IEC TR 63439-1-2

Edition 1.0 2026-06

TECHNICAL REPORT

Robotics for electricity generation, transmission and distribution systems – Part 1-2: State-of-the art and standardization roadmap for electric power system robots

IEC TR 63439-1-2:2026-06(en)

ICS 01.040.25; 25.040.01

ISBN 978-2-8327-1240-5

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews, graphical symbols and the glossary. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 500 terminological entries in English and French, with equivalent terms in 25 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

Robotics for electricity generation, transmission and distribution systems - Part 1-2: State-of-the art and standardization roadmap for electric power system robots

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TR 63439-1-2 has been prepared by IEC technical committee 129: Robotics for electricity generation, transmission and distribution systems. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
129/59/DTR	129/64/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63439 series, published under the general title *Robotics for electricity generation, transmission and distribution systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

– reconfirmed,
– withdrawn, or
– revised.

INTRODUCTION

With the continuous advancement of automation, digitalization, and artificial intelligence, more than 20 countries worldwide - including Canada, China, Japan, New Zealand, the United States, etc. - have actively pursued research and application of power robotics technologies. The global demand for robotic solutions in the power sector is substantial and presents significant growth potential.

Currently, robots carrying out tasks such as patrol, inspection, detection, and maintenance are already widely adopted across power generation, transmission, substation, and distribution systems. Meanwhile, specialized robots - such as those for gas-insulated switchgear (GIS) diagnostics and live working in substations - are under development. These applications have driven new technical requirements for robotic systems designed to assist or replace manual field inspections.

However, the absence of unified international standards has led to significant variations in robot functionality and performance across different countries, resulting in limited interoperability and compatibility. There is a clear need to establish international standards to achieve consensus on functionality, performance, safety, and operational efficiency.

This report encompasses the entire power system workflow and addresses applications such as inspection, maintenance, operation, and emergency response. Both indoor and outdoor high-voltage environments are considered, as well as diverse geographical and climatic conditions. Key factors in adopting power robotics are investigated, including safety issues, human-machine collaboration, system reliability, and cybersecurity. The report also analyses standardization needs based on current applications and proposes a roadmap for standardization. The purpose of this report is to offer guidance for advancing related technologies and products while serving as a reference for developing international standards in the field of power robotics.

This document mainly consists of five parts. Clause 4 provides an overview of power robotics, covering their current applications, technical status, classification methods, system architecture, key components, and operating modes in electric power systems. Clause 5 outlines the key technologies of power robotics, including mobile platforms, positioning/navigation systems, communication networks and cybersecurity. Clause 6 details the core functional technologies of power robots, covering multi-modal inspection capabilities and critical maintenance operations for electric power systems. Clause 7 presents testing frameworks for power robots, ensuring operational effectiveness across all critical system parameters. Finally, Clause 8 outlines the standardization framework for power robotics, reviews existing standards and organizations, and presents the IEC/TC129 structure with a comprehensive roadmap and implementation plan for future standardization efforts.

Further reading:

IEC 60050-191:1990, International Electrotechnical Vocabulary (IEV) - Part 161: Electromagnetic compatibility IEC 60050-161:1990 [1]

IEC 60050-192:2015, International Electrotechnical Vocabulary (IEV) - Part 192: Dependability IEC 60050-192:2015 [2]

IEC 60050-195:2021, International Electrotechnical Vocabulary (IEV) - Part 195: Earthing and protection against electric shock IEC 60050-195:2021 [3]

IEC 60050-300:2001, International Electrotechnical Vocabulary (IEV) - Part 300: Electrical and electronic measurements and measuring instruments - Part 311: General terms relating to measurements - Part 312: General terms relating to electrical measurements - Part 313: Types of electrical measuring instruments - Part 314: Specific terms according to the type of instrument IEC 60050-300:2001 [4]

IEC 60050-651:2014, International Electrotechnical Vocabulary (IEV) - Part 651: Live working IEC 60050-651:2014 [5]

IEC TR 62210:2003, Power system control and associated communications - Data and communication security IEC TR 62210:2003 [6]

ISO 12100:2010, Safety of machinery - General principles for design - Risk assessment and risk reduction ISO 12100:2010 [7]

ISO 18257:2016, Space systems - Semiconductor integrated circuits for space applications - Design requirements ISO 18257:2016 [8]

ISO 19092:2008, Financial services - Biometrics - Security framework ISO 19092:2008 [9]

ISO/TS 27790:2009, Health informatics - Document registry framework ISO/TS 27790:2009 [10]

1 Scope

This part of IEC 63439, which is a Technical Report, specifies a comprehensive study of the robotic technologies in power systems, including generation, transmission, and distribution. The primary objectives are:

a) System overview and classification

Analyze current robotic applications across all power system segments (generation, transmission, and distribution), developing a comprehensive classification framework that categorizes robots by operational scenarios (substations, power lines), functional roles (inspection, repair), and environmental conditions (high-voltage zones, confined spaces).

b) Core technology assessment

Evaluate fundamental robotic technologies encompassing mobility platforms (ground robots, drones, remotely operated vehicles (ROVs)), navigation systems (GPS, LiDAR, vision-based), and communication networks (wired/wireless/hybrid); assess functional capabilities through multi-sensor inspection (visual, thermal, ultrasonic) and maintenance operations (live-line work, cleaning, debris removal), and examine integration aspects with power grid management systems including data protocols and cybersecurity requirements.

c) Testing and validation framework

Establish performance benchmarks for core robotic functions including autonomous navigation, inspection accuracy, and operational efficiency, while developing reliability testing methods that incorporate failure mode analysis (FMEA/FMECA) and environmental stress testing under extreme conditions.

d) Standardization roadmap

Conduct a gap analysis of current power robotics standards (including IEC/TC129) to identify deficiencies, while systematically mapping stakeholder requirements to prioritize standardization needs across hardware, software interfaces, and safety protocols; develop the roadmap with clear timelines for creating new standards, facilitating adoption, and ensuring compliance verification across the industry.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

– IEC Electropedia: available at https://www.electropedia.org/
– ISO Online browsing platform: available at https://www.iso.org/obp

4 Overview of robots applied in electric power systems

4.1 Background

With the rapid development of the economy and society, electricity demand has continued to grow, leading to a significant increase in facilities across power generation, transmission, and distribution. As a result, operation and maintenance (O&M) tasks for power systems have become more intensive, with high workloads and elevated risks, creating a growing demand for highly skilled personnel. There is an urgent need for new technologies to replace or assist manual O&M work, especially with the increase of the following challenges.

a) Harsh environments

   Many transmission and transformation facilities are located in remote outdoor areas with severe natural conditions, making manual inspection difficult.

b) Maintenance of newly deployed facilities

   With the development of ultra-high voltage (UHV) AC/DC power grids, components such as converter valve halls and UHV insulator strings have been introduced. Due to installation constraints and surrounding conditions, conventional manual maintenance is inadequate.

c) Unattended substations and transmission facilities

   Labour shortages and advances in intelligent technologies have driven demand for unmanned substation operations. The development of smart substations imposes new requirements on O&M management models. At the same time, there is a growing shortage of live-line O&M personnel for transmission lines and distribution networks.

d) Routine inspection and maintenance tasks

   Repetitive and labour-intensive tasks - especially under adverse weather conditions - imply that there is a need to reduce manual workload and improve operational efficiency and effectiveness.

With ongoing advancements in robotics, artificial intelligence, and information processing technologies, the use of robots, drones, and similar systems to replace humans in complex, hazardous, and highly repetitive tasks has become a solution. This shift is particularly evident with :

e) Enhanced personnel safety

   Power equipment typically operates under high voltage conditions, posing significant risks to workers. By reducing the need for on-site human presence, robotics can improve operational safety. Robots can be deployed to perform tasks in high-risk environments, minimizing direct human exposure.

f) Reduced operation and maintenance (O&M) costs

   For repetitive inspection tasks in power facilities, automation and remote operation via robots can significantly lower O&M expenditures.

g) Increased inspection frequency and improved system stability

   Enhanced inspection coverage and accuracy through robotic deployment enable more effective preventive and condition-based maintenance, reducing the probability of emergencies and improving the overall stability of power system operations.

h) Improved asset management

   Robots provide new sources of equipment data, enabling a more comprehensive understanding of asset conditions. This supports better health monitoring and helps prevent catastrophic failures.

