

Substation Design

Procedure

This Standard replaces and cancels its previous revision.

The CONTEC - Authoring Subcommittee provides guidance on the interpretation of this Standard when questions arise regarding its contents. The Department of PETROBRAS that uses this Standard is responsible for adopting and applying the sections, subsections and enumerates thereof.

Technical Requirement: A provision established as the most adequate and which shall be used strictly in accordance with this Standard. If a decision is taken not to follow the requirement ("non-conformity" to this Standard) it shall be based on well-founded economic and management reasons, and be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by imperative nature.

Recommended Practice: A provision that may be adopted under the conditions of this Standard, but which admits (and draws attention to) the possibility of there being a more adequate alternative (not written in this Standard) to the particular application. The alternative adopted shall be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by verbs of a nonmandatory nature. It is indicated by the expression: **[Recommended Practice]**.

Copies of the registered "non-conformities" to this Standard that may contribute to the improvement thereof shall be submitted to the CONTEC - Authoring Subcommittee.

Proposed revisions to this Standard shall be submitted to the CONTEC - Authoring Subcommittee, indicating the alphanumeric identification and revision of the Standard, the section, subsection and enumerate to be revised, the proposed text, and technical/economic justification for revision. The proposals are evaluated during the work for alteration of this Standard.

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The use of this Standard by other companies / organizations / government agencies and individuals is the sole responsibility of the users.."

CONTEC

Comissão de Normalização
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SC - 06

Electricity

Introduction

PETROBRAS Technical Standards are prepared by Working Groups - WG (consisting specialized of Technical Collaborators from Company and its Subsidiaries), are commented by Company Units and its Subsidiaries, are approved by the Authoring Subcommittees - SCs (consisting of technicians from the same specialty, representing the various Company Units and its Subsidiaries), and ratified by the Executive Nucleus (consisting of representatives of the Company Units and its Subsidiaries). A PETROBRAS Technical Standard is subject to revision at any time by its Authoring Subcommittee and shall be reviewed every 5 years to be revalidated, revised or cancelled. PETROBRAS Technical Standards are prepared in accordance with PETROBRAS Technical Standard N-1. For complete information about PETROBRAS Technical Standards see PETROBRAS Technical Standards Catalog.

Foreword

This Standard is the English version (issued in 10/2013) of PETROBRAS N-2039 REV. C 12/2012. In case of doubt, the Portuguese version, which is the valid document for all intents and purposes, shall be used.

1 Scope

1.1 This Standard establishes the minimum conditions required for the design of outdoor or indoor substations for PETROBRAS.

1.2 This Standard is not applicable to installations on offshore platforms.

1.3 This Standard applies to procedures started as of their date of issuance.

1.4 This Standard contains Technical Requirements and Recommended Practices.

1.5 The application of this Standard does not exempt from complying with regulations of public bodies for equipment, services and installations.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies.

Portaria no 3214 de 8/6/78 - Norma Regulamentadora nº 10 ([NR-10](#)) - Segurança em Instalações e Serviços em Eletricidade;

PETROBRAS [N-300](#) - Detalhes de Aterramento Empregando-se Conectores Mecânicos;

PETROBRAS [N-1674](#) - Projeto de Arranjo de Instalações Industriais Terrestres de Petróleo, Derivados, Gás Natural e Álcool

PETROBRAS [N-1996](#) - Projeto de Redes Elétricas em Envelopes de Concreto e com Cabos Diretamente no Solo;

PETROBRAS [N-1997](#) - Redes Elétricas em Sistemas de Bandeamento para Cabos - Projeto, Instalação e Inspeção;

PETROBRAS [N-2006](#) - Projeto de Sistemas de Iluminação;

PETROBRAS [N-2040](#) - Elaboração, Apresentação e Gerenciamento de Documentos de Projetos de Eletricidade;

PETROBRAS [N-2830](#) - Critérios de Segurança para Ambientes e Serviços em Painéis e Equipamentos Elétricos com Potencial de Arco Elétrico;

ABNT [NBR 5410](#) - Instalações Elétricas de Baixa Tensão;

ABNT [NBR 5419](#) - Proteção de Estruturas Contra Descargas Atmosféricas;

ABNT [NBR 6939](#) - Coordenação do Isolamento – Procedimento;

