exposed equipment without outage”. The method reduces costs and increase reliability in finding extreme small deformation phenomena in huge facilities.
Using this method make possible to successfully overcome the challenges of extremely high Electro – Magnetic fields near energized components (400 kV and 170 kV), precise and secure navigation, achieving the required resolutions and time to market requests.
This method can be easily used in a wide range of application – inside and outside Substation and switching station yards for energized and exposed Transmission and Distribution equipment, to assess the serviceability, Assets Health and/or simply monitor possible degradation. In some cases, this method can be extrapolated in indoor monitoring applications.

KEYWORDS

UAV, energized network environment, external failures, high voltage network accessories, insulators, advanced image processing, diagnose.

INTRODUCTION

Israel Electric Company ltd. ("IEC") executed between 2018 and 2020 a pioneer project of Unmanned Airborne Vehicle ("UAV") use for Asset Condition Assessment of Switchgear and Substation's exposed equipment without interrupting the facilities' operation. The purpose of the project was to intelligently prioritize the replacement of external diameter's / busbar's equipment, without compromising the reliability of the National Grid. The method, developed in collaboration with an Israeli highly experienced UAV technology company, reduces costs and increase reliability in finding extreme small deformation phenomena in large area facilities.
Using this method made possible to successfully overcome the challenges of extremely high Electromagnetic (EM) fields near energized components (400 kV and 170 kV), precise and secure navigation, achieving the required resolutions and time to the Utility's requests. This method can be easily used in a wide range of application – inside and outside Substation and switching station yards for energized and exposed Transmission and Distribution equipment, to assess the serviceability, Assets Health and/or simply monitor possible degradation. In some cases, this method can be extrapolated in indoor monitoring applications.

OBJECTIVES

The Pilot project objective was to provide a visual identification of every "cap-pin" type insulator deterioration, namely, to perceive and document a displacement of at least 1 mm at all insulators in all strings, see emphasis in Fig.1. A total of 200 ("weak" type tension) dead-end chains, of which some are double string with 4 - 5 insulator in each string, and others single strings with 5 insulators (old Rosenthal antifog/aeroform type).

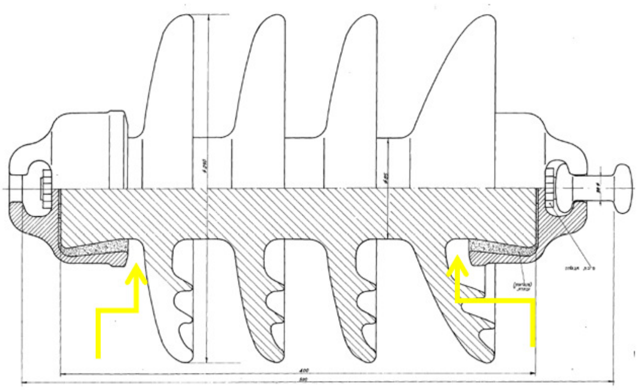


Figure 1: Profile and sizes of Dead-End Antifog - type Insulator:
Emphasis on possible unsheathing areas.

EXECUTION

In both pilot projects, the operations sequences where determinate by strict safety rules, every step was analyzed and approved by the facility responsible prior to deployment of the UAV. Also, due to cyber restricts imposed by the facility management, the collected data was downloaded in a local PC without external link possibilities. Later, the data was processed in safe environment. The main steps of the mission occurred as follows:

a. Airborne System Calibration: First, an off-site calibration was carried out to make sure control capabilities and verify maneuvering capabilities of the UAV in actual weather conditions, near approximately same EM field intensity - from one side only. The focus was to keep, and control specified safety distances.

b. *In-situ* Command and Control deployment, followed by a side flight to proof that it is possible to maneuver the UAV close to an actual EM field with same intensity as in the actual target zone.

c. With the approval and active monitoring by the security supervisor on the site, the mission was performed according to specifications.

