

IEEE Recommended Practice for the Use of Infrared Online Systems for Substation Inspection

IEEE SA Board of Governors

Developed by the
Entity Collaborative Activities Governance Board

IEEE Std 3326™-2025

STANDARDS

IEEE Recommended Practice for the Use of Infrared Online Systems 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: The application of online infrared inspection systems for substations is introduced in this recommended practice. The system composition, functional and performance requirements, test methods, and test rules are provided, as well as a comprehensive framework for realizing accurate and efficient infrared online inspection.

Keywords: alarm, defects, diagnostic basis, equipment management, IEEE 3326™, infrared image, infrared online inspection system, infrared video, inspection, judgment method, substation

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

Copyright © 2025 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 10 June 2025. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 979-8-8557-1930-7 STD27753
Print: ISBN 979-8-8557-1931-4 STDPD27753

IEEE prohibits discrimination, harassment, and bullying.
For more information, visit <https://www.ieee.org/about/corporate/governance/p9-26.html>.
No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers.html>), appear in all IEEE standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within IEEE Societies and subcommittees of IEEE Standards Association (IEEE SA) Board of Governors. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers involved in technical working groups are not necessarily members of IEEE or IEEE SA and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning all standards, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. IEEE Standards documents do not guarantee safety, security, health, or environmental protection, or compliance with law, or guarantee against interference with or from other devices or networks. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document should rely upon their own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus balloting process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English language version published by IEEE is the approved IEEE standard.

Use by artificial intelligence systems

In no event shall material in any IEEE Standards documents be used for the purpose of creating, training, enhancing, developing, maintaining, or contributing to any artificial intelligence systems without the express, written consent of IEEE SA in advance. “Artificial intelligence” refers to any software, application, or other system that uses artificial intelligence, machine learning, or similar technologies, to analyze, train, process, or generate content. Requests for consent can be submitted using the Contact Us form.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual is not, and shall not be considered or inferred to be, the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE or IEEE SA. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter’s views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group. Statements made by volunteers may not represent the formal position of their employer(s) or affiliation(s). News releases about IEEE standards issued by entities other than IEEE SA should be considered the view of the entity issuing the release rather than the formal position of IEEE or IEEE SA.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents.**

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and subcommittees of the IEEE SA Board of Governors are not able to provide an instant response to comments or questions, except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or revisions to an IEEE standard is welcome to join the relevant IEEE SA working group. You can indicate interest in a working group using the Interests tab in the Manage Profile & Interests area of the [IEEE SA myProject system](#).¹ An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.²

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the

¹ Available at: <https://development.standards.ieee.org/myproject-web/public/view.html#landing>.

² Available at: <https://standards.ieee.org/about/contact/>.

applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, neither IEEE nor its licensors waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; <https://www.copyright.com/>. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit [IEEE Xplore](#) or [contact IEEE](#).³ For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#).⁴ Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

³ Available at: <https://ieeexplore.ieee.org/browse/standards/collection/ieee>.

⁴ Available at: <https://standards.ieee.org/standard/index.html>.

Patents

IEEE standards are developed in compliance with the [IEEE SA Patent Policy](#).⁵

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at <https://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

Technologies, application of technologies, and recommended procedures in various industries evolve over time. The IEEE standards development process allows participants to review developments in industries, technologies, and practices, and to determine what, if any, updates should be made to the IEEE standard. During this evolution, the technologies and recommendations in IEEE standards may be implemented in ways not foreseen during the standard's development. IEEE standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, data privacy, and interference protection practices and all applicable laws and regulations.

⁵ Available at: <https://standards.ieee.org/about/sasb/patcom/materials.html>.