ABNT [NBR 9077](#) - Saídas de Emergência em Edifícios;

ABNT [NBR 13231](#) - Proteção Contra Incêndio em Subestações Elétricas de Geração, Transmissão e Distribuição;

ABNT [NBR 13434-1](#) - Sinalização de Segurança contra Incêndio e Pânico - Parte 1: Princípios de Projeto;

ABNT [NBR 13434-2](#) - Sinalização de Segurança contra Incêndio e Pânico - Parte 2: Símbolos e suas Formas, Dimensões e Cores;

ABNT [NBR 13434-3](#) - Sinalização de Segurança contra Incêndio e Pânico - Parte 3: Requisitos e Métodos de Ensaio;

ABNT [NBR 14039](#) - Instalações Elétricas de Média Tensão de 1,0 kV a 36,2 kV;

ABNT [NBR 16401-3](#) - Instalações de Ar-condicionado - Sistemas Centrais e Unitários Parte 3: Qualidade do Ar Interior

ABNT [NBR 17240](#) - Sistemas de Detecção e Alarme de Incêndio – Projeto, instalação, Comissionamento e Manutenção de Sistemas de Detecção e Alarme de Incêndio – Requisitos;

ABNT [NBR IEC 60079-13](#) - Atmosferas Explosivas - Parte13: Proteção de Equipamentos por Ambiente Pressurizado “p”;

ABNT [NBR IEC 60439-1](#) - Conjuntos de Manobra e Controle de Baixa Tensão Parte 1: Conjuntos com Ensaio de tipo Totalmente Testados (TTA) e Conjuntos com Ensaio de Tipo Parcialmente Testados (PTTA);

ABNT [NBR IEC 60947-1](#) - Dispositivo de Manobra e Controle de Baixa Tensão Parte 1: Regras Gerais;

ABNT [NBR IEC 62271-200](#) - Conjunto de Manobra e Controle de Alta-Tensão Parte 200: Conjunto de Manobra e Controle de Alta-Tensão em Invólucro Metálico para Tensões Acima de 1 kV até e Inclusive 52 kV;

ABNT [IEC/TR 60815](#) -Guia para seleção de isoladores sob condições de poluição;

IEC [61936-1](#) - Power Installations Exceeding 1 kV A.C. - Part 1: Common Rules;

IEC [62485-2](#) - Safety Requirements for Secondary Batteries and Battery Installations - Part 2: Stationary batteries;

IEEE [Std 80](#) - Guide for Safety in AC Substation Grounding.

NOTE For documents referred in this Standard and for which only the Portuguese version is available, the PETROBRAS department that uses this Standard should be consulted for any information required for the specific application.

3 Symbols and Abbreviations

CB	- Carregador de Bateria;
CBT	- Caixa de Blocos Terminais;
CCM	- Centro de Controle de Motores;
CDC	- Centro de Distribuição de Carga;
CF	- Conversor de Frequência;
CH	- Chave Seccionadora;
CHT	- Chave de Aterramento;
DB	- Duto de Barras;
DJ	- Disjuntor;
ISOL.P	- Isolador Pedestal;

ONS	- Operador Nacional do Sistema;
PCC	- Painele de Corrente Contínua;
PL	- Painele de Iluminação;
PR	- Pára-raio;
RS	- Resistor de Aterramento;
SPDA	- Sistema de Proteção Contra Descargas Atmosféricas
TC	- Transformador de Corrente;
TF	- Transformador de Potência;
TL	- Transformador de Iluminação e Tomadas;
TP	- Transformador de Potencial.

4 Terms and Definitions

For purposes of this Standard, the terms and definitions indicated in 4.1 to 4.5, ABNT [NBR 5410](#) and ABNT [NBR 14039](#) are adopted.

4.1

Outdoor High Voltage Substation

An outdoor substation with voltage exceeding 15 kV, fed by lines from the utility company or from another substation.

4.2

Outdoor Substation in Modular Boxes (Switchrack)

An open-air substation with a voltage up to 15 kV comprised of a transformer and panel of modular boxes mounted on a metallic structure.

4.3

Indoor Substation

A substation containing high, medium and low voltage panels, with the panels and direct current system sheltered in masonry house and power transformers and disconnecting switches also sheltered or located within a fenced area annexed to the house.