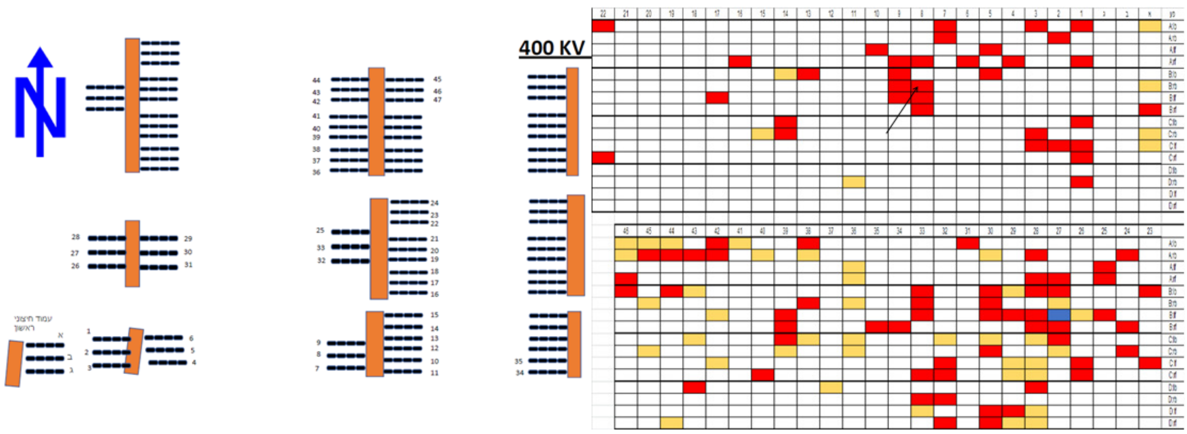
d. Although it is possible to follow actual images taken by the UAV during the flight, there was no need to detect the unsheathing in real-time.

e. During the fly, all insulators' edges (some of the insulators were previously coated with Silicone Guard paste against pollution) are photographed at least 2-3 times so that the photo angle would change in the time, between 80 and 90 degrees, depending on the technical specifications. During the initial deciphering (by the service provider), this method allowed a view from several points of view assuring a proper analysis. A total number of 3500 extremely high-resolution pictures were taken during both projects.

f. The service provider filed an initial report including a risk matrix, conclusions and samples of deciphering a failure after one week, see Figure 2.

g. Experts from IEC analyzed the pictures in a dedicated workshop: all "suspect as fault" cases were discussed and the final conclusion was obtained be "vote". Duration: 2 hours for each project, see examples of this analysis in Figure 3. The results of this phase are shown in Figure 4.

h. The success of the risk matrix provided by the service provider ("learning curve rate") reached 87% after the second project.



(a) (b)

Figure 2: From general (schematic layout) Switchgear profile (a) to "risk matrix" as determined by the service provider (b): RED = Certain Failure, ORANGE = Suspected Failure.

Each matrix element corresponds to several pictures: after the workshop, only one picture was linked to the actual failure, see examples in Annexure. The final stage was to prioritize all the results by grouping accordingly by Diameter (bus bar respectively) identification, see Figure 4.

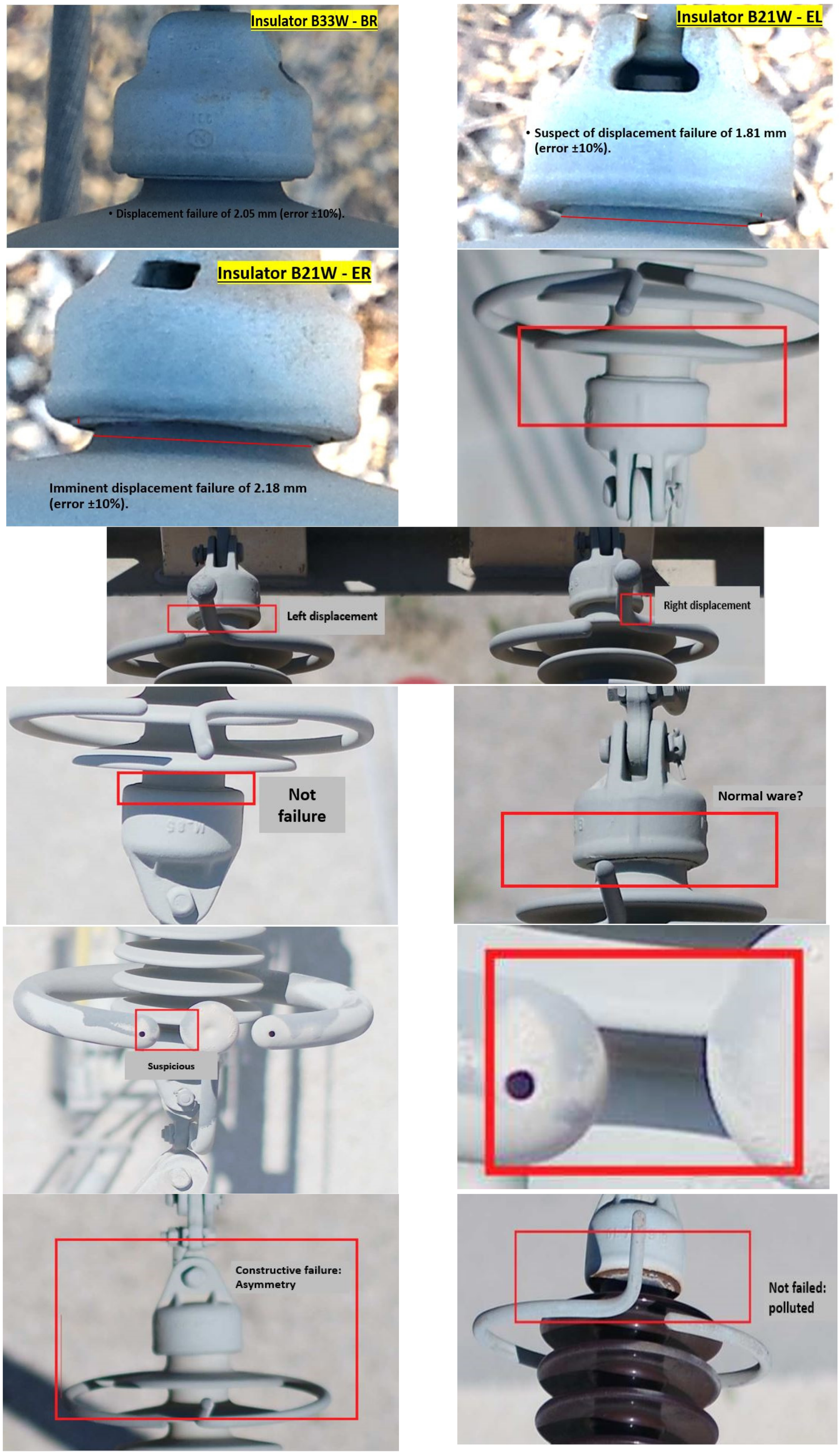


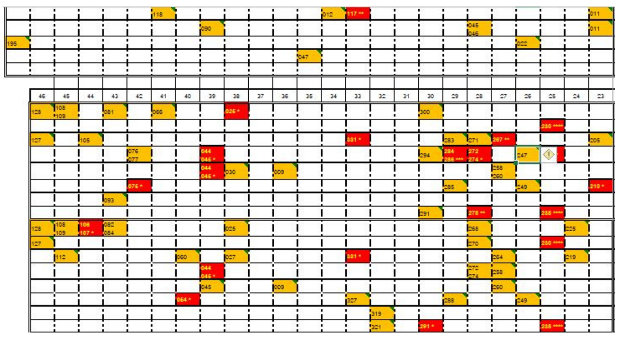
Figure 3: Examples of insulator photos, with IECo's experts diagnose.

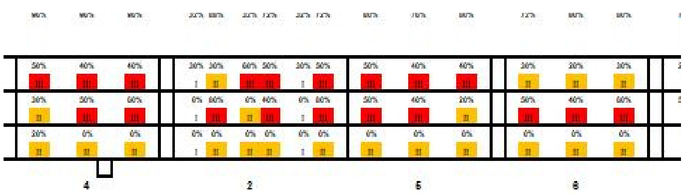
Criticality is assessed by identifying individual failed insulators positioned in the string in such a manner that the failure cannot be avoided in spite the fact that all insulators are in double string construction.

Criticality (Certain failure assessment)	No. of occurrences	String	Classification
	9	A	12
*	2	1	8
*	1	3	10
	1	7	16
(**+) ***	3	8	2
	2	9	15
	1	22	16
(****+) ****	6	25	1
	2	26	15
**	6	27	5
(*+) **	9	28	3
***	3	29	4
	3	30	14
*	2	33	9
	1	36	16
*	4	38	7
(*+) *	4	39	6
	1	43	16
*	1	44	11
	2	45	15
	4	46	13

Figure 4: Classification (Prioritization of insulators strings with criticality specification (same color code as in Figure 2). "*" is the level of imminent failure risk.

The final approved matrix is shown in Figure 5.





(a) (b)

Figure 5: Final stage of Diagnose: (a) the “Certain failure” and “Probably in advanced stage of degradation” failure modes are emphasized in Red and Orange respectively, including the photo ID; (b) the respective Risk assumptions for every string.

DISCUSSION

The main differences between the UAV method and the ground ("bottom – up") observations, with/without photography method are briefly described as follows:

- There is great difficulty in identifying and establishing a comprehensive visual view in the binoculars by simply looking up – mainly near the suspension points (such as for insulators to assess a possible beginning of a "slip out" process in dead – end strings (less than 1 mm);
- All findings based on ground methodology are only "assumption" / suspected failure, and need subsequent confirmation, usually during a planned outage.
- From a snapshot taken from ground, one cannot correctly rank the failure severity and an additional test / method should be employed.
- However, the accumulated documentation after UAV flight – by downward photography, make possible for an objective ranking process, involving Utility specialist in a very short analysis session (usually 2 – 3 hours for a complete substation. After concluding the ranking, a portfolio of works is prepared with appropriate scheduling, priorities and optimal replacement sequence.

TEHNICAL PERSPECTIVE

There are many works published in CIGRE, one of the first Raulf and Claud [6] discussing kinematic control of drones in real time sensing, or such like Roze, Maliet, et. All [1] dealing with the problems arise in executing projects in intense EM fields. The quality of photography using flying robots is discussed by Fiete [2, 3] and different mathematical possibilities to analyze the quality of collected images are explored by Thurman and Fienup [4]. Coelho, Andre and Martins discus Drone using Lidar capabilities and requirements [5]. All those works are dealing in general with Overhead lines inspections, hardly discussing issues regarding maneuverability of a drone inside the EMF of an energized Substation / Switchgear compound.

In this project the Israeli experienced UAV professional team was required by IEC to bring an aerial photography solution for unique phenomenon of anomalies detection in energized Switchgears and Substations. In order to give the best response, a thorough learning process, to understand the challenges, precise planning and throughout preparations were made. The UAV service provider company identified key complex issues to deal with, in order to fulfill the IEC's requirements:

- Regulations-CAAI (Civil Aviation Authority Israel) and IEC regulation and instructions.
- Ultra-high-resolution imagery-Achieving ultra-high resolution in a safe distance (EMF influence) and very strict angle of photography.
- Environmental issues- Determination of environment limitations: light condition, weather conditions.
- Navigation& Orientation - site mapping and real-time orientation method.
- Efficiency- Flight plan under extreme tight condition: imagery order, Line of Sight (LOS), safety.
- Real-time Quality Assurance method.
- Debrief- using proven professional debriefing methods for better understanding and future improvement.
- Outcome analysis - High level of photo analysis for interpretation of unique phenomenon.

Figure 5: Breakthrough flight photo

After identifying all the challenges, an exclusive multidisciplinary approach has been established. Highly experienced specialists were chosen for this mission. The company offered a breakthrough method to answer all the challenges with full safety operation. To reduce risks and to maximize IEC's personnel assurance in this method, the company set a safety, slow and steady progressive flight plan until full scale operation above a critical facility without outage required.

Figure 6: Drone Experts at the C&C inside Substation compound.

Fast and continuous learning curve was the heartbeat of the project. Every move was documented and several breaks for debriefing were made. Real time adjustments and quality assessment were made. At the end of the working day, all data was backed up and sent to analysis.

The 4 stages analysis process comprises:

1. Photos' quality assessment and correction.
2. Preliminary analysis for "Good "versus "Suspicious"
3. Deep analysis of all photos related to a "Suspicious" case
4. Double check of marked findings.