Participants

At the time this IEEE recommended practice was completed, the Substation Inspection—Infrared Online System Working Group had the following membership:

Bo Xu, Chair
Hongyun Li, Vice Chair
Qinjie Ji, Secretary

<i>Organization</i>	<i>Name of Designated Representative</i>
China Automotive Engineering Research Institute	Xiaoping Wang
China Southern Power Grid Co., Ltd.	Jianhui Feng
East China Jiaotong University	Hongbo Cheng
Huazhong University of Science and Technology	Chunyan Zang
North China Electric Power University	Yongqiang Wang
Shandong Electrical Engineering & Equipment Group Co., Ltd.	Hongyun Li
Southeast University	Qinjie Ji
State Grid Corporation of China (SGCC)	Bo Xu
Tsinghua University	Bin Wang
Xi'an Chuangyi Information Technology Co., Ltd.	YanJun Hao

The working group gratefully acknowledges the contributions of the following participants:

Jiangang Bi	You Li	Xiangbo Xia
Hongqiang Chen	Zewen Li	Qingming Xiao
Mingxia Chen	Jia Liu	Guofeng Yang
Yao Cui	Jia Liu	Yang Yang
Fangming Deng	Xiong Liu	Shai Yuan
Wei Deng	Liqing Long	Guoliang Yue
Taiqi Feng	Tao Shi	Han Zeng
Jing Fu	Aiguo Song	Jiusi Zhang
Shuguo Gao	XiaoXin Song	Kun Zhang
Qingkai Lang	Jianeng Tang	Qianqian Zhang
Fan Li	Dan Tao	Xu Zhang
Guodong Li	Qian Wang	Pengchao Zheng
Hao Li	Yi Wang	YanLi Zhi
Jie Li	YiJun Wei	YouPing Zhong
Qin Li		Yu Zhou

The following members of the entity Standards Association balloting group voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

OxSenses Corporation	Huazhong University of Science and Technology	Siemens AG
ABB Ltd.	Hubbell	Siemens Energy
China Automotive Engineering Research Institute	Institute of Biomedical Engineering	Southeast University
China Southern Power Grid Co., Ltd.	North China Electric Power University	State Grid Corporation of China (SGCC)
China Three Gorges University	Shandong Electrical Engineering & Equipment Group Co., Ltd.	Tsinghua University
East China Jiaotong University		Xi'an Chuangyi Information Technology Co., Ltd.
Hangzhou Juqi Information Technology Co., Ltd.		

When the IEEE SA Standards Board approved this recommended practice on 12 February 2025, it had the following membership:

Lei Wang, *Chair*
Vacant Position, *Vice Chair*
David J. Law, *Past Chair*
Alpesh Shah, *Secretary*

Edward Au	Ronald W. Hotchkiss	Daleep C. Mohla
Ted Burse	Tyler L. Jaynes	Annette D. Reilly
Xiaofeng (Alfred) Chen	Thomas Koshy	Robby Robson
Doug Edwards	Howard Li	Jon Walter Rosdahl
Nehad El-Sherif	Xiaohui Liu	Daniel Sabin
J. Travis Griffith	Kevin W. Lu	F. Keith Waters
Deborah R. Hagar	Hiroshi Mano	Sha Wei
Guido R. Hiertz		Luyang (Eric) Zhang

Introduction

This introduction is not part of IEEE Std 3326-2025, IEEE Recommended Practice for the Use of Infrared Online Systems for Substation Inspection.

With technological progress, some countries have applied infrared online inspection systems in substations to inspect power equipment. Compared to infrared temperature measurements made with hand-held equipment, infrared online inspection systems have stronger real-time performance, higher efficiency, and better safety. An online infrared temperature system can detect the temperature of the operating equipment in real time and send out alarm signals according to the preset warning value, so as to improve the ability and foresight of the operation and maintenance personnel. It helps identify the defects of the equipment and assists the operation and maintenance personnel in taking corresponding measures to improve the safety of the equipment operation. The purpose of this method is to provide a recommended practice for infrared online inspection systems in substations and to provide guidance for practical application in substations.

This recommended practice first introduces the composition, main functions, and performance requirements of substation infrared online inspection systems. It recommends the application of technical conditions, test suggestions, inspection objects and methods, judgment methods, defect types, diagnosis basis, management and inspection methods, etc. Annex A provides communication regulations of substation infrared online inspection systems. Annex B provides substation equipment defect diagnosis criteria. Annex C provides some typical infrared images of defects. Annex D provides calibration specifications for substation infrared online inspection systems. Annex E provides typical substation infrared online inspection system application cases.