4.4

Incoming Power Substation

A substation fed by the utility company.

4.5

Area Substation (or Auxiliary Substation)

A substation within the unit fed through the transformer of the incoming power station or by local generators or by another area substation.

5 General Conditions

5.1 The arrangement of the substation shall be simple, functional, compact and, preferably, similar to one of the arrangements shown for guidance in Annex A, Figure A.1 to Figure A.10.

5.2 Necessary space shall be provided for handling, maintenance and removal of equipment.

5.3 Necessary space shall be provided for future expansion of substation.

5.4 Power transformers and other equipment containing oil shall be installed out of buildings and separated from each other, considering the minimum distances between the equipment and buildings, as per ABNT [NBR 13231](#). The installation of a grounding resistor in the same cell of the respective transformer is admitted.

NOTE In case it is not possible to comply with the minimum distances, fire walls shall be used, as per ABNT [NBR 13231](#).

5.5 Oil Containment Basin for Transformers and Other Equipment

5.5.1 Transformers and other equipment containing oil shall be installed over containment basins.

5.5.2 Transformers and other equipment containing oil located indoors shall be installed on impermeable floor and surrounded by a wall with height sized to contain all oil volume of the equipment, making a containment basing as per ABNT [NBR 14039](#) and IEC [61936-1](#).

NOTE The containment basin shall have side drain and valve installed externally, in order to allow the drainage of rain water falling upon the side of the basin.

5.5.3 Transformers and other equipment containing oil in outdoor locations shall be installed on a concrete base. The containment basin shall be sized to contain at least 20 % of the entire oil volume of the equipment, according to Figure A11 of Annex A and IEC [61936-1](#). The containment basing shall be sized to exceed 0.5m the projection of the equipment.

NOTE 1 An oil water separator box shall be built, intended to store oil and drain rain water.

NOTE 2 The oil water separator box may be interconnected to more than one containment basin, and shall be built so as to contain at least the oil volume of the largest equipment interconnected to the box, plus the required volume to keep the hydrous seal.

NOTE 3 The outlet of the separator box shall be interconnected to the drainage system or drainage to ground through a hydric seal (see Figure A.11 of Annex A).

NOTE 4 The oil water separator box shall allow the removal of oil through the manhole.

5.6 Grounding System

5.6.1 Ground grid of incoming power substation shall be designed as per IEEE [Std 80](#).

5.6.2 Grounding inspection manholes designed in accordance with PETROBRAS [N-300](#) shall be installed outside indoor substations or within the boundaries of outdoor substations to measure the continuity the substation's ground grid.

5.6.3 In the underground portion of the ground grid, cable connections shall be permanently made, either through exothermal welding or compression connectors suitable for this purpose.

5.6.4 The PETROBRAS [N-300](#) shall be followed during detail design of the grounding system for structures, equipment, fences and doors

5.6.5 Ground grid cables shall be sized to handle phase-to-ground fault current while protections are opened, and the cross section of the ground grid cables shall be no smaller than 70 mm².

5.6.6 For area substations, a grounding loop shall be provided surrounding the substation area, including the building and external equipment. The loop shall consist of bare copper cables buried in the ground at a depth of no less than 60 cm. This grounding loop shall be connected to the general grounding system at least at 2 points.

5.6.7 Step and touch voltage studies shall be performed in incoming power substations to verify the need for additional protection.

5.6.8 All metallic parts without voltage of equipment and materials which may be energized, such as: panel structure, transformer casing, conduits, trays, and protection fences shall be grounded.

5.6.9 The grounding system design of substation shall provide one or more ground bars to connect the internal equipment and materials of the substation, in accordance with PETROBRAS [N-300](#).

5.7 An SPDA shall be provided, in accordance with requirements of standard ABNT [NBR 5419](#)

5.8 A fire detection and alarm system shall be provided for continuous monitoring of substation facilities, in accordance with ABNT [NBR 17240](#), with local and remote alarm in the supervision and control system.