4.2 Technical and application status

At present, ground inspection robots have been deployed in the power generation sector - including hydropower stations and photovoltaic (PV) plants - for equipment inspection using visual and infrared technologies. Unmanned Aircraft Systems (UAS) inspection systems are also utilized for routine inspections of external plant infrastructure.

Specialized detection robots, such as generator inspection robots, dam inspection robots, and wind turbine inspection robots, have been put into operational use. Additionally, maintenance robots - such as PV module cleaning robots - are being widely promoted and adopted across power generation facilities. The application status of robots in the power generation sector is shown in Table 1.

Table 1 – Application of robots in power generation

Scenarios	Robots in use	Countries
Hydro plants	Underwater inspection robots	Canada, China, France, Italy, Venezuela, Thailand
Wind farms	Wind turbine inspection robots	China, Germany, United States
PV plants	PV panel cleaning robots	China, Japan, Switzerland

Overhead transmission line inspection robots include UAS-based systems that leverage image analysis for precise defect detection. Line-following inspection robots are capable of insulator insulation performance assessment and X-ray-based defect detection. Submarine cable inspection robots utilize sonar imaging to identify cable conditions. Robots can also be used for device-specific inspection such as insulator inspection. Live-line maintenance robots are used for tasks such as strand repair on lines and towers, while de-icing robots are deployed for removing ice accumulation on transmission lines.

In substations, wheeled inspection robots are employed for on-site operations. These robots integrate multiple diagnostic technologies - such as high-definition image acquisition and analysis, infrared thermography, ultraviolet imaging, and ultrasound detection - to enable automated equipment status recognition, thermal defect detection, sound/noise measurement, and partial discharge detection. For more details, please refer to CIGRE TB 807:2020 [11].

Valve hall inspection robots are specifically designed for the unique electromagnetic environment of UHV converter valve halls. These robots operate during live conditions to provide imaging that identifies leakage or hot spots, enabling predictive maintenance planning for the next scheduled outage.

Transformer internal inspection robots have been developed to perform inspections without requiring oil drainage. For maintenance applications, live-line water-washing and cleaning robots are in use. Switchgear operation robots have entered partial deployment, while firefighting robots for emergency response are currently in the trial phase. The application status of robots in the power transmission sector is shown in Table 2.

Table 2 – Application of robots in power transmission

Applications	Robots in use	Countries
Overhead transmission lines	UAS -based robots for Transmission line Inspection	China, France, United Kingdom, United States, Peru
	Transmission line Inspection robots	Canada, China, Japan, South Africa, New Zealand, United States, Peru
	Transmission line De-icing robots	China, Spain, United States
	Insulator inspection robots	China, South Korea, United States
Submarine cables	Cable inspection robots	China
Tunnel cable	Tunnel ground inspection robots	China, United States
Substation	Substation wheeled inspection robots	China, Japan, France, United States
	Gear operation robots	China, United States
	Valve hall ground inspection robots	China, Germany

In distribution systems, UAS-based robots have been adopted to inspect the operational status of distribution network lines. Live-line operation robots are used to perform tasks such as insulation stripping, bolt tightening, replacement of anti-fall devices, and live disconnection or connection of leads. Overhead line insulation coating robots for distribution networks are capable of automatically applying insulating materials to enhance line insulation performance. The application status of robots in the distribution sector is shown in Table 3.

Table 3 – Application of robots in distribution

Applications	Robots in use	Countries
Overhead line tower	Live line operation robots	China, Japan, United States, Peru
Distribution control centre	Distribution control operation robots	China

4.3 Classification of power robots

4.3.1 Classification by application scenario

Power system scenarios are diverse and complex, imposing varying functional requirements on robots across different scenarios. Currently, robotic systems have been deployed across multiple domains of the power system. Based on application scenarios, power robots can be classified as follows:

a) Robots applied in electricity generation scenarios

Applied in power generation environments such as thermal power, hydropower, and wind power plants.

b) Robots applied in electricity transmission scenarios

Used in scenarios including overhead transmission lines and submarine cable transmission.

c) Robots applied in electricity substation scenarios

Deployed in both outdoor and indoor environments of substations.

d) Robots applied in electricity distribution scenarios

Utilized in distribution network scenarios, including overhead lines, poles and towers, and distribution rooms.

4.3.2 Classification by function

Robots in the power sector can be categorized by their functional roles as follows:

a) Robots applied for electric power facilities construction

Used throughout various stages of power infrastructure development, including surveying, design, and construction.

b) Robots applied for electric power facilities inspection

Employed for routine inspection and condition monitoring of power equipment. Functions include equipment status recognition, meter reading, infrared temperature measurement, and partial discharge detection.

c) Robots applied for electric power facilities operation/maintenance

Designed to perform operational and maintenance tasks on power facilities, such as water washing, cleaning, and switchgear operation.

d) Robots applied for electric power facilities emergency

Intended for emergency response involving power infrastructure, including firefighting robots, confined-space emergency UAS, and search-and-rescue drones.

4.3.3 Classification by operating environment

Robots in the power sector can also be classified according to their operating space as follows:

a) Ground mobile robots

Operating on the ground or equipment surfaces, including wheeled, legged, and rail-guided systems used for inspection and operational tasks.

b) Aerial robots

Operating in the air, such as UAS-based transmission line inspection robots and airships.

c) Underwater/submersible robots

Functioning underwater or in liquid environments, including dam inspection robots, submarine cable inspection robots, and submersible transformer inspection robots.

4.4 Power robotic system configuration

4.4.1 System architecture

A power robotic system typically consists of a mobile platform equipped with inspection or operation modules, enabling data acquisition, processing, and analysis of power equipment. The system architecture generally includes the following components:

a) Mobile platform

A mechanical base enabling mobility, such as wheeled, legged, tracked units, and UAS.

b) Inspection/operation subsystem

Modules for data collection or execution of tasks (e.g. cameras, sensors, manipulators).

c) Communication subsystem

Ensuring data transmission between the robot and control centre.

d) Control and HMI

On-site control systems for real-time monitoring and interaction.

e) Auxiliary subsystems

Including autonomous charging stations and environmental support equipment.

Some robots are additionally equipped with auxiliary navigation systems for path planning and obstacle avoidance. Others can integrate with remote centralized control platforms, supporting either fully autonomous or teleoperated modes for inspection, status monitoring, and task execution, as shown in Figure 1.

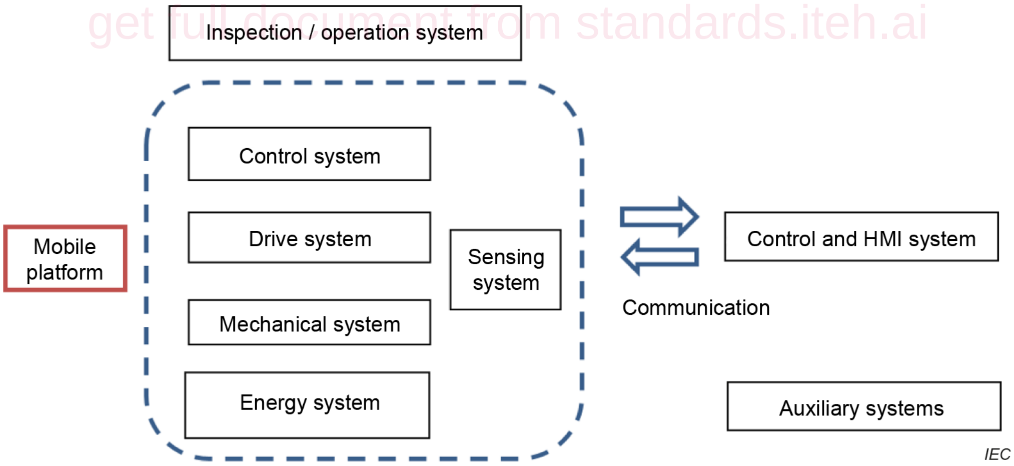

Figure 1 – Architecture of the robotic system

4.4.2 Robotic mobile platform

The robotic mobile platform consists of motion mechanisms and control systems, along with battery and power supply modules. Depending on the operating environment, platforms are equipped with a protective framework, and some are integrated with environmental perception systems to enable autonomous localization and navigation. Common mobility mechanisms include wheeled, rail-guided, submersible oil-immersed, legged and aerial types.

The main control system governs the robot's core operations, with control commands issued either through manual remote control or task settings from a remote monitoring platform.