Contents

1. Overview	12
1.1 Scope	12
1.2 Purpose	12
1.3 Word usage	12
2. Normative references	13
3. Definitions, acronyms, and abbreviations	13
3.1 Definitions	13
4. The composition of the system	14
4.1 System architecture	14
4.2 Network architecture	15
4.3 Auxiliary accessories	15
5. Functional and performance requirements	16
5.1 Functional requirements	16
5.2 Performance requirements	16
5.3 Environmental suitability	17
5.4 Electromagnetic compatibility	17
6. Application technical conditions	18
6.1 Personnel requirements	18
6.2 Safety requirements	18
6.3 Requirements for equipment installation	19
7. Inspection suggestions	19
7.1 Types of inspections	19
7.2 Suggestions for inspection setting	20
8. Inspection objects and methods	20
8.1 Inspection objects	20
8.2 Inspection task	20
8.3 Inspection method	20
9. Judgment methods	23
9.1 Surface temperature/temperature rise judgment method	23
9.2 Similar temperature difference judgment method	23
10. Defect types	24
10.1 Critical defects	24
10.2 Serious defects	24
10.3 Common defects	24
11. Diagnostic criteria	24
12. Management and test	24
12.1 System management	24
12.2 Equipment test	25
Annex A (informative) Communication protocol	28
A.1 General provisions	28
A.2 Communication process definition	29

A.3 Apply the protocol definition.....	29
A.4 Device status	31
A.5 Instance	33
A.6 Control instructions	34
Annex B (informative) Diagnosis criteria	37
Annex C (informative) Typical infrared images of defects.....	43
C.1 Instrument transformer category	45
C.2 Capacitor category	46
C.3 Surge arrester category.....	47
C.4 Cable category	48
C.5 Bushing category	49
C.6 Insulator category.....	51
C.7 Metal connection category	53
C.8 Circuit breaker/GIS category	56
C.9 Motor category.....	59
Annex D (informative) System verification specification	60
D.1 Test the error of the equipment.....	60
D.2 Environmental requirements	60
D.3 Minimum resolvable temperature difference (MRTD) test requirements.....	60
D.4 Detection equipment requirements	60
D.5 Structural and appearance verification.....	60
D.6 Functional verification	61
D.7 Performance characteristic tests.....	61
D.8 Environmental adaptability tests.....	61
D.9 Electromagnetic compatibility test	62
Annex E (informative) Application cases.....	63
E.1 General	63
E.2 Environmental conditions	63
E.3 Selecting the effective payload.....	63
E.4 Inspection task planning.....	63
E.6 Evaluation	70
E.7 Anomaly handling	70
E.8 Archiving	70

IEEE Recommended Practice for the Use of Infrared Online Systems for Substation Inspection

1. Overview

1.1 Scope

This recommended practice applies to the use of infrared online inspection system for inspection and detection of the working temperature state of substation power equipment. The composition of the system, application technical conditions, equipment management and inspection, testing recommendations, inspection methods, monitoring period, judgment methods, diagnosis basis, and determination of equipment defect types.

1.2 Purpose

The purpose of this recommended practice is to provide recommendations for operation and maintenance personnel on the use of an infrared online inspection system to better conduct inspection work. The recommended practice supports comprehensively improving the monitoring efficiency of the working temperature status of substation equipment and the accuracy of fault warnings.

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 *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 *recommended that*).

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

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

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 61000-4-2:2008, Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.³

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.

IEC 61000-4-9:2001, Electromagnetic compatibility (EMC)—Part 4-9: Testing and measurement techniques—Impulse magnetic field immunity test.

UL 94, Classification and Flame-Retardant Thermoplastics.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

infrared inspection device: A device for detecting, displaying, and recording heat radiation information received by an object.

minimum resolving temperature difference: The temperature difference between a target and background that can be distinguished at a specific frequency. It is a comprehensive feature parameter for assessing the thermal resolution and spatial resolution of thermal imagers, including observer subjective effects.

noise equivalent temperature difference: The temperature difference between a target and that of a background when the signal-to-noise ratio (S/N) of the video signal is 1.

routine inspection: The regular inspection of substation equipment according to the preset time, preset position, and test parameters.

silent inspection: The use of one or more infrared inspection devices to conduct long-term, uninterrupted inspection of key equipment.

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 UL publications are available from Underwriters Laboratories (<https://www.ul.com/>).

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.

spatial resolution: The ability of thermal cameras to distinguish the details of object versus space geometry.

NOTE—Spatial resolution is related to the image area size of the infrared detector, the focal length and image quality of the optical system, and the bandwidth of the signal processing circuit. Generally, it can be represented by detector image angle or instantaneous field of view.⁶

special inspection: The system inspection of the substation equipment during special periods (such as extreme weather conditions).

4. The composition of the system

4.1 System architecture

Substation infrared online inspection systems can reflect the running status of substation equipment in real time through infrared imaging and temperature measurement of substation equipment. The system consists of infrared inspection devices, a background inspection system, and auxiliary accessories. An infrared inspection device consists of an optical unit, a detector unit, a processing unit, a data transmission unit, a power supply unit, etc.

The system architecture is shown in Figure 1. The background inspection system is composed of a video processing module, a data processing module, etc. It has infrared inspection and overtemperature alarm and supports automatic inspection, task management, and report generation.

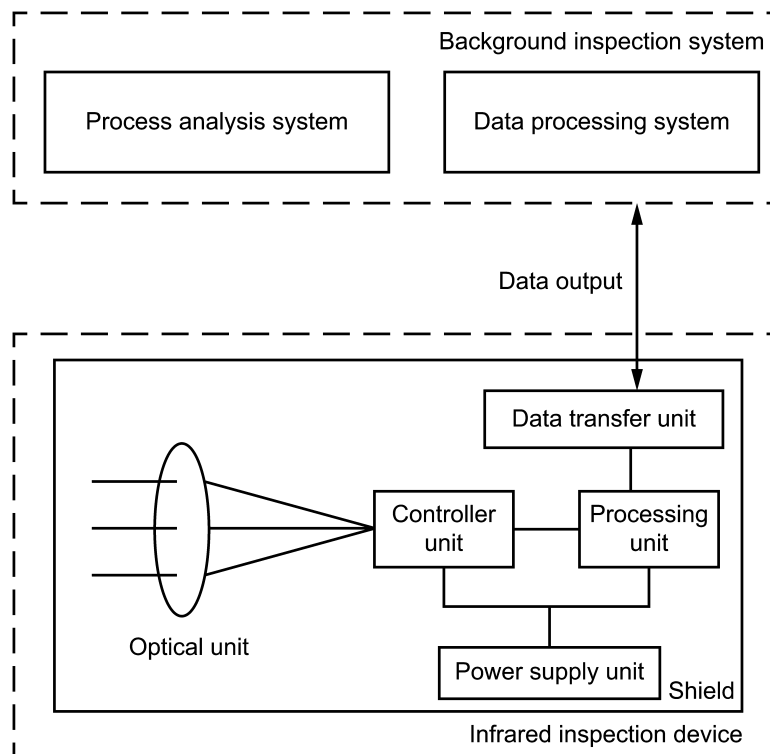


Figure 1—The typical architecture of a substation infrared online inspection system

⁶ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

The infrared inspection device should be connected to a background inspection system through a communication network. The image and video data collected by infrared inspection devices should be compressed and sent to the background inspection system for storage, analysis, and alarm display. Commands issued by the backend monitoring system are transmitted to infrared monitoring devices and the pan-tilt platform through the communication network. These commands control the infrared online monitoring devices to perform data acquisition and control the actions of the pan-tilt platform. Users can decide whether to install cradle head equipment and additional protective devices according to the site requirements.

4.2 Network architecture

Substation infrared online inspection systems can form a large-scale inspection network that can be customized according to the following factors:

- Size of grid area and number of substations
- Management of the background inspection system
- Remote infrared video inspection of secondary substations

The network topology of the system is shown in Figure 2.

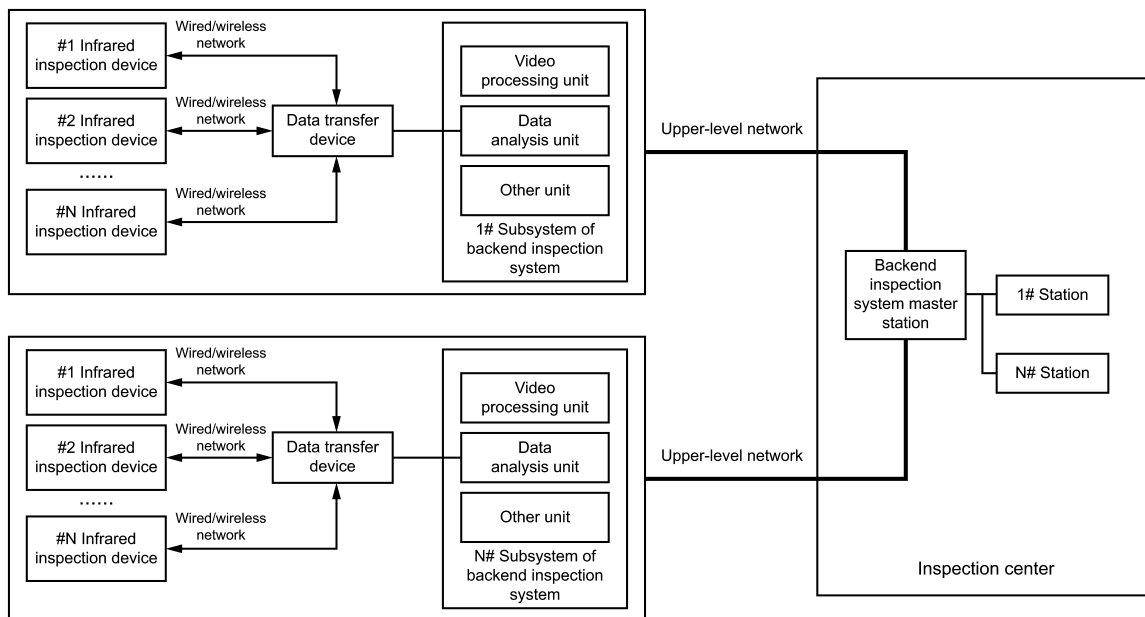


Figure 2—The multi-level network topology of substation infrared online inspection systems

Communication between an infrared inspection device and a background inspection system is conducted through a network. Infrared images uploaded by the infrared inspection devices and the control instructions issued by the background inspection system should follow data transmission regulations (see Annex A).

4.3 Auxiliary accessories

The conventional auxiliary accessories of substation infrared online inspection systems are visible light cameras, shields, bases, guide rails, cloud heads, etc.

Visible light cameras, combined with infrared inspection devices, can realize the observation of the surface of measured equipment while measuring their infrared temperature.

According to different application scenarios, the cover and base of the infrared inspection devices can have a variety of options. For example, in an environment of perennial snow and frequent icing, covers and bases with heating functions can be selected accordingly.

In order to complete the inspection of multiple targets or multiple regions, infrared inspection devices should allow for being moved up and down and rotated.

5. Functional and performance requirements

5.1 Functional requirements

The main functions of substation infrared online inspection systems include:

- a) It should support collecting infrared images and videos of substation equipment, containing all pixel temperature data, and collecting environmental data such as temperature, humidity, and wind speed.
- b) It should support remotely setting preset positions and inspection parameters, including video code stream, resolution, frame rate, video coding format, and radiation rate.
- c) It should support drawing points, lines, or boxes on the display to select objects for real-time inspection and allow the use of multi-display screens.
- d) It should support local storage of infrared images, videos, and data, with remote storage capabilities. The background inspection system should support data queries.
- e) It should support automatically correcting temperature measurements based on environmental data, generating historical temperature change curves of specified equipment, and generating horizontal comparative analysis curves of similar equipment components.
- f) It should support early warning and automatic alarms based on abnormal changes in threshold values, temperature values, and absolute temperature difference during inspections.
- g) It should support setting up inspection tasks, including routine inspection, special inspection, and silent inspection modes, and completing automatic inspection according to specified times, cycles, and regions.
- h) It should support automatically generating, querying, and deleting inspection reports, which should contain equipment information, inspection, time, equipment temperature, and infrared images.
- i) It should support self-checks and recording system operation status.
- j) It shall support 24-hour continuous inspection.

5.2 Performance requirements

The required performance parameters of infrared online inspection devices are as follows:

- a) Maximum allowable error: When an ambient temperature is $23\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$, the maximum allowable error of temperature measurement is $\pm 2\text{ }^{\circ}\text{C}$ or $\pm 2\%$ of the reading (whichever is larger).
- b) Noise equivalent temperature difference (NETD): Less than 150 mK at an ambient temperature of $23\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ and a relative aperture size of 1.

- c) Temperature measurement consistency: The deviation between the measurement results of different areas in the field of view of the infrared inspection device should not exceed $\pm 2\text{ }^{\circ}\text{C}$ or $\pm 2\%$ ($^{\circ}\text{C}$) of the measurement value of the central area (whichever is larger).
- d) Temperature measurement range: From $-20\text{ }^{\circ}\text{C}$ to $350\text{ }^{\circ}\text{C}$.
- e) Resolution: 160×120 , 320×240 (384×288), 640×480 (640×512), or higher resolution, depending on field needs.
- f) Sample frame rate: Should be above 25 Hz.
- g) Spatial resolution: Should be selected according to the size and distance of the measured object. Values between 0.2 mrad to 0.7 mrad should be selected for remote observation, and 1.0 mrad to 5.0 mrad for large close-range targets.
- h) Continuous and stable working time: Not less than 24 hours.

5.3 Environmental suitability

5.3.1 Temperature

All functions of infrared online inspection devices should be normal within the following temperature ranges:

- a) Operating temperature: $-20\text{ }^{\circ}\text{C}$ to $55\text{ }^{\circ}\text{C}$.
- b) Storage temperature: $-40\text{ }^{\circ}\text{C}$ to $60\text{ }^{\circ}\text{C}$.
- c) In extremely cold environments, thermal insulation measures, such as heaters and shells, should be taken to help keep infrared inspection devices working normally.

5.3.2 Humidity

Under conditions of less than 90% relative humidity, infrared inspection devices should function normally.

5.3.3 Impact

Infrared online inspection devices should withstand a peak acceleration of 300 m/s^2 . The pulse duration should be 11 ms, with a semi-sinusoidal Δv of 2.1 m/s for the shock test. Devices should function normally after the test.

5.3.4 Vibration

Infrared online inspection devices should withstand continuous vibration with a frequency range of 10 Hz to 55 Hz and a peak acceleration of 20 m/s^2 .

5.3.5 Drop

Infrared online inspection devices should withstand a free drop height of 250 mm, and all functions should be normal after the test.

5.4 Electromagnetic compatibility

Infrared online inspection devices' anti-electromagnetic interference performance should meet the following requirements (see Table 1).

Table 1—Requirements for anti-interference performance

No.	Anti-interference project	Applicable standard	Trial value	Performance criterion
1	Electrostatic discharge immunity	IEC 61000-4-2:2008 ^a	Contact discharge 4 kV, air discharge 8 kV	B
2	Radio-frequency electromagnetic field radiation immunity	IEC 61000-4-3:2010	10 V/m (80 MHz to 1 GHz) 3 V/m (1.4 GHz to 2 GHz) 1 V/m (2.0 GHz to 2.7 GHz)	A
3	Surge (shock) disturbance immunity	IEC 61000-4-5:2014	Power port: 2 kV, communication port: 1 kV	B
4	Power-frequency magnetic field immunity	IEC 61000-4-8:2001	30 A/m	A
5	Impulse magnetic field immunity	IEC 61000-4-9:2001	300 A/m	A
Performance criterion A: Normal performance within specification limits. Performance criterion B: The function or performance is temporarily reduced or lost, but will recover by itself.				

^a Information on references can be found in Clause 2.

6. Application technical conditions

6.1 Personnel requirements

Engineering and technical personnel using substation infrared online inspection systems according to this recommended practice should meet the following requirements:

- Personnel should be familiar with the basic principles and procedures of infrared detection and diagnosis technology, understand the working principles, technical parameters, and performance of infrared online inspection systems, and master the operation procedures and usage methods of these systems.
- Personnel should have a basic understanding of the structure, performance principles, operational status of internal and external components of the inspected equipment, and the basic causes of abnormal heating of the equipment.
- Personnel should be familiar with this recommended practice and master the detection and diagnosis methods of abnormal heating both inside and outside the equipment.

6.2 Safety requirements

The installation and maintenance of substation infrared online inspection systems should meet the following safety requirements:

- During installation and maintenance, operators shall follow electric power safety work requirements and keep an adequate electrical safety distance from live equipment. The installation of the infrared inspection device should be safe and reliable, with appropriate lightning protection measures. The installation position should meet safe distance requirements of power failure operation and facilitate maintenance. Electrical safety distances are provided in Table 2.
- The installation of the substation infrared online inspection systems should not affect the safe operation of site equipment. The infrared inspection device should be arranged on the external wall or frame of the building in the outdoor equipment area or installed on vertical poles. The vertical poles shall be installed within the protection range of the lightning protection measures and be reliably connected to the substation's grounding network. Sufficient electrical safety distance should be maintained between the vertical poles and the live equipment and leads.
- System cables should be B1 grade or above in accordance with UL 94, and air switches with leakage protectors should be configured.

Table 2—Electrical safety distance table

No.	Classification of voltage (kV)	Recommended safe distance (m)
1	13.8 kV ac and below	0.35 m
2	20 kV ac and 35 kV ac	0.6 m
3	63 (66) kV ac and 110 kV ac	1.5 m
4	220 kV ac	3.0 m
5	330 kV ac	4.0 m
6	500 kV ac	5.0 m
7	750 kV ac	8.0 m
8	1000 kV ac	9.5 m
9	50 kV dc and below	1.5 m
10	500 kV dc	6.8 m
11	660 kV dc	9.0 m
12	800 kV dc	10.1 m
NOTE—The voltage level not listed in the table is according to the high-voltage level.		

6.3 Requirements for equipment installation

Installation and commissioning of substation infrared online inspection systems should meet the following requirements:

- Infrared inspection devices should avoid any occlusions in their line of sight, and an infrared inspection device should cover as many targets as possible.
- Infrared inspection devices should be installed at an appropriate distance from the detected target and be able to carry out continuous online infrared inspection.
- Depending on different application scenarios, infrared inspection devices should be equipped with bases, shields, and guides to realize movement to complete the working temperature state inspection of multiple targets, areas, and high-altitude equipment.
- Cabinets should meet local protection requirements for weather resistance, temperature rise, and access.

7. Inspection suggestions

7.1 Types of inspections

Infrared online inspection of substations is divided into three categories: routine inspection, special inspection, and silent inspection. Inspection suggestions are as follows:

- Routine inspections should be conducted at least twice per day, typically involving automatic inspection, data analysis, and report generation by the system.
- Special inspections should be conducted in addition to routine inspections during the following periods:
 - During large-load operation of substation equipment in summer or winter.
 - During severe weather conditions such as strong winds, heavy rain, heavy snow, and thunderstorms.
 - When the system operation mode changes or there is a steep increase in equipment load.
 - Other situations requiring a shorter period.

- c) Silent inspections should be conducted for equipment meeting the following conditions to determine equipment status:
 - 1) Abnormal temperature detected during routine inspection.
 - 2) Under bad conditions such as lightning strikes, the running state of the equipment should be diagnosed.
 - 3) If similar equipment fails, further investigation is required.
 - 4) Equipment with a poor operating environment, long operation durations, or operational defects.
 - 5) Other abnormalities detected in equipment.

7.2 Suggestions for inspection settings

Parameter settings for substation infrared online inspection systems are recommended as follows:

- a) Before inspection, the surface radiation rate of the monitored equipment should be set correctly, and the ambient temperature, humidity, and wind speed should be automatically collected. The temperature alarm threshold should be set reasonably.
- b) Routine inspections should be carried out during periods of heavy load, and silent inspections should be carried out during idle periods when no routine or special inspections are being conducted.
- c) Silent inspections should choose the inspection device with the best distance and field of view, and try to avoid the radiation influence from other objects on the heat source of the inspected equipment. The target should fill the entire field of view of the inspection device as much as possible.
- d) When appropriate, adjust or add preset positions of the inspection device, and select different angles and positions for joint inspection of key equipment.
- e) When appropriate, record the load current and operating voltage of the monitored equipment. Visible light photos can be recorded at the same time.
- f) The relevant functions of the system (such as image averaging, automatic tracking, etc.) can be used to achieve the best inspection effect. For surface heating parts (such as casing pressure plates), the maximum temperature can be used automatically to locate the high-temperature heat sources. For columnar heating equipment (such as lightning arresters), the linear temperature analysis function can be used to locate high-temperature heat sources.

8. Inspection objects and methods

8.1 Inspection objects

Substation infrared online inspection systems can perform inspection of all primary and secondary equipment and auxiliary equipment in substations.

8.2 Inspection tasks

The priorities of substation infrared online inspection systems, from highest to lowest, are special inspection, routine inspection, and silent inspection. The system determines the execution order according to the priority of distributed tasks.

8.3 Inspection method

8.3.1 General

Substation infrared online inspection systems regularly inspect the primary and secondary equipment and auxiliary equipment. Operation and maintenance personnel should verify inspection data, analyze abnormalities, perform recalibration, and carry out tracking control promptly based on the inspection results. The recommended inspection practice for substation infrared online inspection systems is shown in Figure 3.

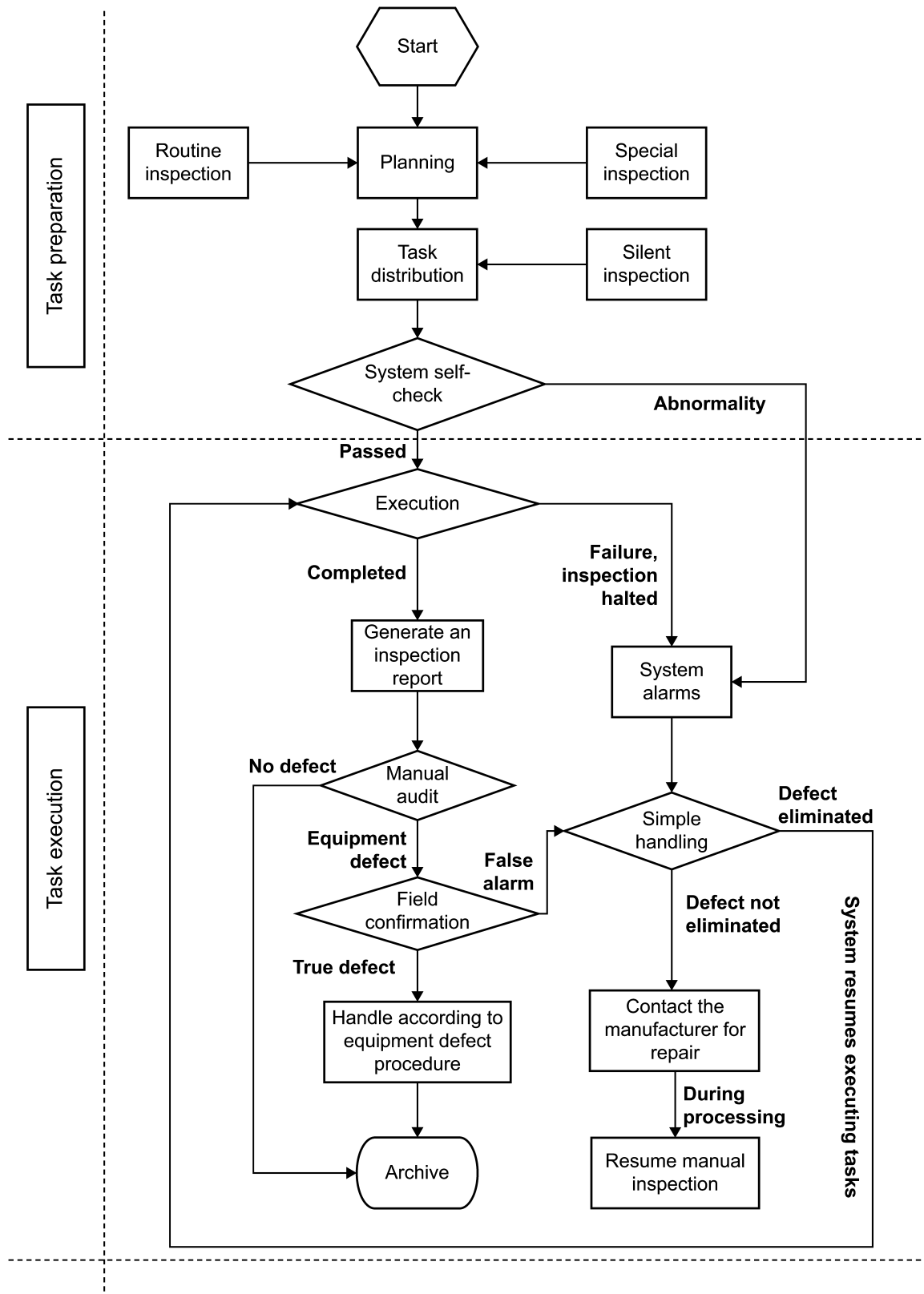


Figure 3—Recommended practice for substation infrared online inspection systems