5.9 Warning and direction signs shall be installed to warn of the hazards of the installations and indicate escape routes, as per standard PETROBRAS and in accordance with ABNT [NBR 13434-1](#), ABNT [NBR 13434-2](#) and ABNT [NBR 13434-3](#)

5.10 With respect to internal traffic and walkways, the requirements contained in ABNT [NBR 14039](#) shall be followed.

5.11 With respect to escape routes (emergency exits), the requirements of ABNT [NBR 9077](#) shall be followed.

5.12 The lighting system of the substation shall be designed in accordance with PETROBRAS [N-2006](#).

5.13 Control and protection cables inside the incoming power station or interconnecting substations shall be multipolar and have electromagnetic shielding.

5.14 Safety requirements shall be addressed in the design, as per PETROBRAS [N-2830](#) and Regulatory Standard no. 10 ([NR-10](#)).

5.15 The location of substations shall comply with the requirements of PETROBRAS [N-1674](#).

6 Specific Conditions

6.1 Outdoor High Voltage Substation

6.1.1 The terms and definitions described in this sub-item are applicable to incoming power substations used to feed industrial installations of PETROBRAS that do not belong to the transmission and distribution system of Brazilian electrical system. The minimum requirements of the local utility company shall be complied with.

6.1.2 PETROBRAS' substations belonging to the transmission and distribution system of the Brazilian electrical system shall follow the minimum grid requirements of ONS and of the local electrical utility company.

6.1.3 The transmission line shall enter the substation, whenever possible, perpendicularly to the entrance gantry. The maximum angle between the entry point of the transmission line and the line perpendicular to the entrance gantry shall be in accordance with the recommendations of the electric utility company.

6.1.4 The entrance gantry shall be sized for the loads recommended by the utility company and the own loads of the substation busbar. Other gantries of the substation and of the busbar support shall be calculated according to specific and local factors, such as length of span, maximum sag, temperature variation, maximum wind speed, etc.

6.1.5 The gantries of the substation and those used for supporting the busbar shall be comprised of pre-cast and standard concrete elements, unless defined otherwise by PETROBRAS.

6.1.6 The substation shall be surrounded by a fence and have a gate for access of people and at least one gate for access of equipment. The gate and the fence shall be in accordance with Figure A.12 and A.13 of Annex A.

6.1.7 The aerial busbar and branches shall be designed in accordance with the following criteria:

- a) they shall preferably be comprised of bare copper cables, without a steel core, made of the same material and having the same gauge as the cables of the transmission line arriving at the substation;
- b) the minimum distances of Table 1 shall be observed. Additionally, the requirements of the local utility company and of the insulation coordination of design shall be followed, as per ABNT [NBR 6939](#);
- c) they shall be calculated and sized to support all efforts resulting from short-circuit, winds and other weather and environmental conditions.
- d) when necessary, pedestal insulators shall be used to establish and maintain the minimum distances in the branches of the busbar to the equipment.

Table 1 - Minimum Clearances (m)

Minimum clearances	69 kV	138 kV	230 kV
Between phases, for rigid bars	2,15	2,40	3,60
Between phases, for flexible bars	2,50	3,00	4,50
Between phase and earth, for rigid bars	1,50	1,50	2,50
Between phase and earth, for flexible bars	2,00	2,20	3,40
Minimum ground clearance of live parts	4,00	4,50	5,00
Minimum ground clearance of parts with voltage reduced to zero (porcelain, insulators)	2,50	2,50	3,00
NOTE 1 The switches on the busbar are considered as flexible bars. NOTE 2 The phase-earth clearances for flexible bars are from the point of maximum sag to the soil.			

6.1.8 To select insulators under pollution conditions, the requirements of ABNT [IEC/TR 60815](#) shall be followed.

6.1.9 All aerial connections (of busbars, branches and lines) shall be made with bolt connectors.

6.1.10 Groups of lightning arresters shall be installed under the entrance of all overhead lines and on the power transformers.

6.1.11 For voltages of 69 kV, 138 kV and 230 kV, the following minimum clear distances shall be maintained from equipment or bases, in the direction of the circuit:

- a) 2,0 m for disconnecting switches, current and potential transformers;
- b) 2,5 m for circuit breakers.

6.1.12 The clearance between the transformer and any other equipment shall be as defined in ABNT [NBR 13231](#). A minimum distance of 1 m shall be considered between the transformer and the fire wall.

6.1.13 The disconnecting switch operating handle shall be located 1,2 m from the ground and with a free space around it, so as to ensure a simple and safe operation.

