

IEEE Recommended Practice for the Use of Wheeled Robots for Substation Inspection

IEEE SA Board of Governors

Developed by the
Entity Collaborative Activities Governance Board

IEEE Std 3328™-2025

STANDARDS

IEEE Recommended Practice for the Use of Wheeled Robots for Substation Inspection

Developed by the

Entity Collaborative Activities Governance Board
of the
IEEE SA Board of Governors

Approved 12 February 2025

IEEE SA Standards Board

Abstract: An application of wheeled robots for substation inspection and live detection is provided by this recommended practice. A system composition, application scenarios, functional and performance requirements, methods for inspection and detection operations, calibration and acceptance, and maintenance and repair requirements are provided. This recommended practice is applicable to wheeled robots used in both ac and dc substation inspection and live detection.

Keywords: IEEE 3328™, inspection operations, substation, testing operations, wheeled robot

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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PDF: ISBN 979-8-8557-1928-4 STD27752
Print: ISBN 979-8-8557-1929-1 STDPD27752

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Introduction

This introduction is not part of IEEE Std 3328-2025, IEEE Recommended Practice for the Use of Wheeled Robots for Substation Inspection.

The inspection of assets and detection of problems in substations are crucial for both planned and unplanned power outages, such as during maintenance, testing, and fault rectification. With the increasing adoption of intelligent, digital, and unmanned operation modes in substations, the workload for substation inspections is growing, making it difficult to help ensure the rate and timeliness of inspections. Compared to traditional manual inspections, which are characterized by high labor intensity, low efficiency, scattered detection quality, and limited means, wheeled robots offer a fully autonomous, efficient, and all-weather inspection capability, with advantages such as high operational precision, safety, and strong adaptability. This recommended practice provides methods for the use of wheeled inspection robots in substations, serving as a guide for their effective implementation in substation operation and maintenance (O&M).

This recommended practice begins by introducing the composition of wheeled robots used for substation inspection. It covers the application scenarios for inspection and live-line detection, discusses the primary functions and performance requirements, and recommends methods for inspection and detection operations, calibration and acceptance, and maintenance and repair. It provides a workflow for inspection and detection operations as a guide for on-site application. Annex A provides the inspection contents for a 500 kV substation. Annex B lists routine maintenance and specialized maintenance items for wheeled robots. In Annex C, using a 500 kV substation as an application scenario, a process is provided for completing transformer inspection operations in a substation using a wheeled robot.

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IEEE Recommended Practice for the Use of Wheeled Robots for Substation Inspection

1. Overview

1.1 Scope

This recommended practice applies to wheeled robots used for intelligent inspection and live detection in substations. The document addresses application scenarios, inspection function requirements, performance requirements, calibration and acceptance, inspection operations, and operation and maintenance.

1.2 Purpose

The purpose of this recommended practice is to formulate an application specification of wheeled robots for substation inspection, so as to specify the application scenarios of wheeled inspection robots, and to clarify the general technical requirements of inspection function and performance. Furthermore, it normalizes the operation and maintenance personnel to calibrate wheeled inspection robots to achieve a better performance state, to use wheeled inspection robots to discover equipment defects in time, and to maintain wheeled inspection robots to extend service life.

This recommended practice is helpful to promote the application of wheeled inspection robots to replace the manual inspection of such repetitive and dangerous work, helping to ensure the safe and stable operation of equipment in unattended substations, and achieving staff reduction and efficiency of power grid enterprises.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{1, 2}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

¹ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

² The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60068-2-1, Environmental testing—Part 2-1: Tests—Test A: Cold.³

IEC 60068-2-2, Environmental testing—Part 2-2: Tests—Test B: Dry heat.

IEC 60068-2-13, Environmental testing—Part 2-13: Tests—Test M: Low air pressure.

IEC 60068-2-14, Environmental testing—Part 2-14: Tests—Test N: Change of temperature.

IEC 60068-2-53, Environmental testing—Part 2-53: Tests and guidance—Combined climatic (temperature/humidity) and dynamic (vibration/shock) tests.

IEC 60529-2013, Degrees of protection provided by enclosures (IP Code) (Edition 2.2).

IEC 61000-4-2:2008, Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.

IEC 61000-4-3:2020, Electromagnetic compatibility (EMC)—Part 4-3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test.

IEC 61000-4-5:2017, Electromagnetic compatibility (EMC)—Part 4-5: Testing and measurement techniques—Surge immunity test.

IEC 61000-4-8:2009, Electromagnetic compatibility (EMC)—Part 4-8: Testing and measurement techniques—Power frequency magnetic field immunity test.

ISO 18251-2:2023, Non-destructive testing—Infrared thermography—Part 2: Test method for integrated performance of system and equipment.⁴

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁵

auxiliary facilities: Construction, mechanical, electronic, and electrical facilities required for the operation of the robot body. *See also:* **substation wheeled robot body**.

background monitoring: Performed by a remote control function system—generally composed of data reception, storage, display, control equipment, and corresponding software—that displays, stores, analyzes,

³ IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

⁴ ISO publications are available from the International Organization for Standardization (<https://www.iso.org/>) and the American National Standards Institute (<https://www.ansi.org/>).

⁵ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

and alarms the data obtained by the robot body and auxiliary facilities. *See also:* **substation wheeled robot body; auxiliary facilities.**

gimbal: A photographic equipment support system that adjusts the direction of the optical axis of the lens.

mobile platform: The combination of all components responsible for the movement of mobile robots.

substation wheeled robot: A robot system with remote control or automatic inspection of outdoor substations, containing the body, background monitoring, and auxiliary facilities, referred to as *robots*. *See also:* **substation wheeled robot body; background monitoring; auxiliary facilities.**

substation wheeled robot body: A patrol device that uses wheels to move in the substation, referred to as the *robot body*.

task load: A device mounted on a mobile platform to realize the inspection function. *See also:* **mobile platform.**

3.2 Acronyms and abbreviations

GIS	gas-insulated switchgear
IR	infrared
RFID	radio-frequency identification
UV	ultraviolet
WR	wheeled robot

4. Robot composition

4.1 General

The substation wheeled inspection robot consists of the robot body, background monitoring, and auxiliary facilities (as shown in Figure 1).

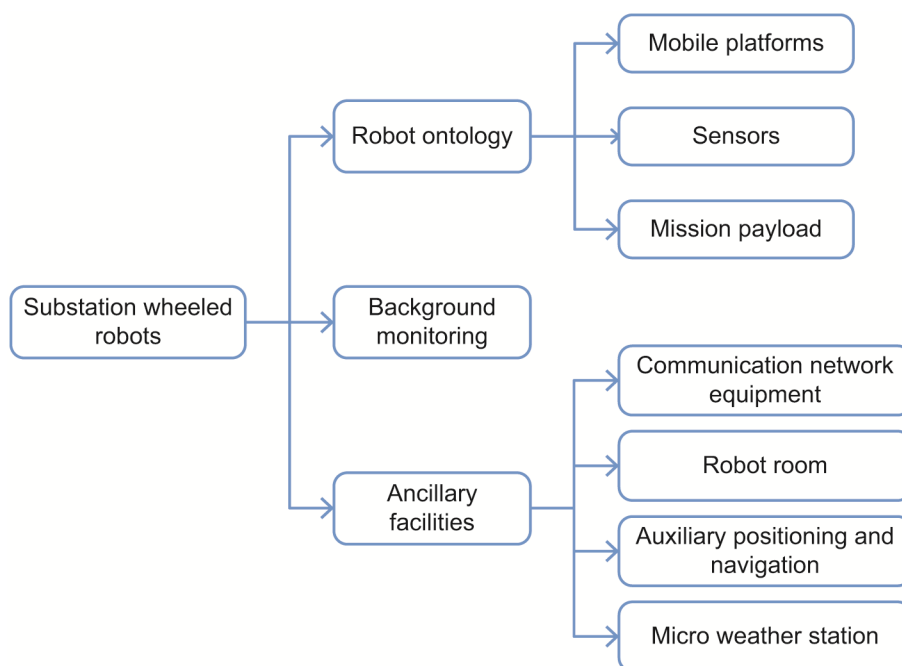


Figure 1 —Composition of a wheeled inspection robot in a substation

4.2 Robot ontology

The substation wheeled inspection robot body is composed of a mobile platform and a task load, and different types of task loads can be configured according to specific operation requirements. Depending on the work content, there is a variety of payloads, such as visible light cameras, infrared (IR) thermal imagers, partial discharge–detection devices, and ultraviolet (UV) imagers (see Table 1 for details). In order to expand the working space of the wheeled inspection robot in the substation, the task load can be configured with a gimbal, robotic arm, and other facilities.

Table 1—Typical inspection operations and recommended task loads

Number	Inspection operation content	Recommended task load
1	Appearance defect detection, meter recognition, and so forth	Visible light camera
2	Temperature anomaly detection	IR thermal imager
3	Partial discharge detection	Partial discharge–detection device
4	Corona discharge detection	UV imager

4.3 Background monitoring

Background monitoring should be deployed in the office where the user is located, and real-time monitoring, data management, abnormal alarm, data analysis, and remote control of the substation wheeled inspection robot should be carried out with the interface and interaction with the substation asset management suite, which is a critical part of background monitoring activity.

4.4 Ancillary facilities

The auxiliary facilities required for the wheeled inspection robot of the substation are recommended as follows:

- For the battery-powered wheeled inspection robot of the substation, it is advisable to configure the robot room in the substation for the installation of charging piles in order to realize the autonomous charging function of the wheeled inspection robot.
- Wireless communication should be used between the substation wheeled inspection robot body and the background monitoring; communication base stations and other facilities can be built according to the requirements of the on-site network. In order to improve the positioning and navigation ability of the wheeled inspection robot in the substation, the required navigation auxiliary facilities, such as magnetic guide rails, barcodes, quick response (QR) codes, radio-frequency identification (RFID), and so forth, can be deployed in the substation.
- In order to reasonably plan the inspection plan of the wheeled inspection robot of the substation according to the weather conditions, a meteorological information collection device can be deployed in the substation, including but not limited to temperature, humidity, wind speed, wind direction, air pressure, and rainfall.

4.5 Configuration principles

The recommended configuration principles of substation wheeled inspection robots are shown in Table 2.

Table 2—Recommended configurations for substation wheeled robots

Number	Substation wheeled robot components	Configuration suggestions
1	Mobile platforms	Should be configured
2	Visible light camera	Should be configured
3	IR thermal imagers	Recommend configuration
4	Partial discharge–detection device	Recommend configuration
5	UV imager	Can be configured
6	Gimbal for mission payload	Can be configured
7	Robotic arm for mission payload	Can be configured
8	Background monitoring	Should be configured
9	Communication network equipment	Should be configured
10	Robot room	Recommend configuration
11	Navigation accessories	Recommend configuration
12	Micrometeorological station	Recommend configuration
13	Gas detectors/optical gas imaging (OGI) devices	Can be configured

5. Application scenarios

5.1 General

Annex A provides the patrol inspection content for the 500 kV ac substations described below.

5.2 Patrols

Typical patrol scenarios are as follows:

- a) Check the operation of substation facilities and equipment, obtain the equipment appearance image and meter data, and find and locate defects as follows. This may also be done through artificial intelligence (AI)–based analytics run separately on premise or in the Cloud.
 - 1) Check the substation equipment, surrounding environment, and ongoing operations; timely detection of the appearance changes and obvious defects of the equipment and facilities.
 - 2) When a fault occurs, determine the inspection site according to the fault information and inspect whether the relevant equipment and environment are abnormal.
 - 3) In particular, strengthen preventive inspection, such as during wind, rain, snow, and post-frost inspection, and other unplanned inspection due to the seasonal characteristics of the equipment, internal and external environment, and special production needs.
- b) Monitor and identify the equipment of the substation (such as transformer, switch, etc.) and generate the operation and maintenance data as follows. Alternatively, to make the process autonomous, a digital twin (DT)–based technology may also be used.
 - 1) *Video transmission*: Transmit the image information during the inspection process to the remote control center in real time. Support multiple video formats and resolutions and obtain the device appearance status information remotely.
 - 2) *Environmental identification*: Identify the defects, obstacles, marks, and equipment status on the inspection path; respond according to the preset rules.
 - 3) *Equipment information identification*: Identify the inspection objects through QR code or bar code; match with the background database to obtain the equipment-related information.

5.3 Live detection

Typical live detection application scenarios are shown as follows:

- a) Check the operation of substation facilities and equipment, obtain equipment status data, and find and locate faults as follows:
 - 1) Check the substation equipment, surrounding environment, and ongoing operations. Detect and find the status changes and obvious defects of the equipment and facilities in a timely manner. Only the data for performing these tasks is collected by the robot. The rest may also be done via additional AI-based analytics tools.
 - 2) When a fault occurs, determine the key inspection part and location according to the fault information and locate other fault parts and environmental anomalies.
 - 3) In particular, strengthen preventive inspection, such as post-thunderstorm inspection, ice inspection, haze inspection, post-disaster inspection, and other unplanned inspections due to the seasonal characteristics of the equipment, internal and external environment, and special production needs.
- b) Equipped with a special task payload, complete the corresponding test as follows:
 - 1) *Appearance detection*: Can be used for appearance inspection, meter reading, and foreign body inspection of transformer, gas-insulated switchgear (GIS), high-voltage reactor, switch, circuit breaker, and other power equipment.
 - 2) *Transient earth voltage partial discharge detection*: Partial discharge detection using a transient earth voltage (TEV) partial discharge–detection sensor.