

THE VALUE OF UNMANNED AERIAL SYSTEMS FOR POWER UTILITIES IN DEVELOPING ASIA

Yunfeng Yue

NO. 78

July 2021

**ADB SUSTAINABLE DEVELOPMENT
WORKING PAPER SERIES**

ADB Sustainable Development Working Paper Series

The Value of Unmanned Aerial Systems for Power Utilities in Developing Asia

Yunfeng Yue

No. 78 | July 2021

Yunfeng Yue is an energy specialist at the Energy Division, South Asia Department, of the Asian Development Bank (ADB). He currently works on energy projects in Bangladesh and supports ADB's energy-related operations in South Asian countries. Before joining ADB, Yue has had over 12 years of work experience in the energy sector, specializing in planning and engineering for energy projects, power system resilience, smart grid, renewable energy integration, and information and communications technology for grid network.



Creative Commons Attribution 3.0 IGO license (CC BY 3.0 IGO)

© 2021 Asian Development Bank
6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines
Tel +63 2 8632 4444; Fax +63 2 8636 2444
www.adb.org

Some rights reserved. Published in 2021.

Publication Stock No. WPS210213-2
DOI: <http://dx.doi.org/10.22617/WPS210213-2>

The views expressed in this publication are those of the authors and do not necessarily reflect the views and policies of the Asian Development Bank (ADB) or its Board of Governors or the governments they represent.

ADB does not guarantee the accuracy of the data included in this publication and accepts no responsibility for any consequence of their use. The mention of specific companies or products of manufacturers does not imply that they are endorsed or recommended by ADB in preference to others of a similar nature that are not mentioned.

By making any designation of or reference to a particular territory or geographic area, or by using the term “country” in this document, ADB does not intend to make any judgments as to the legal or other status of any territory or area.

This work is available under the Creative Commons Attribution 3.0 IGO license (CC BY 3.0 IGO) <https://creativecommons.org/licenses/by/3.0/igo/>. By using the content of this publication, you agree to be bound by the terms of this license. For attribution, translations, adaptations, and permissions, please read the provisions and terms of use at <https://www.adb.org/terms-use#openaccess>.

This CC license does not apply to non-ADB copyright materials in this publication. If the material is attributed to another source, please contact the copyright owner or publisher of that source for permission to reproduce it. ADB cannot be held liable for any claims that arise as a result of your use of the material.

Please contact pubsmarketing@adb.org if you have questions or comments with respect to content, or if you wish to obtain copyright permission for your intended use that does not fall within these terms, or for permission to use the ADB logo.

The ADB Sustainable Development Working Paper Series presents data, information, and/or findings from ongoing research and studies to encourage exchange of ideas and elicit comment and feedback about development issues in Asia and the Pacific. Since papers in this series are intended for quick and easy dissemination, the content may or may not be fully edited and may later be modified for final publication.

Corrigenda to ADB publications may be found at <http://www.adb.org/publications/corrigenda>.

Notes:

In this publication, “\$” refers to United States dollars.

Data regarding satellites in orbit are correct as of 7 April 2021.

ADB recognizes “China” as the People’s Republic of China.

CONTENTS

ACKNOWLEDGMENTS	V
EXECUTIVE SUMMARY	VI
ABBREVIATIONS	VII
TABLES	VIII
1. INTRODUCTION	1
2. UAS APPLICATION IN POWER UTILITIES	2
A. UAS and Sensors for Inspection	2
B. Application Scenario in A Power System	3
3. KEY TECHNOLOGY AND DEVELOPMENT	7
A. Automatic Pilot	7
B. Fault Identification and Batch Processing	7
C. Long-distance Autopilot Solutions	8
D. Applications in Clean Energy Projects	8
E. Other Applications in the Energy Sector	10
4. UAS INSPECTION CENTER	11
A. A Command Center for O&M Works	11
B. Proactive O&M Capability	11
C. Integration With Other Existing Systems	11
D. Regulations	12
E. Implementation Costs	13
F. Benefits	14
G. Collaboration with Private Sector	15
5. CONCLUSIONS	16
REFERENCES	17

ACKNOWLEDGMENTS

This working paper was prepared under the overall supervision of Aiming Zhou, senior advisor to the vice-president, Vice-President Office 1(VPO1) of the Asian Development Bank (ADB). Anthony Joseph Jude (consultant) and Jongmi Son, finance specialist, South Asia Department, ADB, provided invaluable inputs and overall support in finalizing the paper. The paper also benefited significantly from discussions and comments received from ADB's Yongping Zhai, chief of Energy Sector Group, Sustainable Development and Climate Change Department; Arun Ramamurthy, senior infrastructure specialist (digital technology), Sustainable Infrastructure Division, East Asia Department; and team from the Energy Division, Southeast Asia Department. The infographics were provided by Guangdong Electric Power Design Institute from the People's Republic of China.

EXECUTIVE SUMMARY

Electricity is at the heart of modern economies and contributes to rising energy services. Over the past decades, substantial investments in Asia and the Pacific have significantly improved the region's energy infrastructure. Developing Asia's electrification rate has reached 90%. However, with the expansion of power networks, the operation and maintenance of facilities are highly complicated and difficult. Power utilities are facing various challenges such as natural hazards, emerging disruptive renewable generation, less public tolerance of blackouts and interruptions, and increasing energy security concerns. Meanwhile, Industry 4.0¹ and the emergence of new technologies have unlocked more smart tools for solving development problems. The core challenge for developing Asia is to keep up with the accelerated speed of global technological progress and take advantage of the opportunities provided (ADB, 2019).

ADB's Strategy 2030 pays great attention to adopting digital and advanced technologies in developing countries to achieve efficient and sustainable development. ADB also enacted the Digital Agenda 2030 and start the journey of digital transformation to empower its operations and meet the high expectations of its developing member countries (DMCs). The application of innovative and digital technology in operations, such as Unmanned Aerial System (UAS), is in line with ADB's Digital Agenda 2030 supported by ADB's Strategy 2030.

This paper underscores the benefits of applying UAS in power systems and identifies challenges in the energy sector that the technology can help address. It also presents successful applications in selected countries where UAS serves as a cost-effective and safe tool for inspection and data collection. Similarly, the paper takes into account the potential of this technology to advance renewable energy and low carbon technology development in the energy sector of ADB DMCs.

¹ The term "Industry 4.0" was coined by the German government which describes and encapsulates a set of technological changes in manufacturing and sets out priorities of a coherent policy framework with the purpose of maintaining the global competitiveness of German industry. Generally, Industry 4.0 refers to the means of automation and data exchange in manufacturing technologies including Cyber-Physical Systems, Internet of Things, big data and analytics, augmented reality, additive manufacturing, simulation, horizontal and vertical system integration, autonomous robots as well as cloud computing. It serves a role to help integrate and combine the intelligent machines, human actors, physical objects, manufacturing lines and processes across organizational stages to build new types of technical data, systematic and high agility value chains.

ABBREVIATIONS

ADB	-	Asian Development Bank
BVLOS	-	beyond visual line of sight
CAPEX	-	capital expenditure
CNN	-	convolutional neural networks
DMP	-	data management platform
EMS	-	energy management system
ERP	-	enterprise resource planning
GIS	-	geographic information system
GPS	-	global positioning system
LiDAR	-	Light Detection and Ranging
PRC	-	People's Republic of China
OPEX	-	operating expenditure
O & M	-	operation and maintenance
UAS	-	Unmanned Aircraft System
UAV	-	Unmanned Aerial Vehicle
VAN	-	vision-based autonomous navigation
VR	-	virtual reality

TABLES AND FIGURES

TABLES

1	Drone Types by Weight and Performance	2
2	Inspection Object and Sensor Selection	4
3	Cost Estimates for UAS inspection Center (\$'000)	13
4	UAS Inspection Cost	14
5	Conventional Inspection Cost	14

FIGURES

1	3D Model Formulated by Drone LiDAR Survey	6
2	Infrared Image and Temperature Measurement for PV Panels by UAS	9

1. INTRODUCTION

Climate change and an increasing number of extreme weather events pose both long-term and short-term risks to energy infrastructures and can lead to power outages, increased maintenance, and capital costs. Coronavirus disease (COVID-19), a new form of risk, can have far-reaching impacts on power system design, markets, and operation, such as a large reduction in demand, substantial changes of load profile, and continuity of operations and maintenance. It has become a prolonged crisis that grid operators are now worried that if huge numbers of essential staff were contracted, key infrastructure could become inoperable. Uninterrupted electrical service is paramount as health sectors, food industries, supply chains, and other lifeline facilities count on a stable power supply to maintain functions. Operation and maintenance to achieve a reliable power supply without social contact and mutual aid became even more challenging.

Power system reliability and resilience depend on the quality of equipment, installation, construction, and more importantly, on the years of dedicated professional operation and maintenance (O&M). With the increasing demand for electricity, power facilities continue to expand. However, the O&M of those facilities still rely heavily on manpower. The work has become increasingly burdensome, dangerous, and challenging. Problems and shortcomings that have been observed are as follows:

- (i) Workforce safety hazards: Power engineers often have to travel to remote areas and climb on high towers. Occupational risks include falling, electrical shock, animal bite, etc. Long time working in such environment would create tremendous psychological pressure.
- (ii) Low working efficiency: Manually climbing to inspect towers, insulators, and conductors is time-consuming. It often takes 3–4 hours to prepare and climb for a single tower inspection which would result in long delays of operation or recovery.
- (iii) Limitation at hard-to-reach locations. Private properties, difficult terrains, restricted areas, or natural hazard-affected areas are hard to approach or cross for engineers.
- (iv) Misjudgments, lack of complete documentation, and nontraceable inspections: The inspection results mostly depend on the naked eyes and the personal experience of a lineman or engineer. Little imaging or data is recorded for future review.

There are other inspection solutions such as robots, which have been introduced for automation (Tavares 2007). Helicopters with engineers on board are also used in many countries (Schaller 1999). These solutions are more complex and costly, and many utilities cannot afford and easily adopt them.

The fast-evolving energy sector highlights the importance of adopting a broad and dynamic approach to energy security. With the development of communications and digital technology, Unmanned Aircraft System (UAS)—or commonly known as drones—applications have appeared in the energy sector in the past 5 years, providing utilities with a smart tool kit while streamlining the entire inspection process.

UAS solutions have been widely accepted by power utilities and renewable energy companies in many countries like Australia, Canada, the People's Republic of China (PRC), Spain, the United Kingdom, and the United States particularly by power companies running tens of thousands of kilometers of transmission lines. The national grid in England and Wales has been using six drones for the past 2 years to help inspect its 7,200 miles of overhead lines (Vaughan 2018). Duke Energy of North Carolina in the US, is using drones to conduct infrared equipment inspections, survey storm damage, and inspect tall structures (Wells 2018).

Drone-related startups are also emerging in some of the developing economies and the commercial use of drones is experiencing exponential growth in many sectors. In India, the drone has been seen applied in many civilian sectors for aerial photography; survey and mapping; reconnaissance and surveillance; and inspection of transmission towers. (Amazon 2014). Indonesia has been using drones since 2014 for various purposes, such as fire spot identification in forests, coastline delineation, and surveillance of oil palm plantations. Drones have also been utilized in towns of the Philippines to spray fertilizer on vegetable farms located on mountain slopes (Malasig 2018). Drones are also used in other sectors like telecoms, insurance, transport, and logistics. As the capacity continues to grow, the broader will be the expansion of the industry application.

Equipped with hundreds of drones, China Southern Power Grid Company inspected more than 500,000 km of transmission lines in 2019 (CSG 2019). With new tools, 60% of the inspection personnel were mobilized to support operations. This enhanced the overall maintenance capabilities, efficiency, and responsiveness of the team.

The UAS application in the energy sector has been tested successfully in some countries. Yet, it is not widely recognized and applied in most ADB DMCs. Duplicating these UAS applications bring similar benefits including safety, efficiency, and reliability.

2. UAS APPLICATION IN POWER UTILITIES

A. UAS AND SENSORS FOR INSPECTION

An unmanned aircraft system (UAS) includes a drone, a ground-based controller, and a communications system between the two. There are many types of drones, which can be categorized into small, medium, and large in terms of weight; and fixed-wing, and rotary-wing drones in terms of wing type. The load capacities, speeds, and flying ranges are varied depending on the size and type. The selection of which type of drone to use will have to meet the requirements for a specific inspection. The performance is shown in Table 1.

Table 1: Drone Types by Weight and Performance

Drone size	Fixed-wing	Rotary wing	Load capacity	Flight range	Battery life
Large	20kg above.	116kg above	60kg	200km	4 hours
Medium	7kg-20kg	7kg-116kg	20kg	100km	2-3 hours
Small	7kg below	7kg below	5kg-10kg	5km	1 hour

Source: National Energy Administration, Electric Power Industry Standard, PRC. DLT 1482-2015 Technical Guidelines for UAV Inspection Operation of Overhead Transmission Lines.

Today, UAS are selected and deployed subject to inspection scenarios. The commonly used quadrotor or multirotor drones are capable of precise flying and hovering for detailed tower examination, while fixed-wing drones are often designed for long-range line route inspection. However, this is not always the case. A large size rotary drone is capable of both long-distance and detailed inspection. Regarding the inspection requirements, UAS is equipped with different sensors and cameras to take visual, infrared, or ultraviolet images to detect various types of faults or defects.

The visible light camera is the primary equipment to take clear and sharp images for components and parts of power lines. The inspection often requires higher resolution and better optical zoom functions. Defects can be snapshotted such as broken wires, loose bolts, damaged insulators, pollution flashover or damper deformation, etc.

The infrared camera mainly serves as the thermal detector for overheated fittings or parts due to its mechanical or mounting defects. It can also be used to monitor wildfires along line corridors. The ultraviolet camera is used for examining the discharge by detecting corona or arc happening on the conductors, insulators, or fittings.

Light Detection and Ranging (LiDAR) is another essential equipment for inspection and survey. The equipment with laser light can measure distance, make high-resolution maps and build 3D models. LiDAR and drones are perfectly fitted for the survey and mapping of the long-distance transmission corridor.

B. APPLICATION SCENARIO IN A POWER SYSTEM

UAS has been used in routine inspections for high voltage transmission lines and towers, corridors, substations, distribution networks, and emergencies, etc. The UAS and its payloads shall match the application scenarios as shown in Table 1. Supporting systems like database and analysis software are also needed for batch processing of footages and data.

Routine line and tower inspection

The routine line and tower inspections are preventative detail-oriented maintenance. The inspection was conducted on a tower basis, requiring higher accuracy to bolts and pins. Small or medium multirotor wing UAVs are the most commonly used, carrying visible and infrared cameras. About 1 hour of flight time can complete inspections for two to three high voltage towers (See image in page 4).

In some solutions, drones are manually controlled via screens or virtual reality (VR). Manual operations are sometimes constrained by weather conditions, distance, and operator capacities. Currently, autopilot drones have been developed for tower inspections and become more popular.

As the design of the transmission towers is often standardized, the tower types is limited to dozens at one voltage level. The automatic flight route can be predefined accordingly. The path coordinates are set to give the UAV the best position to take the shot at a safe distance. Operators simply select and confirm the type of the target tower before taking off.



Transmission Tower Inspection. An aerial view of a drone used to inspect a transmission tower (photo by Guangdong Electric Power Design Institute).

Table 2: Inspection Object and Sensor Selection

Inspection	Object	Fault Specification	Sensors
Line and tower	Tower	Tilted, deformed, and corroded tower; the missing bolt and pin; damaged and displaced foundation; foundation defects.	Visible light camera
	Conductor	Loose, rupture, damaged lines; wire break; overheating; corona detection, corroded, ice-coating lines; line sagging; attachment, twinning; distance to the ground object.	Visible light camera, Infrared camera, LiDAR
	Insulator	Overheating; contamination; Missing, cracking piece; corona detection; parts corrosion.	Visible light camera, Infrared camera, ultraviolet camera
	Fittings and Ancillaries	Fitting fracture, abrasion, rust; missing pins; corrosion; loose part; burning trace; adherent object; corona detection.	Visible light camera, Infrared camera, ultraviolet camera
Line corridor	Buildings	Unauthorized building or structure; unexpected antenna; newly built road and railway; insufficient safe distance.	Visible light camera, LiDAR
	Vegetation	Ultra-high or high vegetation encroachment; fast-growing plant.	Visible light camera, LiDAR
	Construction site	Lift truck or crane operation; unauthorized construction	Visible light camera
Emergency management	Natural disaster	Impact of floods, earthquakes, landslide, lightning, etc.	Visible light camera

continued

Table 2 continued

Inspection	Object	Fault Specification	Sensors
	Roads and bridges	Inspection route; road and river; bridge.	Visible light camera
	Contaminant	Emerging contaminant; pollution source.	Visible light camera, Infrared camera
	Fire hazard	Fire; inflammable and explosives; smoke.	Visible light camera, Infrared camera

Source: National Energy Administration, Electric Power Industry Standard, PRC. DLT 1482-2015 Technical Guidelines for UAV Inspection Operation of Overhead Transmission Lines.

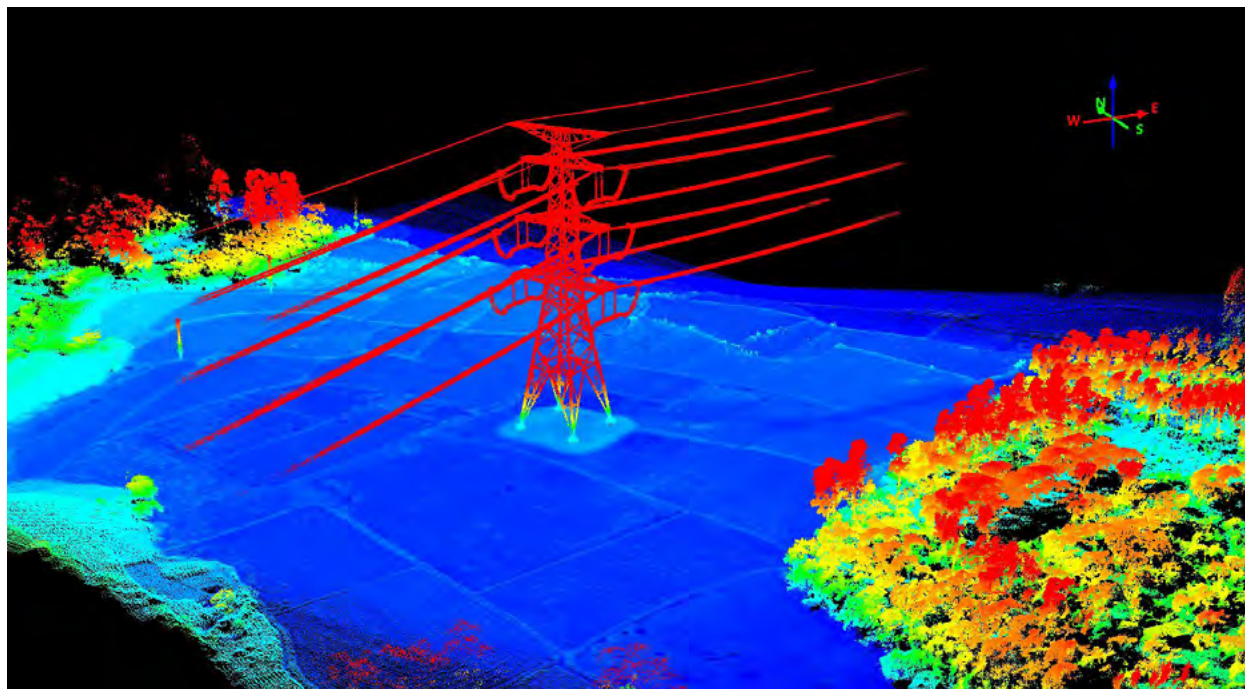
Line corridor inspection

Line corridor inspections are generally landform scanning and measurement of the object underneath or nearby power lines to identify the potential risk and danger. By and large, corridor inspection includes fast scanning and detailed mapping.

Fast scanning is a quick examination of the line corridor for major external potential risks with visible light and infrared camera. The scanning is to search for foreign objects on the wire or tower such as plastic bags and kites, examine vegetation, unexpected buildings or construction sites, etc. Fixed-wing drones have inherent advantages which offer faster flight speeds with a wider range. The compact design makes it more portable and noiseless.



Survey via line corridor inspection. Line corridor inspections scan and measure objects underneath or those nearby power lines, involving fast scanning and detailed mapping (photo by Guangdong Electric Power Design Institute).

Figure 1: 3D Model Formulated by Drone LiDAR Survey

Source: Guangdong Electric Power Design Institute, PRC.

Detail mapping applies LiDAR to obtain 3-dimensional (3D) data of the towers, lines, and corridor environment. The geological data is recorded and a 3D digital model for the entire power line can be built with all the vegetation encroachment, building, and surroundings.

This is very useful when facilities are in mountainous places or disaster-prone regions. The model sets up the baseline for monitoring, operations, and planning. The user can analyze vegetation growth and simulate the impact of extreme weather events such as strong wind, flood, ice-coverage, and high/low temperatures. It enables the prediction for future threats with many unforeseen variables.

Emergency management

In case of emergencies such as earthquakes, landslides, or wildfires, the affected area may not be accessible. The O&M teams would miss the best timing to rescue. UAS can conduct a post disaster inspection and impact survey. With the image, the maintenance team could assess the damage first, and prioritize the operations and the distribution of resource. The data would also support grid dispatchers to take quick actions to restore the power. The whole repair and recovery process can be accelerated.

Drones equipped with lasers, flame guns, or electric wires can be used to clear hanging objects on facilities, such as kites, balloons, plastic bags, etc.

In case of power failure, the fault location program in the power system can't provide the precise position. The location results deviate from half to several kilometers. It often costs the maintenance team a long time to find the fault. UAS can speed up the fault searching process.

3. KEY TECHNOLOGY AND DEVELOPMENT

A. AUTOMATIC PILOT

While flying drones manually, the human vision has limitations for positioning which may lead to misjudgment. Autopilot by software and algorithms becomes indispensable. Most of the navigation systems rely on GPS and Telecom communication. Modern positioning accuracy can reach the centimeter-level which is sufficient for most of the application scenarios.

Where GPS or communication facilities are not in place, an image recognition algorithm could support self-driving, vision-based autonomous navigation (VAN). VAN is a fully off-line inspection that only relies on the detection and recognition of the tower shape or transmission line by the image. This method or process means the drone could “see” the object, which is called machine vision. Existing VAN systems with different data sources have been developed (Nguyen 2018, Matikainen 2016). Many studies have been conducted using methods of detecting lines (Ceron A, 2014). Other methods are using the detection and recognition of towers (Steiger 2014) or the towers and line combined (Hui 2017).

With advanced analytics emerging and the accumulation of data, image recognition continues to evolve by Deep Learning. In the last few years, Deep Learning architectures such as deep neural networks, deep belief networks, recurrent neural networks, and convolutional neural networks (CNNs) have been applied to machine vision, which uses to extract conceptual target features from the input by multiple layers algorithm. Deep Learning-based systems are well-suited for VAN since it is better at grabbing target features in complex backgrounds. Some approaches like faster region-based CNNs (Dai 2016) and single-shot multibox detectors (Liu 2016) have achieved better detection performance on towers and lines. New automatic driving technologies currently being developed can give rise to more ways of navigation.”

B. FAULT IDENTIFICATION AND BATCH PROCESSING

Inspection with UAS will bring tons of data and images. The data will be uploaded, reviewed, and examined both by the inspector and staff at the base. Identifying a fault from a huge number of images taken by drones can become tedious. Manual recognition seems more reliable but takes longer. The advantage of the machine is the accuracy and subtle changes can be found through machine measurements, such as the tilt of a tower or a missing pin. However, it can't estimate the extent of the damage or the level of risk. Engineers, at this point, become more important to identify and confirm the risk. At present, the two ways are combined to ensure the findings: batch processing with machines and selective review by engineers.

One of the basic fault identification methods is image comparison, that is, to set up an image baseline for equipment to compare with the images taken from each inspection. The difference between the images can be regarded as the exception for further examination. Some identification algorithm can capture salient shape features to identify the fault. For instance, the missing or broken insulator pieces can be found by morphology, BP neural network algorithm, and genetic algorithm (Shan 2010).

Deep Learning methods are suitable to identify the component on the transmission lines because the objects inspected are limited, and the features are well-defined. The more images they are presented with, the smarter the neural network performance can reach, and more accurate recognition results can

be achieved. After recognition of components like an insulator, conductor, or cross-arm of the tower, they will be classified, then detailed and small parts will be examined using different algorithm workflow according to its features. Deep Learning is good at addressing complex surface and cosmetic defects such as rusty or dents on parts of the fittings (Zhao 2016).

The current image recognition method is not yet reliable enough to meet the stringent safety requirements of the energy industry. However, it will free the engineers from wading through massive amounts of unmanageable data and checking down to the finest detail. Nonetheless, more efficient and accurate inspection results will be obtained.

C. LONG-DISTANCE AUTOPILOT SOLUTIONS

For long-distance transmission lines located in remote areas, a small multicopter drone is not effective enough, and the fixed-wing drone can't hover for the detailed image. That's where the large rotary drone comes in. The large rotary drone is designed to carry all the cameras, sensors, and enough batteries both for a long distance and detailed inspection.

To achieve end-to-end autopilot, UAS is designed as fully self-navigated at ultralow altitude with complex terrain conditions. The UAS will strictly follow the preset trajectory. The cameras and sensor equipment automatically take images or videos of lines and corridors without human interventions. This operation requires reliability and redundancy in communication. When loss of connections, it can automatically avoid obstacles, readjust or return to base. High-precision positioning is a necessity to ensure a safe flight.

Sometimes, a communication vehicle is needed as mobile positioning stations to receive GPS data from the base nearby. The navigation and positioning are achieved by real-time differential positioning technology. Since the large rotary drone has a flexible speed, it can hover when necessary to collect the desired high-resolution images.

The long-distance autopilot drones have been adopted by the China Southern Power Grid since 2014 (Peng 2016). The inspection results show that the solution can effectively check the safety clearance of the line corridor as well as the details of insulators and fittings.

D. APPLICATIONS IN CLEAN ENERGY PROJECTS

Application in solar projects

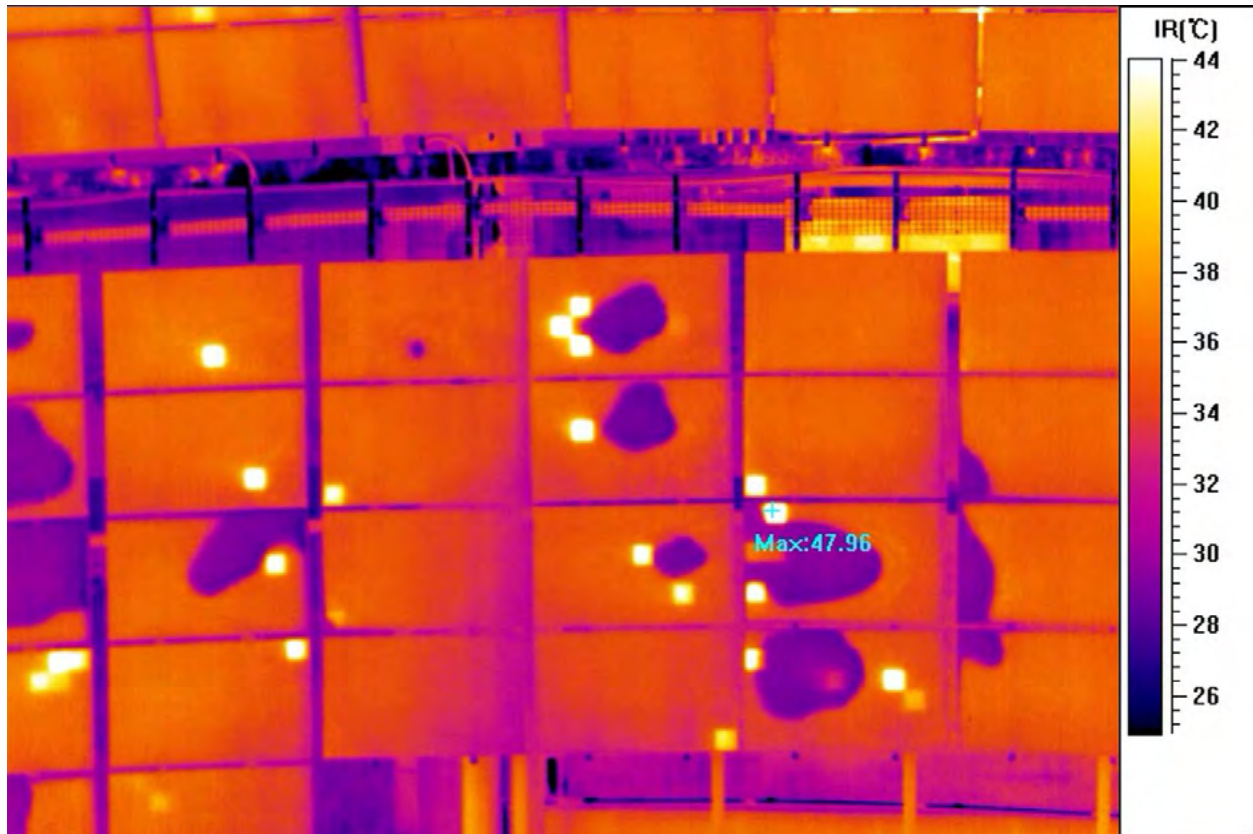
Operating utility-scale solar projects in harsh environments pose several challenges for project developers. The manual inspection is costly and time consuming due to the dispersed area. It is difficult to detect the abnormal conditions of photovoltaic panels, such as dirt, cracks, tear, shading, and overheat. If the failures are not handled on time, accidents would happen while causing OPEX losses.

UAS solutions have been used by solar farm operators in Australia, the PRC, India, and the US in monitoring key points of failure (Precisionhawk, Percepto). In solar farms, problems such as cracks and damages on photovoltaic modules may often occur, sometimes together with bird droppings, dust, or fallen leaves. Because the obstruction cast shadows, the current and voltage of certain cells in the solar module will increase, which may lead to local temperature rise. If the temperature of the hot spot exceeds a certain limit, the panel or joint will be damaged. With visual and infrared cameras,

the drone can quickly scan to detect abnormal heat and hot spots and identify operation problems and locate the broken photovoltaic panels in a timely manner. As shown in Figure 2, intelligent inspections by UAS reveal abnormal hot spots on photovoltaic modules.

The inspection results are spliced through the program, which is convenient for operators to review and locate. An inspection that took weeks in the past, now it only needs a few hours.

Figure 2: Infrared Image and Temperature Measurement for PV Panels by UAS



Source: Guangdong Electric Power Design Institute, PRC.

Application in wind power projects

The maintenance of wind power plants has similar problems as photovoltaic power plants, which can also be solved by drones.

In the wind power industry, with the continuous capacity increase of wind turbines in the market, the blades are getting longer from 30 meters up to 70 meters. During the life cycle of 25 years or more, blades will inevitably be damaged and malfunction. O&M works are difficult due to the height of the structure. In particular, the increase in blade length and weight brings greater challenges. Traditional inspection methods include observation by telescope and manual inspection with helicopters and ropes. The disadvantages are obvious including safety, low efficiency, high cost and duration, and loss of generation.

By UAS, the surface can be checked anytime, and actions can be taken on time. During long-term operation of the wind turbine, the blade coating might fall off and surface cracks would cause blade damage and corrosion. Lightning, icing, or external forces would also result in blade deformation, damage, or bolt breakage. O&M personnel could hover drones and take close shots for defects location. These could enhance the accuracy of telescope observations.

Maintaining higher energy output with lower operating costs is the future trend for clean energy development and integration. UAS with digital technologies can achieve these goals of efficiency, quality, and accuracy.

E. OTHER APPLICATIONS IN THE ENERGY SECTOR

Survey and mapping

UAS has become an indispensable tool for surveys and mapping for projects. The traditional way of surveying is time-consuming due to the unavailability of data and geographic restrictions, the issue is outstanding in mountainous and subsidence areas.

Drones are not confined by terrain. The flight trajectory covering the survey area can be automatically generated by the software. Besides, the measurement output could be stitched together seamlessly for the final output. If required, 3D models can be constructed. With accuracy brought by UAS, the subsequent project design and construction can benefit from fewer deviations.

Compared with satellite remote sensing, UAS can provide high-resolution optical images, oblique photographs, and facility images obtained at low altitudes. UAS is also not affected by weather or clouds.

Project progress and safeguard monitoring

Many companies have started using drones to gather site information and monitor project progress and safeguard issues. Monitoring data can be shared for remote management and report. Construction issues, environmental damage, or misconduct can be found easily and in time, corrective measures can be undertaken right after.

UAS are also used to establish environmental baselines at the beginning of the project and deal with resettlement issues. Using drones to collect and record data has greatly improved work efficiency and transparency. The live footage could also be used to ensure safeguard compliance and shared with all the stakeholders.

Construction

Drones can carry light cargo or equipment to help the construction team in transporting small items. For instance, the power transmission corridor often traverses across difficult terrains with dense forests, valleys, or rivers, it is of great inconvenience to mount the conductors to the towers during the installation.

In the past, a working path along the route has to be explored by cutting trees or plants. Horses are used to pull the leading rope that is connected to the conductors and drag from one tower site to another. Now, these leading ropes can be easily carried by the drone. The flyover saves time and won't cause any damage to the vegetation.

4. UAS INSPECTION CENTER

A. A COMMAND CENTER FOR O&M WORKS

The establishment of an inspection center is to standardize the working process, reallocate the maintenance resource, and manage the inspection data. As UAS improves efficiency, the O&M working schedules and guidelines need to be upgraded, and new procedures shall be streamlined. Safety instructions shall be formulated to ensure daily operation.

Data Management Platform (DMP) is a database, communication, and analytic center for all the inspection teams. All data collected by UAS inspection teams are sent back for analysis and report. Modules that build in the platform include overall grid structure and geographical information, team information and real-time location, data acquisition module, defect library, image analysis module, inspection results management module.

Drone units and engineers work separately but collectively by sharing the same database. With the platform, information of the fault, available resource, and location will be managed and displayed, thereby the decision-making process is more concise, and the engineers would gain sufficient support to restore the power almost immediately.

B. PROACTIVE O&M CAPABILITY

In analyzing the inspection data in chronological order along with other information like weather forecasts, utility engineers can not only examine what has happened but can also predict what will happen next. Taking preventive actions before the risk would mitigate the actual impact.

For instance, with the weather information obtained from public service or sensors installed on the transmission line, more reliable predictions can be achieved. The possible impact on power system facilities can be assessed. Special forces can be sent to check the facility and enhance if needed.

A large portion of power outages is caused by trees or vegetation that are close to the power lines. The growth of vegetation shall be carefully monitored to maintain a safe air clearance. With the input of the growth rates of particular plants and their current height, a program for vegetation management can be set up to give growth projections and guide field teams where and when to manage and prune the trees on a regular basis. Other slow and long-term risks like soil erosion or foundation washout, which often happens in mountainous region, can also be detected and predicted. The alarm clock can be set for corrective actions at a proper time before it causes major losses.

C. INTEGRATION WITH OTHER EXISTING SYSTEMS

The combination of UAS inspection information and supervisory control and data acquisition (SCADA) realizes comprehensive monitoring and full visualization of the power grid. The SCADA system obtains only the electrical signals of the substations to realize the remote viewing measurement, control and dispatching, and other functions so that substation can be unattended.

The visual information by the UAS is an add-on that brings detailed updated or near real-time transmission line status. Operators could take action with more adequate evidence and information.

SCADA only monitors and manages the equipment by the electrical signals and lacks effective means to detect non-electrical signals, leaving many hidden dangers. These video data of the substation could also share with the UAS data management platform (DMP) for image processing and auto-fault identification together with the data procured from the transmission line.

The inspection data and the oblique photograph are a very important supplement to other existing systems like enterprise resource planning (ERP) and geographical information systems (GIS). For example, inspection data can be a up-to-date and high resolution input for GIS map, demonstrating the actual equipment and facilities running status with time tag; the routine maintenance plan will become more focused and effective; assets status and decommissioning can be organized and optimized with the reference of the data from DMP; sharing the data with ERP could promote assets management to initiate more precise planning for renovation, retrofit, and construction.

D. REGULATIONS

Civil aviation departments in many nations have published their regulations related to drones for public safety and privacy which apply to both commercial and recreational uses. These guidelines have stipulated when, where, and how to fly a drone such as the permissions, visual line of sight (VLOS), height, distance, and carriages. Procedures and rules are also in place to govern commercial usage including drone registration, drone categorizations, and risk classification, operator and/or pilot training, license, and insurance. Policymakers are trying to not only design for better supervision but also facilitate market development.

Energy utilities have been authorized to use drones for inspections for years. San Diego Gas & Electric was granted permission of usage by the US Federal Aviation Administration (FAA) more than 6 years ago (McNeal 2014). However, these applications are mostly limited to flying within the visual line of sight (VLOS). The biggest value of drones in inspections lies in the automatic cruise along the right of way beyond the visual line of sight (BVLOS). FAA requires that a drone remains within the pilot's VLOS throughout the entire flight (New 2020). Many other nations followed the same because of safety concerns.

The power facility inspection is to ensure the safety of energy supplies for the public. Performing BVLOS flight will maximize the benefit, and it is necessary in the situation of emergency. The flight time and route can be planned, tagged and recorded in advance with the data made available to the regulator. In some countries like UK, Poland, and China, the utilities is allowed to obtain a special waiver to perform BVLOS flight. European watchdogs have also granted special permits to allow utilities to test prototypes (Stephen 2018). The European Union Aviation Safety Agency (EASA) would also streamline the procedures and grant authorizations for the specific operations. BVLOS will be the next driver for drone operation expansion.

E. IMPLEMENTATION COSTS

Compared to a conventional inspection, a UAS inspection can save time and human resources. With new tools, the hours spent on climbing can be reduced to dozens of minutes, and fewer field engineers are required.

The cost of UAS hardware fluctuates as the technology keeps evolving. An estimated cost breakdown is given in Table 3 for establishing a small-scale UAS inspection center.

Table 3: Cost Estimates for UAS inspection Center (\$'000)

No.	Item	Descriptions	Unit	Total Price
1	UAS system	Four rotors, wheelbase 643mm	4	45.7
2	Camera	High resolution aerial digital camera	4	28.6
3	Sensors	Thermal infrared imager; Laser range finder.	4	28.6
4	Data management platform	Defect library Patrol data processing	1	100.0
5	Training	UAV operator training; Data management platform training.	1	6.0
6	Servers and database	Two file servers (CPU, Memory, SSD hard drive, Gigabit LAN)	1	100.0
Total Cost				309.0

Source: Author.

To make a brief comparison of the two methods, we choose a scenario of inspection of 2 kilometers 400kV transmission line inspection including 6 towers in Bangladesh as an example to evaluate the cost difference.

The consolidated cost for UAS inspection included the UAS system, engineers, transport expenses, and other miscellaneous costs. The service life of the equipment is around 5 years with 10% annual O&M cost for spare parts and batteries. Allocating the total investment to the daily cost, the average cost for a UAS center is \$340 per day for four UAS teams. The median salary for the electrical engineer in Bangladesh in 2019 is around 28,400 BDT (Bangladesh taka) per month, equivalent to \$335 per month and \$1.90 per hour. Two engineers with one drone can complete the inspection within a day. The data will be sent back to the Inspection center for processing, review, and generating the report. Detailed cost breakdown for a UAS inspection of this case is shown in Table 4.

Table 4: UAS Inspection Cost

	Items	Unit cost (US \$/hour)	Working time (hour)	Total cost (US \$)
1	UAS System (1 day flight)	85.0/day	-	85.0
2	Manpower (2 Engineers)	3.8	8	30.4
3	Transportation cost	4.0	8	32.0
4	Review and Report	1.9	8	15.2
5	Allowance and Others	1.0	8	8.0
	Total cost			170.6

Source: Author.

Three engineers are required in the conventional way of inspection for the towers and lines with the same salary level. The cost breakdown is in Table 5.

Table 5: Conventional Inspection Cost

	Items	Unit cost (US \$/hour)	Working Time (hour)	Total cost (US \$)
1	Manpower (3 Engineers)	5.7	32	182.4
2	Tools and safety measures	5.0	-	5.0
3	Data processing and Report	1.9		3.8
4	Transportation cost	4.0	10	40.0
5	Allowance and Others	1.0	32	32.0
	Total cost			263.2

Source: Author.

The high voltage transmission lines or substations are often located in remote areas or mountainous regions. The conventional method often takes more time than planned in these cases.

F. BENEFITS

Power availability. To ensure personnel safety during inspections, the power utility had to schedule a maintenance plan together with power curtailment or downtime. It would affect customers and causing financial losses to the utility and indirect economic losses to the region. In contrast, UAS inspection does not require power downtime.

Reliability enhancement. More potential risks and defects can be revealed with the detailed and accurate inspection result. Among all the defects which can be identified by UAS, the defects that are difficult to find by manual inspection account for 78.5% (Yitao 2018).

Correction and fixation of these potential problems further reduce the possibility of system failure. With the application of smart technology in the O&M from 2015 to 2020, China Southern Power Grid has achieved the line trip rate decreased by 7.5% annually to 1.15 times per 100 kilometers per year. Meanwhile, the average length of lines maintained per maintenance staff increased by 8% annually to 39.28 kilometers (Chinasmartgrid 2021).

Safe working environment. UAS transforms the “labor intensive work” into a “technical job.” Although tremendous effort has been made to ensure safety, the climbing risk and psychological pressure persist. The adoption of UAS for inspection has fundamentally changed the way work is done and has greatly reduced the occupational hazards.

G. COLLABORATION WITH PRIVATE SECTOR

Power utilities could work together with the industry and enjoy the best available service with a less initial expense. The drone industry is a new and promising sector with many stakeholders, manufactures, software developers, service providers, testing, and consultants. Partnering with the private sector, power utilities can absorb the technology in a fast and flexible way. For most of the utilities, it may take a longer time to build an internal drone inspection team from scratch. Investment decisions, establishing systems, obtaining application permits, and training pilots all require plenty of investment and work. On the other hand, as UAS applications continue to evolve, private companies and startups are able to provide all kinds of up to date drone-related services.

Some utilities have small service areas that only require one or two inspections per year. The cost would be too high to maintain an inspection team. Some may have doubts on the implementation accountability from an energy “outsider.”

Phase approaches can be adopted as the business grows. Initially, drone companies may be engaged in some specific or temporary work to test their performance, then utilities could decide whether to outsource part of the works. With more professional drone service provided by the private sector, the risks can be minimized, and so does the issue of feasibility, upgrades, repairs, maintenance, and regulatory compliance.

Utilities could cooperate with the private sector to experiment and develop new drone solutions: 3D simulation, virtual reality (VR), digital twin, and real-time monitoring. The private sector will bring huge benefits and diversity.

5. CONCLUSIONS

In recent years, the UAS has been seen as a new smart tool in many industries including public management, emergency rescue, energy, agriculture, transport, and spatial survey, etc. These intelligent tools have expanded people's capabilities, kept them away from danger, and enhanced work efficiency.

ADB commits itself to assist its developing member countries in all these areas and supports strengthening governance and institutional capacity. In the energy sector alone, ADB has approved \$42.5 billion of financing for the energy sector during 2009–2019, making it the second-largest sector that ADB supports. Electricity transmission and distribution was the dominant subsector overall with total approvals amounting to 39% of the total portfolio. Renewable energy projects, mostly solar photovoltaic and wind power plants, comprised 13% of the portfolio. Hydroelectric projects accounted for another 8%, ADB (2020). All of these projects have the potentials to adopt the technologies for the survey, planning, construction, monitoring, and operations throughout the project life cycle.

The drone civil application was only started about 5 years ago, but the technology is becoming mature in many countries. In 2019, ADB approved the first drone application in one of its energy projects. This project aims to set up a drone inspection center for Power Grid Company of Bangladesh, Ltd.

Digital technology is empowering utilities to meet future challenges, such as energy access to all, low carbon development, and rising operation costs. Power utilities now realize that it is critical to adopt digital technology and formulate a digital development strategy. Some utilities may have a conservative attitude and may prefer to adopt after the technology has been proven, but UAS can be a good starting point.