6.1.14 The blades of disconnecting switches, when the latter are of the simple opening type, shall be located on the side of the load and/or circuit breaker so as to be without voltage when opened. If the switch is mounted in the vertical position, the articulation of the blade shall be located on the bottom part of the switch so that its own weight keeps the switch opened.

6.1.15 The circuit breaker operating mechanism shall preferably be located 1,5 m from the floor. Provision shall be made for the installation of command push-buttons at this height, when the operating mechanism is installed at a higher level.

6.1.16 In the design of substations, the location of the energy input and output pins of the circuit breaker shall be observed, since the pins may be located at different levels. The input pin shall preferably be placed at a level above the circuit breaker.

6.1.17 Power, control and auxiliary terminal boxes of transformers shall not be placed on the surface corresponding to the displacement direction of transformers, so as not to block the removal of transformers.

6.1.18 The connection between the transformer neutral bushing and the ground resistor shall be aboveground, unless otherwise indicated, by means of a bare copper tube 1/2" IPS in diameter. In that case, the base of the bushing of the resistor and that of the transformer neutral shall be at a minimum height of 2.5 m. If the connection is underground, it shall be made through an insulated cable with insulation class equal to or higher than the transformer neutral pin.

6.1.19 The connection to the ground grid of the resistor casing shall be independent from the ground connection of the resistor itself.

6.1.20 Transformers shall be mounted on rails embedded in concrete bases. The rails shall extend until the access point for handling the transformer. Points shall be located for the attachment of trolley for facilitate the displacement of transformers.

6.1.21 The supporting structures of the substation equipment indicated below shall be made of in accordance with the following criteria:

- a) individual structures for each lightning arrester, current transformer, potential transformer and ground resistor;



- b) for voltages of 138 kV or below, a single structure shall be used for the 3 poles and for the operating mechanism of the circuit breaker, calculated considering not only its weight and the effect of wind but also the momentary dynamic stress transmitted by the impact of the opening and closing of the circuit breaker.

6.1.22 Unless otherwise indicated, the measurement system of the utility company shall be as follows:

- a) the meter panel shall be specified, built and installed in accordance with the guidance of the utility company;
- b) routing of metering cables shall be separated from other circuits.

6.1.23 The substation shall have one or more lighting panelboards. When installed outdoors, they shall be attached to a supporting structure formed by metallic shapes, and cables shall arrive at the panel through metallic conduits.

6.1.24 The SPDA shall comply with at least the following criteria:

- a) the SPDA shall be sized according to level I of ABNT [NBR 5419](#);
- b) the protection against lightning surges in command and control room shall be integrated to SPDA of the entire substation.
- c) all equipment shall be located within the area protected by the SPDA;
- d) guard wires of the substation shall be interconnected to the guard wires of the transmission line and to all lighting rods;
- e) all structures shall have drop cables for grounding of SPDA. The number of drops shall correspond at least to the number of bases or foundations of these structures;
- f) all drop cables of SPDA grounding shall be interconnected to the ground grid of the substation. Each drop cable shall correspond to an interconnecting point with the ground grid with ground rods.
- g) all auxiliary materials for attachment and branching of the guard wire system shall be galvanized, except connectors.

6.1.25 The design of the grounding system of the outdoor high voltage substation shall comply with the criteria of IEEE [Std 80](#).

6.1.26 Equipment and structures shall be interconnected to the substation ground grid in accordance with the following criteria:

- a) all metallic parts not intended to conduct electrical power shall be interconnected to the ground grid;
- b) the SPDA shall be interconnected to the substation ground grid;
- c) metallic supports and gantries, fences, gates, rails, lighting arresters and guard wires shall be connected to the ground grid;
- d) in aerial connections, bolted connections shall be used, and the drop to the ground grid shall be through a bare copper cable with at least 70 mm².
- e) at the point where ground cable penetrates the soil, the cable shall be protected by a piece of PVC conduit, for mechanical protection of the cable;
- f) in the drop to the grid, the ground cable shall be attached to the structure by means of suitable connectors;
- g) underground connections shall be made through exothermal welding or compression connectors suitable for this purpose;
- h) the connection of transformer rails to ground grid shall be made with bolted connectors suitable for this purpose.

6.1.27 The routing of cables within the substation yard shall be through channels with covers and adequate supports for the cables, unless otherwise indicated. The following criteria shall be followed: