Drones' Inspection and AI Usage for OHL Supply and Demand Stability and Reliability in NGSA by Predicting Failures

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Abstract

Overhead lines in National Grid SA are a major source of failures in the transmission network. Spacer damper, connectors, insulators, bolts...etc.; around 14 items configure the tower equipment. Any item failure could make many losses within the NG, causing damage to network power stability and availability. Due to the importance of failures of items in the OHL network and the difficulty in the southern NG SA network, a technical study was conducted throughout the maintenance TSD lead by Eng. Mohammad Hussain concluded the use of an unmanned aerial vehicle (UAV). This technology was new to the region in 2014, studied by different teams, and discussed with a different approach. This paper would highlight the most effective solutions for UAV use as DRONE and the sensors used, contesting for the output and the benefits of the project, and its impact on the network stability and reliability. Finally, the paper will describe the possible development in the DRONE use for maintenance inspection with an artifactual intelligence (AI) to do the analysis, recommend a proper action, and record the reading as a history of the health of a certain item. The possible future application and changes that come with it are huge, considering the next step.

KEYWORDS

DRONE, unmanned aerial vehicle (UAV), artifactual intelligence, maintenance inspection.

I. INTRODUCTION

In NG, power transmission lines link power plants and the points of consumption through substations. Most importantly, assessing damaged power lines and rusted conductors is extremely important for safety; hence, power lines & associated components must be periodically inspected to ensure the supply and identify faults & defects. To achieve these objectives, recently, Unmanned Aerial Vehicle (UAVs have been used in the southern area; in fact, DRONES provide a safe way to bring sensors close to OHL and their components without halting the equipment during inspection and reducing cost and risk. In this project, a drone, equipped with multi-modal sensors, captures images in the infrared, visible and ultraviolet domain. Finally, transmits them to the ground station. For the project it used inspection experts to analyze and highlight all expected faults (i.e., hot spots) or possible damaged components of the electrical infrastructure (i.e., damaged insulators).

II. DRONE PROJECT

The drone project was derived from the enthusiasm of implementing new technology into the maintenance inspection work done by ground and elevated inspection teams. Started by categorizing the project area into segments regarding the history of maintenance and importance for the network. Covering 4000 km circuit length by inspecting two types of drones as mentioned in table 2 in appendices. The sensing technology used is the IR thermal, Ultraviolet, and LIDAR sensors, discussed afterward.

III. SENSING TECHNOLOGY

It is tempting to say that the main subject of sensing technology covers all aspects; however, table 3 in the appendices shows the technology used to sense any failures. The four most Effective sources of sensing are discussed in the following context. Those are covering most fault items, as shown in Table 3 in the appendices. Table 1 shows different applications covered in the Drone project.

I. Optical Image Sensing

It includes methods within which a picture provided by a camera is interpreted by computer analysis to detect, spot, or identify specific conditions.

Different camera systems can provide image representations in visible, infrared, or ultraviolet spectral bands, and each of these bands has advantages for detecting different conditions or defects. Other various methods for positioning or deploying imaging cameras, with some choices more suitable for detecting certain kinds of defects. Optical imaging is an automated analog of visual inspection methods and has potential applications for a high percentage of the OHL components to be inspected. Computer analysis of images to detect specific conditions or abnormalities is widely employed in manufacturing and other structured areas where images are obtained with consistent lighting, viewpoint, magnification, and other factors. Outdoor images analysis with wide variations in illumination is more complex, but adaptive methods are available to compensate for changing conditions of shadow & sun. Statistical methods are used to minimize the effects of slowly changing artifacts such as shadows and glare spots and normalize image intensity. Computer analysis typically consists of several steps:

1. Image capture using color, monochrome, ultraviolet cameras, or infrared. If an analog camera is used, images are converted then to a digitalrepresentation in a digital camera internally or by a frame grabber.

