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

ICS 01.040.25; 25.040.01

ISBN 978-2-8327-1240-5

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

THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2026 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

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 It also gives information on projects, replaced and withdrawn publications.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

FOREWORD 5
INTRODUCTION 7
1 Scope 9
2 Normative references 9
3 Terms and definitions 9
4 Overview of robots applied in electric power systems 9
4.1 Background 9
4.2 Technical and application status 10
4.3 Classification of power robots 12
4.3.1 Classification by application scenario 12
4.3.2 Classification by function 12
4.3.3 Classification by operating environment 12
4.4 Power robotic system configuration 13
4.4.1 System architecture 13
4.4.2 Robotic mobile platform 13
4.4.3 Task-specific subsystems 14
4.4.4 Control and interaction subsystems 14
4.4.5 Communication module 14
4.4.6 Other auxiliary facilities 14
4.5 Operating modes 15
5 Basic technologies of robots for electric power systems 15
5.1 Robotic mobile platform 15
5.1.1 Ground mobile platform 15
5.1.2 UAS-based platform 17
5.1.3 Underwater remotely operated vehicles (ROVs) platform 19
5.2 Positioning and navigation technology 20
5.2.1 General 20
5.2.2 GPS and IMU positioning and navigation 21
5.2.3 LiDAR-based positioning and navigation 22
5.2.4 Vision-based positioning and navigation 23
5.2.5 Ground beacon-based navigation 23
5.2.6 Path planning technology 24
5.3 Communication technology and network security 24
5.3.1 General 24
5.3.2 Wired network 24
5.3.3 Wireless network 25
5.3.4 Cyber security 25
5.4 Control backend software 26
5.4.1 General 26
5.4.2 Integration with power systems 27
5.4.3 Data analysis and intelligent decision-making 27
6 Functional technologies of robots for electric power systems 28
6.1 Inspection, recognition and detection 28
6.1.1 Visible image and video defect recognition 28
6.1.2 Infrared-based thermal defect detection 33
6.1.3 Voiceprint-based equipment fault diagnostics 33

6.1.4 Partial discharge detection 34
6.1.5 Magnetic-based insulation detection 36
6.1.6 X-ray-based flaw detection 38
6.2 Operation and maintenance 38
6.2.1 General 38
6.2.2 Electrical equipment operations 39
6.2.3 Power facility foreign object removal 40
6.2.4 Power equipment cleaning 42
6.2.5 Live-line maintenance 43
7 Testing and evaluation 45
7.1 General 45
7.2 Performance evaluation 45
7.2.1 Autonomous mobility performance 45
7.2.2 Routine inspection performance 46
7.2.3 Operation specific performance 46
7.2.4 Communication performance 46
7.2.5 Software testing 47
7.3 Reliability testing methods 47
7.3.1 General 47
7.3.2 Classification of reliability indicators 47
7.3.3 Failure mode and effects analysis (FMEA/FMECA) 47
7.4 Environmental adaptability 47
7.4.1 Operating environment simulation 47
7.4.2 EMC standards and testing procedures 48
7.4.3 Safety distance and insulation 48
7.5 Cyber security 48
8 Standards demand and roadmap 49
8.1 Standardization objectives 49
8.2 Standardization demand analysis 49
8.2.1 Stakeholder analysis 49
8.2.2 Standards in robotic technologies 50
8.2.3 Standards in power robot products 50
8.2.4 Standards in power robot applications 51
8.2.5 Standards in power robot interfaces and data analysis 51
8.3 Power robotic related standards 51
8.3.1 Standardization organizations 51
8.3.2 Existing IEC/TC 129 standards 52
8.4 IEC/TC129 structure and roadmap for power robot 52
8.5 Power robot standardization plan 56
Annex A (informative) Use cases 57
A.1 Penstock inspection robot for hydropower station 57
A.1.1 Technical requirements 57
A.1.2 System composition 57
A.1.3 Key functions and performance 58
A.1.4 Work process 58
A.1.5 Scope of application 59
A.1.6 Application effectiveness 59
A.2 Transporting materials to a power transmission tower using a UAS 60
A.2.1 Technical requirements 60

A.2.2 System composition 60
A.2.3 Key functions 60
A.2.4 Work process 60
A.2.5 Application effectiveness 60
A.2.6 Scope of applications 60
A.3 Live-line work support robot for power distribution lines 61
A.3.1 Technical requirements 61
A.3.2 System composition 61
A.3.3 Key functions 61
A.3.4 Work process 62
A.3.5 Application effectiveness 62
A.3.6 Scope of application 63
Annex B (informative) List of existing standards, documents or development projects 64
B.1 Related standardization organizations 64
B.2 Related standards 67
Bibliography 68

Figure 1 – Architecture of the robotic system 13
Figure 2 – A type of rail-guided robot 16
Figure 3 – A type of wheeled robot 16
Figure 4 – A type of tracked mobile robotic platform 17
Figure 5 – A type of quadruped robotic platform 17
Figure 6 – A type of multi-copter UAS 18
Figure 7 – A type of fixed-wing UAS 19
Figure 8 – A type of inspection ROV 20
Figure 9 – Submarine cable inspection ROV 20
Figure 10 – Illustration of GPS and IMU system 21
Figure 11 – Principle of LiDAR-based navigation system 22
Figure 12 – LiDAR constructed 500 kV substation 23
Figure 13 – An example of vision based robotic navigation 23
Figure 14 – Control software architecture 27
Figure 15 – Improved centering effect by automatic offset servo control 29
Figure 16 – Improved region-specific focus effect by applying servo control 29
Figure 17 – Improved exposure by applying servo control 29
Figure 18 – Transmission line equipment defect recognition 30
Figure 19 – Automatic meter reading 31
Figure 20 – Switch status recognition 31
Figure 21 – Typical defects detection in substation facilities 31
Figure 22 – Typical defects recognition in distribution network 32
Figure 23 – Smoke and fire detection 32
Figure 24 – Infrared detection results 33
Figure 25 – PV panel defects inspection 33
Figure 26 – Typical voiceprint signals for transformer anomalies 34
Figure 27 – UV detection 35
Figure 28 – Ultrasound-based PD detection 35

Figure 29 – Transmission line insulator inspection robots 36
Figure 30 – A UAS-based insulator inspection robot 37
Figure 31 – X-ray inspection robot and fault detection 38
Figure 32 – Multi-axis arm based switchgear operation robot 39
Figure 33 – Transformer oil sampling robot 40
Figure 34 – Overhead line de-icing robot 41
Figure 35 – Substation live line water washing robot 42
Figure 36 – Live insulation coating robot 43
Figure 37 – Remote operation of live line maintenance robot 44
Figure 38 – IEC/TC129 work structure 53
Figure A.1 – Penstock inspection robot 57
Figure A.2 – Inspection operation example of penstock inspection robot 59
Figure A.3 – Example of transporting the extension cable 61
Figure A.4 – Moving six-axis with a single-arm operation 63
Figure A.5 – Example of using assist arm at work 63
Figure A.6 – Example of wire insulation stripping 63

Table 1 – Application of robots in power generation 11
Table 2 – Application of robots in power transmission 11
Table 3 – Application of robots in distribution 12
Table 4 – Stakeholders of power robots 49
Table 5 – ISO current standards for robotics 52
Table 6 – IEC/TC 129 existing standards for robotics 52
Table 7 – List of IEC projects 54
Table B.1 – Standardization organizations 64
Table B.2 – Related documents 67

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.