In the coming years, ADB will increase its investments on renewable energy and low carbon technology development. T&D and renewable energy projects make up the bulk of ADB's energy projects in many countries, ADB (2020b, 2020c, 2020d, 2020e). ADB will strengthen its role as a knowledge provider and expand its operations not only in the energy sector but in transportation, agriculture, urban development, and many other areas. Promoting the broad use of highlevel technology and science will play an important role to achieve ADB 2030 operational priorities.

REFERENCES

- A. Ceron, B. Mondragon, F. Prieto, et al. 2014. *Power Line Detection Using a Circle-based Search with UAV Images*. In: *2014 International Conference on Unmanned Aircraft Systems (ICUAS)*, IEEE. Orlando, FL, USA.
- A. Vaughan. 2018. *AI and Drones Turn an Eye towards UK's Energy Infrastructure*. <https://www.theguardian.com/business/2018/dec/02/ai-and-drones-turn-an-eye-towards-uks-energy-infrastructure>.
- Amazon PimeAir. Heron. 2014. *Drones in India*. <https://dronecenter.bard.edu/drones-in-india>.
- Asian Development Bank. 2020. *Sector-wide Evaluation: ADB Energy Policy and Program, 2009-2019*. Manila.
- _____. *Asia's Journey to Prosperity: Policy, Market, and Technology Over 50 Years*.
- _____. 2020b. *Bangladesh: Country Operations Business Plan (2020-2022)*. Manila.
- _____. 2020c. *India: Country Operations Business Plan (2020-2022)*. Manila.
- _____. 2020d. *Indonesia: Country Operations Business Plan (2020-2022)*. Manila.
- _____. 2020e. *Pakistan: Country Operations Business Plan (2020-2022)*. Manila.
- Bradley New. 2020. *Drone Use For Power Line Inspection*. <https://droneguideusa.com/drone-use-for-power-line-inspection>.
- C. Shan, H. Wu, et al. 2010. *Insulator Defect Detection Method in Image Processing*. Journal of China Institute of Meteorology.
- Chinasmartgrid. 2021. *During the "Thirteenth Five-Year Plan" Period, China Southern Power Grid's Line Trip Rate Decreased by 7.5% Annually*. <http://www.chinasmartgrid.com.cn/news/20210107/637511.shtml>.
- China Southern Power Grid Company. 2019. http://www.csg.cn/xwzx/2019/gsyw/202001/t20200103_307223.html.
- G. McNeal. 2014. *FAA Approves Limited Use Of Drones For Utility Company*. Forbes. <https://www.forbes.com/sites/gregorymcneal/2014/07/12/faa-approves-limited-use-of-drones-for-san-diego-utilitycompany/#3e78e1f6a0d2> (accessed 28 December 2020).
- J. Dai, Y. Li, K. He, and J. Sun, 2016. *R-fcn: Object Detection via Region-based Fully Convolutional Networks in Advances in Neural Information Processing Systems*.
- J. Malasig. 2018. *How Technology is Innovating Agriculture in the Philippines*. <https://interaksyon.philstar.com/breaking-news/2018/08/20/131961/technology-innovating-philippines-agricultural-sector>.
- J. Schaller and U. Lohr. 1999. *Integrated Heli-corridor-Mapping (IHCM)*, 1999 Esri User Conference. San Diego, USA.

- J. Wells. 2018. *5 Ways Duke Energy is Using Drone Technology*. Duke Energy Corporation. <https://illumination.duke-energy.com/articles/5-ways-duke-energy-is-using-drone-technology>.
- L. Matikainen, M. Lehtomaki, et al. 2016. *Remote Sensing Methods for Power Line Corridor Surveys*. ISPRS Journal of Photogrammetry and Remote Sensing.
- L. Sydell. 2017. *Telecom Companies Turn To Drones For Help After Hurricanes*. NPR. <https://www.npr.org/2017/09/10/549922317/telecomcompanies-turn-to-drones-for-help-afterhurricanes>.
- L. Tavares and JS. Sequeira. 2007. *Riol-robotic Inspection Over Power Lines*. International Federation of Automatic Control Proceedings.
- O. Steiger, E. Lucas, and Y. Maret. 2014. *Automatic Detection of Transmission Towers*. In: SENSORS, IEEE, Valencia, Spain.
- Percepto. <https://percepto.co/solar-energy-industry/> (accessed June 2020).
- PrecisionHawk. <https://www.precisionhawk.com/solar> (accessed June 2020).
- S.I. Tay, L.T. Chuan, A.H. Nor Aziati, A.N. Aizat Ahmad 2018. *An Overview of Industry 4.0: Definition, Components, and Government Initiatives*, *Journal of Advanced Research in Dynamical and Control Systems*.
- S. Jewkes and C. Steitz. 2018. *Power to the Drones: Utilities Place Bets on Robots*. <https://www.reuters.com/article/us-utilities-drones-europe-analysis/power-to-the-drones-utilities-place-bets-on-robotsidUSKBN1K60TS>.
- V. N. Nguyen, R. Jenssen, and D. Roverso, 2018. *Automatic Autonomous Vision-based Power Line Inspection: A Review of Current Status and the Potential Role of Deep Learning*. International Journal of Electrical Power & Energy Systems.
- W. Liu, D. Anguelov, et al, 2016, *Ssd: Single Shot Multibox Detector*. European Conference on Computer Vision. Springer.
- X. Peng, J. Qian, et al. 2016. *Automatic Power Line Inspection Technology of Large Unmanned Helicopter and Its Application*. Southern Power System Technology. China.
- Xiaolong Hui, Jiang Bian, et al. 2017, *Vision-based Autonomous Navigation Approach for Unmanned Aerial Vehicle Transmission-line Inspection*. International Journal of Advanced Robotic Systems.
- Yitao. 2018. *Outlook 2018: Application and Prospects of UAVs in the Field of Electric Power Inspection*. <https://uav.huanqiu.com/article/9CaKrnK6mtN>.
- Z. Zhao, G. Xu, et al. 2016. *Multi-patch Deep Features for Power Line Insulator Status Classification from Aerial Images*. IEEE International Joint Conference on Neural Networks (IJCNN).

The Value of Unmanned Aerial Systems for Power Utilities in Developing Asia

Unmanned aerial systems (UAS) such as drones are increasingly being used to automate the planning, building, and maintenance of energy facilities around the world. The effectiveness of UAS and digital technologies are transforming energy sector operations to be faster, safer, and more cost-efficient. This working paper introduces UAS and discusses the latest technological developments as well as current applications. It also assesses the feasibility of UAS adoption in developing Asia's energy sector.

About the Asian Development Bank

ADB is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty. Established in 1966, it is owned by 68 members—49 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