Table 1 Summary of application covered

Application		Optical	Infrared	Ultraviolet	LIDAR
Mechanical/structural Integrity	Tower structure	ü	x	x	x
	Hardware	ü	x	x	x
	Connectors, Splices	ü	x	x	x
	Conductors	ü	x	x	x
Electrical/Operational Integrity	Connectors, Splices	x	ü	x	x
	Conductors	x	ü	x	x
	Insulators	x	ü	ü	x
	Transmission Line Surge Arrestors	x	ü	ü	x
Clearance	Trees	ü	x	x	ü
	Avian	ü	x	x	ü
	Encroachment	ü	x	x	ü
	Line Sag	ü	x	x	ü
	Galloping Conductors	ü	x	x	x
Security	Tampering (in the process)	ü	x	x	x
	Tampering (Result of)	ü	x	x	x

2. However, to remove image noise, normalize illumination, or enhance image contrast, a filtering step is usually included.

3. The image is segmented to identify regions corresponding to a physical object such as towers, insulators, conductors, or trees. Segmentation algorithms may be based on finding corners or other shapes of edges. Segmentation may also be based on differences of color or differences in image texture or other patterns.

4. By describing a set of features, each object identified in the segmented image is characterized. These feature sets include intensity, area, perimeter, shape, color, and connections to other objects.

5. To identify specific types of objects, feature sets are matched against a database. For example, while a long thin object with no connection to other objects could be classified as a conductor between towers, a large green object with a generally round shape would be classified as a tree or bush.

6. Finally, the analysis of each object is done by comparing the conditions specified in the database with specific characteristics of the observed object. In the case of a conductor condition might be the absence of a marker ball or the amount of mid-span sag, while for a tree or bush, the comparison might be related to the position in the right-of-way.

7. If certain conditions are met or not, the computer system will signal to an operator for corrective action.

The condition of transmission lines changes slowly, and there is a relatively low level of activity on and around a line. This may make the processing of images more feasible. However, many of the conditions being inspected for are hidden from clear view or require multiple lines of sight, making it difficult. Summary of Cameras specifications shown in table 4.

Table 4 Summary of Cameras specifications

Physical interface requirements	Optical methods are non-contact. To increase the stand-off distance, cameras can be equipped with telephoto lenses though this reduces the field of view. Also, to provide large scene overviews and highly magnified views of critical locations, zoom lenses can be used.
Image format	35 mm full size (35.9 mm × 24.0 mm), CMOS image sensor Effective pixel number of camera: Approx. 42 400 000 pixels
Power requirements	Battery pack: Rechargeable battery pack NP-FW5. Approx. 3.2 W
Size/weight	The Sony camera will be considered typical for this group. It is 126.9mm x 95.7mm x 60.3mm and weighs 625g.

II. Infrared Image Sensing

Infrared cameras are sensitive to longer wavelengths than conventional color cameras. The most useful infrared band for transmission line inspection is long-wave or thermal IR, from 8 to 14-micron wavelength. Early thermal infrared cameras used a single detector with a scanner to build up an image, but current systems use microbolometer arrays and quantum well devices fabricated with a typical resolution of 320 x 240 pixels. Today, many infrared camera systems are designed for operators conducting thermal surveys and include image enhancement software and an LCD viewing screen. Most are intended for use at a fairly short range, and long focal length lenses (made from germanium) are expensive. Radiometric cameras are calibrated so that accurate surface temperature can be read from the thermal image. Non-radiometric cameras indicate relative temperature but do not give an absolute temperature. The amount of infrared radiation from a source depends on the temperature of the surface and the emissivity of the source. Very smooth or shiny surfaces emit a smaller amount of radiation than rough or dull surfaces. Accurate temperature measurements require knowledge or assumptions of the surface emissivity. When the surface condition is unknown, it is still possible to spot hot spots by determining temperature differences while the absolute temperature can't be measured. IR cameras are often classified as cooled or uncooled. High-end thermal IR cameras often provide a Peltier or compressor system to cool the detector to reduce thermal noise. Uncooled cameras are typically less expensive, smaller, and have less power but are less sensitive and have more image noise. Costs for thermal infrared cameras range from $7K to $50K reckoning on the features, resolution, accuracy, and lenses included. In the OHL inspection systems, thermal IR cameras are most often wont to identify hot spots caused by leakage current dry band arcing on insulators or failing connections, e.g., splices o dead ends compression connectors. Summary of used IR Sensor specifications shown in table 5.