Figure 7: UAV over Live EHV circuits

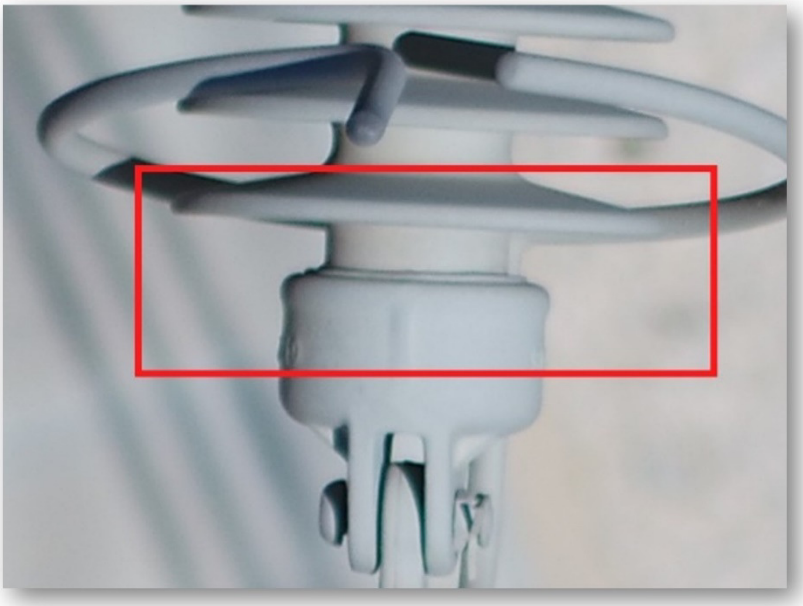


Figure 8: Good light, good focus, Ultra-Resolution achievement

Over 1700 insulators were photographed in a single working day (Figure 7), using 3 different cameras and 7 different imagery methods to guarantee full coverage. The main challenges were to keep 100% orientation, navigation and imagery standardization to meet the required output quality (Figure 8).

The common goal of a Utility and the Service Provider - our vision - is to have an AI algorithm capable to execute an unbiased analysis:

- To develop its own of the photographic images taken in controlled / monitored conditions;
- To achieve this goal a Big DATA platform should be established first. Even then, the complexity leads to the need of a "human in the loop" procedure for deep interpretation of raw and post processed data.

This multidimensional high responsibility assignment should be carried by a professional group with vast and proven experience in the field, to avoid any possible damage to the airborne equipment or in the Utility facility (site) and any interpretation shortfalls.

One have to remember that flight regulation and local safety rules obedience are crucial.

MAIN FINDINGS

The main conclusions of several experiments executed in IEC in the last 3 years:

1. There is currently no substitute for an external service provider in all issues related to the use and operation of UAV in an energized network environment. Only so one can ensure the most advanced and valuable tools for a precisely and secure execution of specific tasks.
2. It is possible and economical advantageous to discover external failures in (extra) high voltage network accessories - and insulators - by implementation of UAV techniques and advanced image processing.
3. The key-condition for a successful implementation of this technology is a clear technical specification in which the conditions are accurately described: how and when to collect pictures – photography conditions, how to submit results - including minimal thresholds for failure detection in a primary deciphering by the service provider himself, etc.
4. The final deciphering has been carried out by IEC skilled workers, with great experience in distinguishing failures and their severity.
5. After the final assessment, a decision on replacing the failure prone equipment is then transferred to specialized division to prepare an optimized schedule for execution.
6. After removing / replacing the faulted equipment, the elements are usually transferred to a specialized laboratory for evaluation of the failure severity, thus creating an affiliation between image and End of Life (EoL) assessment – possible trends / directions of future failures of similar equipment installed elsewhere in the system, possible under other operational and environmental conditions.
7. After accumulating experience, it will be possible to assess the technical state of the item from photography itself and even determine the recommended action.
8. Finally, using this particular technology, make possible to achieve important reduction of O&M cost (for this particular type of missions), due to:
    a. Optimal operations sequencing in order to de-energize the bus bars / diameters where near to failure equipment will be replaced.
    b. Avoiding n-k type System risks due to uninterrupted power supply to all feeders from the remaining energized equipment.
    c. Avoid "bottleneck" type of cost due to the use of more costly generation fuels in order to provide continuity of energy supply to customers.
    d. Create proper condition to execute work in the most convenient schedule, without jeopardizing planned maintenance works.

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