Physical interface requirements	As an optical method, thermal IR imaging is non-contact. Stand-off distances can range from several feet to several hundred feet if telephoto lenses are used.
Image format	Thermal Image is Uncooled VOx Microbolometer Photo Format JPEG, TIFF, R-JPEG Video Format 8 bit: MOV, MP4 14 bit:
Power requirements	22.8V from Drone M210 battery type LiPo 6S
Size/weight	Dimensions With 25 mm lens: 123.7×112.6×127.1 mm With other lenses: 118.02×111.6×125.5 mm weighs 629g.

III. Ultraviolet Image Sensing

Charge-Coupled Device (CCD) imaging arrays can be optimized to detect ultraviolet light by making the silicon substrate very thin and directing the incident radiation onto the back surface. This overcomes conventional front-illuminated CCDs' performance limits by illuminating and collecting charge through the back surface aloof from the polysilicon electrodes. Ultraviolet cameras, sensitive to wavelengths shorter than the color spectrum, are widely employed in astronomy and for inspection of silicon wafers. The first use of UV cameras in OHL inspection is to locate corona sources. one among the difficulties of detecting corona on OHL is that the large UV content of radiation is way greater than typical OHL corona sources. To spot corona outdoors within the daytime, it's necessary to filter the light to use only a narrow band of the UV spectrum (250–280 nanometers) where solar UV is absorbed by the atmosphere. Cameras using this method are termed "solar-blind." Several manufacturers supply UV cameras for use in OHL inspection. These are typically intended to be hand-held or mounted on a tripod. The operator will direct the camera at a potential corona source and observe an LCD screen to see if a UV source have presence. The cameras include controls adjusting the sensitivity & software measuring the intensity of corona by counting photon events. Cameras obtain images at both ultraviolet and visible wavelengths that can be combined in the display are available. This provides the operator with the ability to locate the UV source with scene features accurately. While this is very useful to operator inspections, it should have less value to automate systems that will probably include a separate visible camera from the UV. The Summary of the used Ultraviolet Imaging sensor specifications is shown in table 6.

Table 6 Summary of Ultraviolet Imaging sensor specifications

Physical interface requirements	Absolute – at all sunlight and all weather conditions, the target can be inspected with the sun in the field of view /Minimum Discharge Detection1pC @ 15 meters/Minimum UV Sensitivity 1.9 x 10-18 watt/cm²
Power requirements	7.5÷30 VDC, 14 Watts
Size/weight	Weight 1.4kg / Dimensions L x W x H L245 x W125 x H101 mm

IV. LIDAR

Light Detection And Ranging use the same principle as RADAR. The LIDAR is an instrument that transmits light out. It uses this light to target where a portion of the light is reflected back to the instrument. Finding the time for light photons to travel out to target and back to the LIDAR instrument, is used later to determine the range to the target. The simplest instruments are single-point LIDAR distance rangefinders. These have recently found their various consumer uses, such as distance to golf holes space, the dimensions of rooms, the dimensions space of parking lots. This consumer market has lowered cost of simple laser rangefinders. Typical laser rangefinders range up to 3000 feet and have a range accuracy of +/- 3 ft. These are typically hand-held devices without data interfaces and require modifications in an automated measurement system. More complex LIDAR systems use an optical scanner to direct the laser in fans or raster patterns, it then measures length over a line, or use two for an area. These systems are often combined with GPS/Inertial navigation technology to confirm stability. Also, to uniform measurements. LIDAR systems are also used for spotting encroachment measuring the height of objects or movements into the right of way ground. If the system is deployed on a line-crawling robot, a line scanning LIDAR, like airborne systems, it could construct a swath's elevation profile under the line. Any points that rise above reference level over a specified amount it would be spotted as encroachment. Utilities currently use LIDAR to map their right of way and determine the conductor's position. They do this infrequently and use the results to design new lines or determine whether their lines meet the NGSA conductor to ground clearance requirements. The Summary of used LIDAR sensor specifications is shown in table 7.

Table 7 Summary of LIDAR sensor specifications

Physical interface requirements	10 mm survey-grade accuracy scan speed up to 200 scans/second measurement rate up to 500,000 meals./sec (@ 550 kHz PRR & 330° FOV) operating flight altitude more than 1,000 ft field of view up to 330° for practically unrestricted data acquisition regular point pattern, perfectly parallel scan lines
Power requirements	11 - 34 V DC / typ. 60 W
Size/weight	Compact (227x180x125 mm), lightweight (3.5 kg), and rugged

IV. RESULTES AND BINIFITES

The project results are reviewed per segment and helped discover a borderline to do the necessary maintenance. Drone-based inspection of transmission assets involves two key steps drone operations and expert analysis and solution.

Drones are equipped with sensors based (e.g., visual, thermal, UV, LiDAR) on failure modes to be tested. Drone operations provider pilots conduct flights using multi-rotor or fixed-wing drones. The pilot and expert teamwork to predict faults in asset images, then faults are reported to the maintenance team for repair and recorded. The southern region was selected for drone pilot due to the following reasons:

1. Mountainous terrain with difficult to reach areas, making manual inspection either extremely slow or unfeasible

2. Old assets that had not been inspected in a long time

3. A high-security area with safety risks

4. unclear instructions and share with them investigating results.

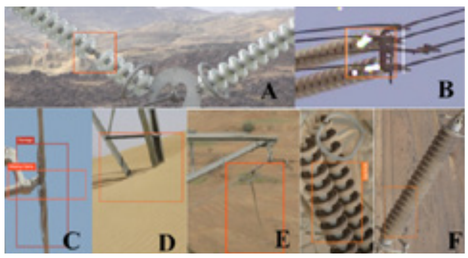
Operations for the drones pilot started in July 2018 and were completed in April 2020 (18 months). Drones pilot is planned to cover ~4,000 km of high voltage (380kV) transmission lines in the southern regions of Asir, Jizan, and Bahah. The pilot-scale and technical requirements were extensive, covering multiple drone types and sensors. The pilot led to three key tangible benefits across safety, operations, maintenance costs, and asset availability/ reliability. Table 8 shows the benefits of the drone project.

V. AI DEVELOPMENT ON DRON

Power transmission lines are the means of electricity distribution, and it is of utmost importance to confirm the continual supply of electricity and also the high performance of those lines. Constant surveillance and inspection of power lines can play a vital role in avoiding power shortages: detecting defects in power equipment at an early stage can prevent severe and costly damage and even be used to expect future anomalies. Generally, the electrical equipment undergoes a maintenance and repair process, based on their condition, termed preventive maintenance.

Table 8 Summary of DRONE project benefits

Safety	Cost Savings	Asset Availability/ Reliability
During 2019 Safety incidents were (0) during drone inspection vs. 7 incidents during the manual inspection in 2018	Inspection costs were reduced by ~25-30%. reduction in costs between drone and manual inspection 2,275 (2019) vs. 3,150 (2018) SAR/ km	improvement after drone inspection in: 1. SAIFI reducing it by 30% 2. SAIDI & ENS reducing it by 34% 3. MAIFI reducing it by 2%
		Dispatched points (DPs) affected are reduced by 34% improvement (90 vs. 140 DPs annually/ 1Klines).
	Reduction in corrective maintenance (CM) costs as a result of better inspection and preventive maintenance savings by ~ 2.0-2.5M SAR, in 2019 as a result of drone inspection	Increasing inspection speed up to ~5-6X increase in inspection speed six times vs. current manual process
	Revenue loss avoided ~0.4M SAR. After drone inspection 2019	



igure 1 A sample of common defects: (A) missing plate along the nsulator chain; (B) Corona discharge (C) damaged strand of the ductor and broken clamp; (D) sand accumulates around tower foo l foundation; (E) cable joints, which are more frequently hot spot sensitive; (F) a string of insulators, polluted.

The primary damages in OHL could be broken wires, damage to insulators, conductor corrosion, and vibration damage; a number of these defects are shown in Figure 1. Several methods are employed to spot and analyze these anomalies. Some of these methods identify faults and classify their severity in power equipment using different image analysis approaches [1]. Also, different methods for classifying the level of faults in electrical equipment [2]. In the past, the two most common power equipment inspection methods were foot patrol and helicopter-assisted investigation. Inspection based on foot or patrolling is highly to be inaccurate, slow, and is simple for the surfaces of the OHLs' equipment and thus, more substantial defects can sometimes be overlooked. The pilot flies the aircraft over the power lines in helicopter-based inspection while the camera operator films the conductors, insulators, pylons, and power transmission lines. Over the recent years, manned and unmanned aerial vehicles or Drones are used for a broad spectrum of applications, supporting humans in dangerous and challenging environments, including the inspection, operations, and maintenance of power equipment. Advanced flight control techniques and image processing allow unmanned aerial vehicles (UAVs) to carry out fast inspections from some distance.

Based on GPS data of both the UAV and electric towers, the embedded algorithms can perform the automatic tracking of power lines [3–7]. The acquired data, generally a sequence of images, are analyzed to assess status of power equipment. Also, the inspection by drones allows using different sensing payloads and, hence, to comprehensively inspect both OHL and associated components using different kinds of sensors from an optimal point of view. With that in mind, Artifactual intelligent started as an idea to improve the drone inspection analytic part, where NGSA suggested implementing a software part to do the analysis. An MVP study of the global market was done in 8 weeks. The results are big potential benefits. A summary of the benefits of applying AI to the drone project data is shown in Table 9.

Table 9 Summary of DRONE project benefits

<table>
<tr><th>Safety</th><th>Cost Savings</th><th>Asset Availability/ Reliability</th></tr>
<tr><td rowspan="4">Zero incident expected during the elevated inspection using drones</td><td rowspan="2">Inspection costs were reduced by ~13M. 30% savings annually by 2024 after drones inspection</td><td>improvement after drone inspection in:
4. SAIFI reducing it by 17% (0.23 vs. 0.28)
5. SAIDI (12.2 vs. 14.9) & ENS (0.002 vs.0.003) reducing it by 19%
6. MAIFI (0.0316vs.0.032) reducing it by 1%</td></tr>
<tr><td>Dispatched points (DPs) affected are reduced by 19%
improvement (7.1 vs. 8.7 DPs annually/ 1Klines).</td></tr>
<tr><td>Reduction in (CM) costs by ~13.4M SAR
And 11% annually by 2024 after drone inspection</td><td rowspan="2">Increasing inspection speed up to ~7-8X
increase in inspection speed Eight times vs. current manual process</td></tr>
<tr><td>Revenue loss avoided ~ 0.4M SAR. after drone inspection annually by 2024.</td></tr>
</table>

Providing a pilot project model for an AI to analyze spacer damper faults out of 200 test pictures. 2250 pictures trained the models, 250 of them defected. AI solution will retrieve drone data from SEC data, run the analytics, and return the outputs back to the system (reports/ SAP PM input); the AI solution Overview is shown in figure 2.

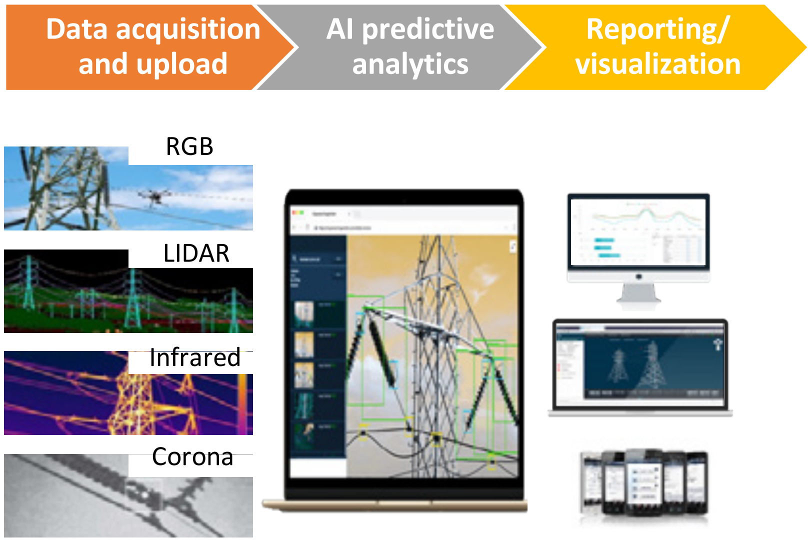


Figure 2 AI solution overview

The MVP evaluation Panel was made of:

1. Functional experts (1)

2. AI experts (3)

3. SEC experts (4)

Each of the eight panelists submitted a detailed evaluation scorecard for each provider; each provider's scores and feedback were cumulated. Two key metrics to measure model performance. Confusion matrix created to compare the expected vs. predicted results (of AI model) on faulty vs. healthy images. AI model should maximize accuracy while optimizing false positives/ negatives, which could either increase costs/ worsen asset health. e.g., False positive means that SEC sent maintenance crew to fix an actually healthy asset, while false negative means that no crew was sent to fix a faulty asset (because the model classified it as healthy). The F1 score is used to assess the latter above – i.e., how well does the model optimizes false positives/ negatives; Higher the F1 score, better the model performance/ fidelity, the F1 score is a combination of two key metrics (precision and recall). Precision (P) is calculated as TP/ (TP + FP) while recall (R) = TP/ (TP + FN). F1 is a harmonic mean of precision and recall, equal to 2*P*R/ (P+R). Therefore, keeping a record of Table 10 parameters makes it easy to evaluate and configure the Precision (P) & recall (R) and F1. There are several strong points for the top three vendors selected after evaluation of those as follow:

- Sophisticated AI modeling techniques with a clear process to re-train and enhance the models over time
- Comprehensive and mature solutions with advanced functionalities such as drone flight planning
- Simplified UI/ UX and reporting with key application integrations such as SAP, IBM Maximo, etc.
- Cloud agnostic architectures with demonstrated experience in deploying on-premise and supporting client-specific data encryption protocols
- Strong experience in utilities and providing services across the value chain (i.e., drone operations and AI/ ML)
- Open to partnering with SEC and supporting upskilling of client teams on both drone operations and AI/ ML

Table 9 Parameters to record for configuration of P, R, F1

Expected results (based on manual identification)			
Predicted results (based on AI model)		**Faulty**	**Healthy**
	Faulty	True positive (TP)	False-positive (FP)
	Healthy	False Negative (FN)	True negative (TN)

VI. CONCLUSION

It has been shown that the incidents Application of computer vision methods to analyze electrical faults and diagnose the condition of specific components of the infrastructure has been proved as one of the safer procedures for inspection. In the present work, we applied computer vision-based methods on visible images to perform maintenance inspection of spacer damper components. Results, with different statistical parameters, are compared to the performance of obtained output with the manual ground truth. With an average of 88.5% Accuracy index and 76.8% an average of the F1 score index, the method effectively detects power lines spacer dampers. The method achieved a state-of-the-art performance, but we also provide a classification based on their status (pointing out even the opening clamp) to allow predictive maintenance of it. The need to notice that even the comparison with previous research is biased by the differences in data used for training the model. In the use of such data most cases are made unavailable, difficult, and costly to be collected. Also, an extra value is to be implemented, is an application and an online service; to make it easier for operators to use the tool. However, on the other hand, to permit to enlarge our dataset and improve further the performances and/or increase the interpretation of the insulator status. Hence, we conclude from our results that may improve the efficiency of drone surveying of the electrical infrastructure and open the way to the development of a novel monitoring payload (to be embedded in UAV) able to provide accurate and fast detection of faults and anomalies in power lines and its accessories. Along with AI applications, Communication diagnostics systems of substations, robotics applications, and permanent surveillance systems. As data feed for the future Big Data of Power system transmission network as National Grid SA are considered to be analyzed to develop of digital substations to enable communication of digital data directly from the equipment monitoring system with less configuration layers to have real time data for applications of predictive analysis.

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APPENDICES

Table 2 types of Drone used in the Southern area project

Type	Dimensions (mm)	MAX SPEED	MAX ALTITUDE (ASL):	Max Flight Time	Operating temperature MIN, MAX
MATRICE 600 PRO	1668 × 1518 × 727	65 km/h	4500 m	No payload: 38 min, 5.5 kg payload: 18 min	-10° C to 40° C
M200 V2	883×886×398	81 km/h	3000 m	38 min (no payload), 24 min (takeoff weight: 6.14 kg)	-20° to 50° C
H6 Harris	1425	54 km/h	2000 m	5 hours	-20 ~ 40 °C
TRON F90 Plus	1775 x 325 x 428	65 km/h	2000 m	60 min	0 °C to 45

Table 3 fault detection, causes, probability, and sensing technology

Item application	Cause	Result	Update interval	Probability	Consequence	Sensing technology
System Tampering	Terrorism	Tower/line down	Real-time	Low	High	Optical
System Encroachment	Avian Nesting, Waste, & vegetation	Flashover, & Fire	3,6, and 12 Months	High	High	Optical, LIDAR
Shield Wire	Corrosion, & lightning	Flashover, & Outage	1-3-6 Years	Med	High	Optical, IR
Insulator (Polymer & Ceramic)	Age, Material Failure, Contamination, & Gunshot	Outage, & Flashover	Real-time- 3 Months 6-12 Years for Age, & Material Failure	For Age, & Material Failure Med for Polymer and Low for Ceramic. And Med for others.	High for Outage Med for Flashover	Optical, IR, & UV
Phase Conductor	External/ internal strands broke, and corrosion of steel core	Line down, & Fire	1 Year	Low	High	Optical, IR, & UV
Connector Splice	Workmanship, Thermal cycling, & Age	Line down, & Fire	1 Year	Med	High	IR
Hardware	Age	Line down, & Fire	6 Years	Low	High	Optical, & IR
Phase Spacer	Age, Galloping event	Line down, & Fire	6 Years	Low	Med	Optical, & UV
Aerial Marker Ball	Vibration Damage, & Age	Safety Concerns	1 Year	Low	Med	Optical, & UV
Structure (steel lattice & steel pole)	Corrosion, Age, Bent, Damaged members, & Internal Deterioration	Reliability Concerns	10 Years for Corrosion, & Age 1 Year For Bent, Damaged members, & Internal Deterioration	Med	Med	Optical, & IR
Foundation	Corrosion, & Age	Reliability Concerns	10 Years	If Foundation (Direct Embedment, Anchor, Screw-In, or Rods) it is High If Foundation (Perform) it is Med If Foundation (Anchor Bolt, Stub Angles) it is Low	High	Optical
TLSA (Transmission Line Surge Arrestor)	Lightning Strikes, & Age	Reliability, & Lightning Concerns	1 Year	Med	Med	Optical, & IR