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INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL ISSUE.
A	REVISED WHERE INDICATED.
B	REVISED ITEM 4.1, ACCORDING TO CLARIFICATION NOTICE DUE TO BIDDER QUESTIONS.
C	REVISED ITEMS 5, 6.5, 6.7, 6.9, 6.10 AND 6.11 ACCORDING TO CONTINUOS IMPROVING PROCESS (MELHORIA CONTÍNUA) SUGGESTIONS AND MINOR ADJUSTMENTS TO IMPROVE CONSISTENCY WITH OTHER ELECTRICAL TECHNICAL SPECIFICATIONS.
D	REVISED WHERE INDICATED.
E	REVISED ITEM 5.4. KEPT THE REVISION MARKS OF REVISION D FOR REFERENCE.

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	MAR/24/20	JUN/26/20	NOV/03/20	FEB/12/21	SEP/08/22	DEC/13/22			
DESIGN	ESUP	ESUP	ESUP	ESUP	ESUP	ESUP			
EXECUTION	CTLX	CTLX	U3OI	U3OI	UQBK	UQBK			
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APPROVAL	UQBE	UQBE	UQBE	UQBK	UQBE	UQBE			

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1. OBJECTIVE

The objective of this Specification is to provide the general guidelines to support the electrical studies to be carried out for the Detailed Design.

2. DEFINITIONS

2.1. “Owner” – Petrobras.

2.2. “Bidder” – The Company entrusted with the Engineering, Procurement and Construction of the production Unit.

3. REFERENCE DOCUMENTS

3.1. Applicable Standards

The latest revision of the standards listed in this section shall apply.

IEEE – Institute of Electrical and Electronics Engineers

IEEE Std 141	Recommended Practice for Electric Power Distribution for Industrial Plants
IEEE Std 142	Recommended Practice for Grounding of Industrial and Commercial Power Systems
IEEE Std 242	Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
IEEE Std 399	Recommended Practice for Industrial and Commercial Power Systems Analysis
IEEE Std 519	Recommended Practice and Requirements for Harmonic Control in Electric Power Systems
IEEE Std 1584	Guide for Performing Arc-Flash Hazard Calculations
IEEE Std 1584.1	Guide for the Specification of Scope and Deliverable Requirements for an Arc-Flash Hazard Calculation Study in Accordance with IEEE Std 1584™
IEEE Std C37.04	Standard for Ratings and Requirements for AC High-Voltage Circuit-Breakers with Rated Maximum Voltage Above 1000 V
IEEE Std C37.011	Guide for the Application of Transient Recovery Voltage for AC High-Voltage Circuit-Breakers with Rated Maximum Voltage above 1000 V
IEEE Std C37.96	Guide for AC Motor Protection
IEEE Std C37.110	Guide for the Application of Current Transformers used for Protective Relaying Purposes
IEEE Std C57.12.01	Standard for General Requirements for Dry-Type Distribution and Power Transformers
IEEE Std. C57.13	Standard Requirements for Instrument Transformers

IEC – International Electrotechnical Commission

IEC 60034-15	Rotating electrical machines – Part 15: Impulse voltage withstand levels of form-wound stator coils for rotating a.c. machines

IEC 60034-25 Rotating electrical machines – Part 25: AC electrical machines used in power drive systems – Application guide

IEC 60076-3 Power transformers – Part 3: Insulation levels, dielectric test and external clearances in air

IEC 60092-401 Electrical installations in ships – Part 401: Installation and test of completed installation

IEC 60909 Short-circuit currents in three-phase a.c. systems – All parts

IEC 61363-1 Electrical installations of ships and mobile and fixed offshore units – Part 1: Procedures for calculating short-circuit currents in three-phase a.c.

IEC 61869-1 Instrument transformers – Part 1: General requirements

IEC 61869-2 Instrument transformers – Part 2: Additional requirements for current transformers

IEC 61892-6 Mobile and fixed offshore units – Electrical installations – Part 6: Installation

IEC 62271-100 High-voltage switchgear and controlgear – Part 100: Alternating-current circuit-breakers

IEC 62305 Protection against lightning – All parts

IEC/IEEE 62271-37-013 High-voltage switchgear and controlgear – Part 37-013: Alternating-current generator circuit-breakers

NFPA – National Fire Protection Association

NFPA 70E Standard for Electrical Safety in the Workplace

NFPA 780 Standard for the Installation of Lightning Protection Systems

DPC – Diretoria de Portos e Costas – Marinha do Brasil

NORMAM 27 Normas da Autoridade Marítima para Registro de Helideques Instalados em Embarcações e em Plataformas Marítimas (from the version approved by Portaria n° 394 of 10 December 2018 onwards)

3.2. Design Documentation

[1] I-ET-3010.00-5140-700-P4X-001 - SPECIFICATION FOR ELECTRICAL DESIGN FOR OFFSHORE UNITS

[2] I-ET-3010.00-5140-700-P4X-002 - SPECIFICATION FOR ELECTRICAL MATERIAL FOR OFFSHORE UNITS

[3] I-ET-3010.00-5140-700-P4X-009 - GENERAL REQUIREMENTS FOR ELECTRICAL MATERIAL AND EQUIPMENT FOR OFFSHORE UNITS

[4] I-ET-3010.00-5140-772-P4X-001 - MEDIUM-VOLTAGE FREQUENCY CONVERTER FOR OFFSHORE UNITS

[5] I-ET-3010.00-5143-700-P4X-001 - ELECTRICAL SYSTEM PROTECTION CRITERIA

4. GENERAL INFORMATION

4.1. The electrical studies are part of Bidder's scope of work and shall be performed in three stages, as stated in item 4.9, by one specialist company, hereinafter called "Consultant".

4.2. The electrical studies shall be performed for the whole electrical system, which comprises all equipment and installation of the production unit.

4.3. Bidder is responsible for collecting and providing all necessary information and data related to the electrical system of the production unit.

4.4. Bidder is also responsible for checking the consistency of data forwarded by the equipment manufacturers. As a matter of example, data sheets of generators may contain inconsistencies between reactances and time constants, in such a way that, when entering the numerical values (provided by the manufacturers) of the former into the equations to get the latter, a time constant by far different from the one provided in the data sheet is yielded.

4.5. The direct communication and exchange of information between all parties involved (Owner, Consultant, Bidder, and manufacturers of electrical equipment and protective devices) shall at any time be allowed.

4.6. Owner reserves the right to convey technical meetings gathering different companies involved in the Detailed Design, aiming at facilitating the sharing of information among the parties.

4.7. At the beginning of each stage to which item 4.9 refers, Owner will convene a technical meeting gathering all parties involved in the work aiming at defining the following issues related to the studies to be carried out: main assumptions, scenarios, operational conditions and acceptable operational ranges of electrical quantities (voltages, currents and so on). All the issues addressed on the meeting shall be adequately considered from the first report of each study.

4.8. Consultant shall issue the following documents for Owner approval at the beginning of each stage of the studies, as stated in item 4.9, only after the meetings to which item 4.7 refers has been held:

4.8.1. Data Bank, a list containing all necessary data to perform the studies, including:

- Electrical parameters of circuits and main equipment (generators, transformers, motors, converters, reactors etc.);
- Dynamic mathematical models of machines, loads, AVRs, speed governors etc.

Data bank models shall be completely updated at least one time (revision A) during each stage of the studies, to reflect any electric equipment design data changes to minimize the electrical design risks, as stated in item 4.9. All respective electrical studies shall be also revised considering the Data bank models updates.

4.8.2. Methodology, a comprehensive report containing the methodology and the guidelines to be followed, as well as the scenarios and operational conditions to be considered for each study.

4.9. During the detailed design, the electrical studies shall be carried out in three steps, corresponding to the three distinct stages of development of the project, namely:

a) Preliminary studies;

b) Intermediate studies;

c) Final studies.

4.9.1. Preliminary Studies

Preliminary studies shall be performed at the beginning of the contract lifecycle in order to confirm the electrical system specifications adequacy and to support the release of main electrical equipment procurement.

At this preliminary stage, it shall be used the updated electrical load balance for all necessary loading conditions, cable lists and, if available, the main electrical equipment (generators, medium-voltage motors etc.) manufacturers technical proposals information.

The use of estimated data and typical models may be accepted, provided they are previously submitted and approved by Owner. Also, intentional pessimistic allowances shall be introduced into equipment parameters to compensate for the existing uncertainties over the available data and for the effect of the simplified modelling on the results.

4.9.2. Intermediate Studies

Intermediate studies shall be performed in a later stage of the project development, when the design will have advanced in such a way that main information and technical data from manufacturers are made available. Hence, all the data sheets technical information shall be applied in this phase. Simplified models will not be accepted.

4.9.3. Final Studies

Final studies shall be issued at the end of consultancy contract as a closing revision of the intermediate studies, when the electrical system design is expected to be consolidated and all equipment data will have already been confirmed by factory tests. Hence, all the FAT technical data shall be applied in this phase. Simplified models will not be accepted.

5. STUDIES TO BE PERFORMED

5.1. The following electrical studies shall be performed in the preliminary stage of Detailed Design:

5.1.1. Steady State Analysis:

a) Short-Circuit;

b) Ground Fault;

c) Load Flow;

d) Static Motor Starting;

e) Harmonics;

f) Incident Energy (Arc-Flash).

5.1.2. Time Domain Analysis:

a) Transient Recovery Voltage (TRV);

b) Electromagnetic Transients (Transformers energization, Interruption of Small Inductive Currents and Arc Reignition);

c) Delayed Current Zeros;

d) PWM Switching Overvoltages.

5.2. The following electrical studies shall be performed in the intermediate and final stages of Detailed Design:

5.2.1. Steady State Analysis:

a) Short-Circuit;

b) Ground Fault;

c) Load Flow;

d) Static Motor Starting (optional for intermediate stage only);

e) Harmonics;

f) Incident Energy Calculation (Arc-Flash);

g) Protection Coordination and Selectivity.

5.2.2. Time Domain Analysis:

a) Transient Recovery Voltage (TRV);

b) Electromagnetic Transients (Transformers energization, Interruption of Small Inductive Currents and Arc Reignition);

c) Delayed Current Zeros;

d) PWM Switching Overvoltages;

e) Dynamic Motor Starting;

f) Electrical System Stability.

5.2.3. 3D Modelling Analysis:

a) Lightning Protection sizing.

5.3. When compared to the other studies required by this specification, the Lightning Protection sizing study presents remarkable differences related to modelling and software requirement. This may lead to be more convenient to have the Lightning Protection study carried out by Bidder rather than Consultant. Hence, as an exception to that requested in item 4.1, Bidder, instead of Consultant, may perform the Lightning Protection study.

5.4. It may be necessary additional simulations regarding any of the studies performed in each stage (preliminary, intermediate, and final), either to confirm the adequacy of suggested corrective measures or to refine and adjust the results initially obtained, in order to comply with the contractual requirements. These possible complementary simulations shall be included in the scope of work of both Bidder and Consultant.

5.5. Electrical Studies shall comply with all requirements defined in the Basic Design technical documentation for the electrical system. The overall electrical system requirements are mainly detailed on the technical specification I-ET-3010.00-5140-700-P4X-001 [1] and on the specific ELECTRICAL SYSTEM DESCRIPTIVE MEMORANDUM. All the Detailed Design Electrical Studies shall consider at least the operational scenarios detailed on the specific ELECTRICAL SYSTEM DESCRIPTIVE MEMORANDUM.

5.6. A single software, chosen from among ETAP (from OTI, Operation Technology, Inc.), PTW (Power Tools for Windows, from SKM Systems Analysis, Inc.) and Powerfactory (from Digsilent GmbH), shall be used to perform all the electrical studies, exception made to: (i) Transient Recovery Voltage (TRV) analysis, Electromagnetic Transient analysis, PWM Switching Overvoltages analysis and Delayed Current Zeros analysis, that shall be carried out using either ATP (Alternative Transient Program, free), PSCAD (from Manitoba HVDC Research Centre) or Powerfactory; (ii) and Lightning Protection sizing, that shall be performed with the aid of a 3D computer engineering design tool.

5.7. All electronic files generated with the software used to perform the electrical studies shall be forwarded to Owner simultaneously with the respective electrical study report.

5.8. The results of each study shall be presented in reports, the contents of which comprising at least the following items:

a) Objective;

b) List of reference documents (data sheets, standards, technical literature, manufacturer catalogues etc.);

c) Main assumptions and evaluation criteria;

d) Acceptable operational limits of the electrical quantities (voltages, currents, active power, reactive power etc.);

e) Description of the computational run programs used;

f) Description of the system modelling;

g) Description of circuit topologies, scenarios, and operational conditions, which shall comprise both normal and contingency assessment of all production unit systems (main, auxiliary, and emergency);

h) Summary of the results obtained (by means of texts, tables, charts etc.) from computer simulations of the different system topologies and operational conditions as stated in paragraph "g)". Computer Program listings shall not be included in this item;

i) Conclusions, which shall clearly indicate limit violations of the main electrical quantities (voltage, current, active power, reactive power etc.), including those found for equipment and circuit ratings.

j) Recommendations and alternative solutions to bring the electrical quantities back to acceptable operational limits, which shall be provided within the body of the text and in a dedicated table as well;

k) Annexes, which shall contain complementary documentation (such as one-line diagrams, illustrations, program lists etc.) not suitable to be included along the main body of the report, but essential to an adequate comprehension of the technical issues.

5.9. Due to extensive different terminology standards and premises considered in the electrical design technical bibliography, these definitions shall be adopted for the studies:

- Condition: Electrical system loading condition that shall be considered for the simulation;

- Scenario: Electrical system topology (generators running, energized transformers, motors running, energized panels, tie, and back-feeders circuit-breakers positions etc.) based on a previously defined loading condition;

- Case: Sub-scenario or a previous defined scenario with minor variation due to specific events or situations.

6. ADDITIONAL INFORMATION

6.1. Data Bank

The minimum conditions, scenarios and cases, defined on item 5.9, shall consider at least the following main electrical equipment modelled, subdivided in Detailed Design Steady State Analysis Studies, detailed in 5.1.1 and 5.2.1, and Time Domain Analysis Studies detailed in 5.1.2 and 5.2.2.

6.1.1. Steady State Analysis Equipment modelling

To achieve adequate detailed design electrical studies development the following equipment shall be modelled to support the Steady State Analysis Studies:

- Individual modelling of all medium-voltage and low-voltage generators;
- Individual modelling of all medium-voltage power transformers;
- Individual modelling of all lighting transformers and AC UPS by-pass transformer;
- Individual modelling of all medium-voltage motors;
- Individual modelling of all low-voltage motors connected to switchgears (CDCs);
- Individual modelling of the largest motor connected to the low-voltage MCCs;
- Individual modelling of motors with rated power of 55 kW or greater in low-voltage Package panels;
- Remaining motors (from low-voltage MCCs and Package panels) can be grouped and modelled as an equivalent motor considering the total contribution of Is/In of 5 pu (total impedance of 0.2 pu and X/R = 2.38 as stated by IEC 60909).
- Individual modelling of all low-voltage non-motor loads connected to the switchgears (CDCs) as “constant power” type, except for heater type loads that shall be modelled as “constant impedance”;
- Individual modelling for the largest non-motor load connected to the low-voltage MCCs, Thyristorized and Package Panels as “constant power” type, except for heater type loads that shall be modelled as “constant impedance”;
- Remaining non-motor loads can be grouped and modelled as equivalent non-motor load “constant power” type;
- Individual modelling of all switchgears, MCCs, Thyristorized and Package Panels busbars rated at 480 V and greater, the 220 V panels busbars supplied by transformers with rated power equal to or greater than 100 kVA;
- Individual modelling of all medium-voltage and low-voltage VSDs and soft-starters that start motors with rated power of 55 kW or greater;

- Individual modelling of all short-circuit limiting current input reactors of low-voltage MCCs and Package Panels;
- Individual modelling of all busbar trunking;
- Individual modelling of all feeding power cables of the equipment individually modelled.

6.1.2. Time Domain Analysis Equipment modelling

To achieve adequate detailed design electrical studies development the following equipment shall be modelled to support the Time Domain Analysis of Transient Recovery Voltage (TRV), Electromagnetic Transients and Delayed Current Zeros analysis, which are further detailed:

- Individual modelling of all medium-voltage generators;
- Individual modelling of all medium-voltage generators voltage regulators;
- Individual modelling of all medium-voltage power transformers;
- Individual modelling of all medium-voltage motors;
- Individual modelling of all medium-voltage motors VSDs;
- Individual modelling of all medium-voltage grounding resistors and transformers;
- Individual modelling of all medium-voltage switchgears and MCCs busbars;
- Remaining low-voltage switchgears loads can be modelled as equivalent ones;
- Individual modelling of all medium-voltage busbar trunking;
- Modelling of the medium-voltage short-circuit limiting device;
- Individual modelling of medium-voltage generators and motors surge protection devices (surge arrestors and surge capacitors).

To achieve adequate detailed design electrical studies development the following equipment shall be modelled to support the Time Domain Analysis of PWM Switching Overvoltages analysis:

- Individual modelling of all medium-voltage and low-voltage with rated power equal to or greater than 55 kW motors driven by VSD, considering a frequency dependent model;
- Individual modelling of all necessary VSDs components of medium-voltage and low-voltage that drive motors with rated power of 55 kW or greater, considering at least: DC link voltage, switch rise time and number of levels of the inverter;
- Individual modelling of all power cables from the VSDs to the motors, considering a distributed and frequency dependent model.

6.1.2.1. The medium-voltage generators voltage regulators models shall be considered for Delayed Current Zeros and Electromagnetic Transients Transformer Energization analysis.

6.1.2.2. For those medium-voltage motors which the surge protection devices are not possible to be installed at their terminals, the modelling shall consider the real location, i.e., the cables between the surge protection devices and the motors terminals shall be modelled.

6.2. Short-Circuit

6.2.1. Three-phase short-circuit calculations shall be performed for a given set of operational conditions, in accordance with the requirements of IEC 60909, IEEE Std 141 and IEEE Std 399. Faults shall be considered to happen at all busbars of the electrical system.

6.2.2. Operational conditions mentioned in item 6.2.1 shall include not only worst-case scenarios, but also electrical system topologies on which minimum three-phase short-circuit currents are expected to flow.

6.2.3. The short-circuit calculations shall be performed considering "non-meshed" and "meshed" source contributions, as established in IEC 60909, and automatically identified by the simulation software. For "meshed" contributions, the Method B shall be chosen to calculate the X/R ratio, in order to provide more conservative results and to compensate the application of the fictitious resistance (RGf) for the contributions of the synchronous generator, as established in IEC 60909.

6.2.4. In the specific case of the preliminary study, all impedances not available from manufacturer tests shall be estimated with consideration to pessimistic allowances.

6.2.5. The results of the short-circuit studies shall be used to size equipment and as inputs to further evaluations, such as electrical system protection study, current transformer saturation assessment and arc-flash study (incident energy calculation).

6.2.6. As a first approach, attempts of sizing MCC incoming feeders of smaller cross-sections shall be made prior to employing the “higher cross sectional area incoming feeder plus reactor” sets traditionally used.

Note:

Generally, at early stages of the electrical system design, strict requirements of voltage drop lead to either the sizing of higher cross-sectional area feeders or the employment of many more cables per phase for a given feeder.

Consequently, a reduction in the impedances of individual circuits is expected, which in turn causes an increase in short-circuit current values at MCCs and the necessity of employing reactors at their incomes. Nevertheless, this issue is only detected by short-circuit studies normally conducted in a later stage of development of the design, when feeder cables have already been sized.

The reasons given above explain why the “higher cross-sectional area MCC incoming feeder plus reactor” sets are traditionally used and justify the need of pursuing all efforts to replace this combination by MCC incoming feeders of smaller cross-sections.

6.2.7. The sizing of short-circuit limiting reactors is considered as a natural development of the short-circuit study and shall therefore be included in the contractual scope of work for the three stages to which item 4.9 refers.

6.2.8. Limiting reactors shall be sized under the following guidelines:

a) Firstly, in compliance with the short-circuit limiting values as established on technical specification I-ET-3010.00-5140-700-P4X-001 [1];

b) After that, as a complementary step, they shall be optimized in such a way that different ratings (e.g., 12 mΩ, 15 mΩ etc.) are restricted to a minimum.

Note: Once the reactors ratings are optimized, load flow and motor starting cases shall be immediately revised accordingly.

6.2.9. It is also included in the scope of this study a general evaluation of the proposed system to ensure that the short-circuit capacity of equipment as defined by the technical specification I-ET-3010.00-5140-700-P4X-001 [1] is not exceeded in the worst calculation condition.

6.3. Ground Fault

6.3.1. Phase-to-ground short-circuit calculations shall be performed for a given set of operational conditions, in accordance with the requirements of IEC 60909, IEEE Std 141, IEEE Std 142 and IEEE Std 399. Faults shall be considered to happen at all busbars of any high resistance grounded voltage level.

6.3.2. Calculations by hand shall also be presented if a high resistance grounded system is employed at any voltage level. These calculations have the main aim of sizing the grounding resistor and its respective tap selection to properly match the amount of system capacitance.

6.3.3. The hand calculations mentioned in item 6.3.2 shall consider the impedance of the grounding transformer, when it is applied in conjunction with the grounding resistor.

6.3.4. It shall be considered the evaluation criterion that the use of an impedance to ground (ZN – total impedance of the grounding transformer + grounding resistor) with a value less or equal to 1/3 of the capacitive reactance of the system to guarantee that the overvoltages will remain within the safety limits.

6.3.5. Ground fault study results shall also be used to:

a) Size the grounding transformer, when it is applied in conjunction with the grounding resistor;

b) Assess the extent of damages resulting from phase-to-ground faults on stator laminations of generators and motors;

c) Properly set the ground fault protection functions and check their selective coordination and sensitivity.

6.4. Load Flow

6.4.1. Load flow studies shall follow the requirements of IEEE Std 141, IEEE Std 399, IEC 61892-1 and technical specification I-ET-3010.00-5140-700-P4X-009 [3].

6.4.2. Load flow studies shall calculate all bus voltages and angles, as well as all active and reactive power flows throughout the electrical system equipment and components, under some predicted operational conditions (normal and contingency scenarios) and topologies (see item 4.7).

6.4.3. Voltage drops and voltage regulation calculations shall also be carried out as part of the load flow studies. These calculations shall determine the voltage profile of the network under the operational conditions (normal and contingency scenarios) and topologies previously established (see item 4.7).

6.4.4. The magnitude of the calculated quantities (bus voltages and angles, active and reactive power flows, voltage drops, etc.) shall be presented in tables, provided within the load flow study report to be issued at the end of each of the three stages to which item 4.9 refers.

6.4.5. The load flow calculation results shall also be used as a basis for the assessment of:

a) The system voltage profile;

b) Transformer ratings and taps;

c) Medium and low-voltage switchgears and MCCs ratings;

d) Circuit loadings;

e) Active and reactive power losses;

f) Active and reactive power flows through medium and low-voltage branches.

6.4.6. Whenever load flow results indicate violations in the operational limits of the quantities mentioned in item 6.4.4. Consultant shall suggest and implement corrective measures to attain acceptable operational ranges.

6.5. Static Motor Starting

6.5.1. This study shall be carried out to determine the electrical system voltage profiles upon the starting of large motors. Requirements of IEEE Std 141, IEEE Std 399, IEC 61892-1 and technical specification I-ET-3010.00-5140-700-P4X-009 [3] shall be followed.

6.5.2. The starting simulation of the largest motor connected to each panel (switchgear, MCC and package's) shall be performed under normal and contingency operational conditions of the electrical system.

6.5.3. By virtue of the "cable length plus motor size" combinations, the starting of smaller motors of a given panel may place a more harmful frame to the electrical system than the one expected for the largest machine. The assessment of such situations shall therefore be performed as part of the contractual scope of work.

6.5.4. The voltage dips caused by the starting of a given motor at any electrical system point shall lie on an acceptable operational range, which shall be agreed by all parties (Bidder, Owner and Consultant) as required in item 4.7.

6.5.5. Whenever motor starting study results indicate voltage limit violations, corrective measures to bring the affected voltages back to an acceptable operational range shall be taken. Just for the sake of exemplification, some corrective measures are mentioned below:

a) Use of a soft-starter device or VSD (this equipment selection shall follow the rules defined on technical specification I-ET-3010.00-5140-700-P4X-001 [1]);

b) Change of the controlled-bus voltage (for main generators);

c) Change on transformer taps;

d) Application of motors with reduced starting current.

6.5.6. Static motor starting simulations shall be carried out by performing load flow (static) calculations, which consider the simplified model E'q (quadrature axis transient internal voltage) behind X'd (direct axis transient reactance) to represent the synchronous machines.

6.6. Harmonic Analysis

6.6.1. This study aims to evaluate the degree of distortion caused in current and voltage waveforms by non-linear loads (such as frequency converters, UPSs, rectifiers and so on) that act as harmonic sources to the electrical system. The output results shall be analysed based on IEEE Std 519 and technical specification I-ET-3010.00-5140-700-P4X-009 [3] requirements.

6.6.2. The scope of the study includes:

a) Calculation of harmonic voltages and corresponding distortion factors associated to each busbar of the electrical system;

b) Calculation of harmonic currents and corresponding distortion factors throughout the electrical system equipment and components;

c) Assessment of the impact of current harmonics on electrical system equipment (generators, motors, and transformers) rating;

d) Assessment of the network frequency response (impedance scan), in order to detect possible resonant conditions (only if there are large capacitors in the electrical system design).

6.6.3. In case the distortion factor calculated from a voltage or current waveform happens to exceed any limit established by the standards, Consultant shall review the corresponding simulation to seek for a solution capable of keeping the distortion within an acceptable range. The employment of filters or the use of frequency converters with updated technology (higher number of pulses in the rectifier input, internal PWM or multilevel technology etc.) are, amongst others, possible solutions to achieve the required goal. The solutions presented shall be analysed based on technical specifications I-ET-3010.00-5140-700-P4X-009 [3] and I-ET-3010.00-5140-772-P4X-001 [4].

6.7. Incident Energy Calculation (Arc-Flash)

6.7.1. Arc flash study shall be performed in accordance with IEEE Std 1584, IEEE Std 1584.1, NFPA 70E and technical specification I-ET-3010.00-5140-700-P4X-009 [3] requirements.

6.7.2. The study shall determine potential arc flash incident energies, arc flash boundaries and proper Arc-Flash personal protective equipment (PPE) Category.

6.7.3. As the incident energy depends on the product of time and current squared, special care shall be taken in seeking for the worst fault condition for this study, since circuit-breakers take a relatively long time to trip at low magnitudes of fault currents and that may be worse than a high current magnitude that would provoke almost instantaneous trip.

6.7.4. Based on the results of the arc-flash study, the Arc-Flash PPE Category clothing class necessary to withstand the calculated incident energy in working distances shall be determined for all electrical panels with rated voltage higher than 220VAC and, at least, for 220 VAC rated panels fed by a transformer with rated power higher than or equal to 100 kVA. It shall be provided the minimum information required for warning labels detailed on technical specification I-ET-3010.00-5140-700-P4X-009 [3].

6.7.5. Owner's operation personnel are expected to use Arc-Flash PPE Category 2 protective clothing (suitable for an incident energy of up to 8 cal/cm^2, as calculated at the working distance). Hence, all the possible measures shall be evaluated to result in incident energy of up to 8 cal/cm^2 for all electrical panels as also defined on technical specification I-ET-3010.00-5140-700-P4X-001 [1].

6.8. Protection Coordination and Selectivity Analysis

6.8.1. All protection coordination and selectivity studies shall follow the protection criteria philosophy defined on technical specification I-ET-3010.00-5143-700-P4X-001 [5].

6.8.2. The protection coordination and selectivity studies shall comply with IEEE Std 242.

6.8.3. The protection coordination and selectivity studies shall include, besides the electrical generators and electrical panels, the UPSs (AC and DC) systems.

Note 1:

"Electrical panels" shall mean all medium-voltage and low-voltage switchgears (CDCs), MCCs and all other low-voltage distribution panels of the production unit, including UPSs (AC and DC) distribution panels, while "generator control panels" shall mean the control panels of main, hull, auxiliary and emergency generators.

Note 2:

For electrical panels with rated voltage lower than or equal to 220VAC or 125VDC, such as lighting and small power or UPSs (AC and DC) distribution panels, their incoming, tie and outgoing circuits protection coordination and selectivity analysis may be done by Bidder, manufacturer or other company chosen by Bidder, instead of the Consultant, in order to focus the analysis efforts on the suitability of the coordination and selectivity protection between the major equipment of the electrical system.

6.8.4. The manufacturers of the electrical generators, electrical panels and UPSs (AC and DC) systems shall validate and detail the Consultant Final Protection and Coordination Study in accordance with the corresponding requirements of the electrical design specification I-ET-3010.00-5140-700-P4X-001 [1]. Consultant and Bidder representatives may be requested by Owner to take part in technical discussions.

6.8.5. Final revision in protection studies may be needed as a consequence of comments from manufacturers of relays and electric panels. The corresponding costs arising from that shall have already been taken into account in the contractual scope of work.

6.8.6. The reports of intermediate and final studies shall be issued in the format of a comprehensive technical memorandum, as stated in 5.8, including explanatory notes and calculations to support the choice of protective solutions and device settings.

6.8.7. The protection function settings of the protective devices installed inside electrical panels, generator control panels and UPSs (AC and DC) systems shall be presented in tables attached to both intermediate and final reports. Owner highlights that the tables shall comprise only those settings available for configuration through either the human-machine interface or the specific setup software of the purchased protective devices.

6.8.8. A dedicated section intended to check CTs selection shall be included in both intermediate and final reports. This verification shall be performed in accordance with the requirements presented in item 6.8.10.

6.8.9. Taking into account that intermediate and final studies require a great deal of explanatory notes which shall be clearly written in order to avoid misunderstanding, these studies in special shall be issued in both Brazilian Portuguese and International English languages.

6.8.10. Assessment of the adequacy of the selected current transformers (CTs)

Current transformers shall be investigated as to the possibility of saturation, which may jeopardize the proper operation of the instantaneous overcurrent protective functions (ANSI 50, 67 and 87). This investigation shall be carried out based on IEEE Std C37.110, IEEE Std C57.13, IEC 61869-1 and IEC 61869-2, and shall comprise the following steps:

a) Evaluation of the CTs regarding the possibility of saturation:

“Maximum secondary voltage” and “X/R plus 1” criteria shall be applied to the selected CTs, aiming to provide an indication of the possibility of saturation due to symmetrical and asymmetrical short-circuit currents, respectively.

Note:

Bidder shall check the adequacy of the set of CTs belonging to the differential protection of main, hull, and auxiliary generators as to the possibility of:

- Saturation due to symmetrical and asymmetrical short-circuit currents;

- False differential currents that may arise as a result of the difference between the transient secondary responses to phase faults outside the zone of protection at the primary side.

b) Assessment of the response of numeric microprocessor-based relays to saturation

All the saturation cases that happen to fail the “maximum secondary voltage” and the “X/R plus 1” criteria shall be further assessed with due regard to the attenuating effect of numeric relays.

The response of numeric microprocessor-based relays to saturation shall be evaluated by using a transient analysis software (ATP, PSCAD, Powerfactory, for instance). Alternatively, the computer spreadsheet produced by IEEE/PES Power System Relay Committee (available for free at http://www.erlphase.com/support.php?ID=CT_SAT_Calculator) can be accepted instead.

6.8.11. Time Current Curves (TCCs)

6.8.11.1. Time current curves (TCCs) shall be prepared to show the graphical proof of protection coordination achieved between subsystems such as:

- Main generator, main switchgear incoming, main switchgear “tie” circuit-breaker, and main switchgear biggest motor outgoing feeder;
- Main generator, main switchgear incoming, main switchgear “tie” circuit-breaker, and main switchgear biggest transformer outgoing feeder;

- Hull generator (if any), Hull switchgear incoming (from Hull generator), Hull switchgear “tie” circuit-breaker, and Hull switchgear biggest motor outgoing feeder;
- Hull generator (if any), Hull switchgear incoming (from Hull generator), Hull switchgear “tie” circuit-breaker, and Hull switchgear biggest transformer outgoing feeder;
- Primary and secondary sides of all transformers;
- Incomings (including back-feeders, if any), “tie” circuit-breaker, and biggest motor outgoing feeder (to be provided for all medium-voltage switchgears and medium-voltage motor control centres);
- Incomings (including back-feeders, if any), “tie” circuit-breaker, and biggest “non-motor” load outgoing feeder (to be provided for all medium-voltage switchgears and medium-voltage motor control centres);
- Incomings (including back-feeders, if any), “tie” circuit-breaker, and biggest motor outgoing feeder (to be provided for all low-voltage switchgears);
- Incomings (including back-feeders, if any), “tie” circuit-breaker, and biggest “non-motor” load outgoing feeder (to be provided for all low-voltage switchgears);
- Outgoing feeder (at low-voltage switchgear), incoming, and biggest motor outgoing feeder (to be provided for all low-voltage MCCs);
- Outgoing feeder (at low-voltage switchgear), incoming, and biggest “non-motor” load outgoing feeder (to be provided for all low-voltage MCCs);
- Emergency generator and the corresponding incoming at the essential switchgear;
- Auxiliary generator and the corresponding incoming at the auxiliary switchgear.

6.8.11.2. TCCs shall be prepared by applying the actual characteristics (parameters, equations, settings, curves, etc.) of the protective devices (relays, fuses and circuit-breakers) provided by the manufacturers. As stated in item 4.5, Consultant may at any time contact the manufacturers to clarify issues related to the protective devices.

6.8.11.3. Each TCC sheet shall have an appropriate identification and a simplified one-line diagram applicable to the specific portion of the system associated with the time-current curves on that sheet.

6.8.11.4. The TCCs shall clearly display the protected equipment thermal and mechanical limit curves. Just for the sake of exemplification, some of the time-current characteristics required are mentioned below:

- Motor overload capability curves;
- Motor acceleration thermal limit curves (for 80% and 100% of the rated voltage);
- Transformer through-fault protection curves;
- Generator short-time thermal capability curves.

6.8.11.5. The TCCs shall also display the protective device curves corresponding to the part of the system under study.

6.8.11.6. Whenever logical protection is employed, corresponding block diagrams as well as comprehensive explanatory notes shall be added to the TCC sheet.

6.8.11.7. Voltage and current scales shall be clearly identified. Even in case power transformers are involved, only one base voltage shall be selected for each TCC diagram.

6.8.11.8. The following protection points and protection curves shall also be indicated in TCC sheets:

- Motor starting curves (for 80% and 100% of the rated voltage);
- Generator decrement curves (ac component of the generator short-circuit contribution to three-phase and phase-to-phase faults on high and low-voltage systems);
- Cable damage curves;
- Transformer inrush points;
- Starting current of motors (for 80% and 100% of the rated voltage);
- Starting time of motors (for 80% and 100% of the rated voltage);
- Permissible locked rotor time of motors (for 80% and 100% of the rated voltage);
- Maximum symmetrical and asymmetrical short-circuit currents (three-phase and phase-to-phase faults);
- Minimum symmetrical short-circuit currents (three-phase and phase-to-phase faults).

6.8.12. Protection reports shall comprise at least the following annexes:

a) Simplified one-line diagram of CTs and relays, intended to provide the location of such devices in the electrical system;

b) Time-current curves (TCCs), as per item 6.8.11;

c) Extensive calculations, such as those required for:

- Setting thermal-model-based motor protective functions, such as ANSI 49 (thermal image) and ANSI 66 (restart inhibit);
- Checking the adequacy of the set of CTs belonging to main generator differential protection as to the possibility of saturation (see paragraph “a)” of item 6.8.10);
- Checking the adequacy of the set of CTs belonging to motor self-balancing differential protection as to the possibility of saturation due to an internal phase fault;
- Setting generator loss of excitation protection (ANSI 40).

6.8.13. The validation of the thermal time constants of motors shall also be included in the scope of this study.

6.8.14. It shall be defined the actuation settings and final inhibition logic of the short-circuit current limiter device sets based on the short-circuit and electromagnetic transients analysis.

6.8.15. It shall be confirmed the proof of coordination between voltage regulator (AVR) and main, hull, emergency and auxiliary generators protections.

6.9. Transient Recovery Voltage (TRV)

6.9.1. The TRV analysis aims to evaluate the voltage that appears across the poles of medium-voltage circuit-breakers (incomings, "ties" and feeders) upon the interruption of a three-phase fault.

6.9.2. The rate of rise and the peak of the calculated TRVs shall be compared with the corresponding withstand capabilities described in IEC 62271-100, IEC/IEEE 62271-37-013 and ANSI/IEEE C37.04 and C37.011 standards.

6.9.3. In case either the rate of rise or the peak of a calculated TRV happens to exceed any limit established by the standards, Consultant shall review the corresponding simulation to seek for a possible solution capable of keeping the TRV within acceptable limits.

6.9.4. Prior to the beginning of this transient study, Consultant shall submit to Owner for approval a report containing the modelling approaches intended to be adopted in its elaboration. Later on, the approved models shall be attached to the study report.

6.10. Electromagnetic Transient Analysis

6.10.1. These studies aim to analyse the performance of electrical system equipment and components when subjected to overvoltages arising from switching transient events.

6.10.2. The following transient analysis shall be carried out:

a) Energization of power transformers;

b) Interruption of small inductive currents by medium-voltage vacuum circuit-breakers and contactors (current chopping);

c) Arc reignition in medium-voltage vacuum circuit-breakers and contactors.

6.10.3. Prior to the beginning of the transient studies, Consultant shall submit to Owner for approval a report containing the modelling approaches intended to be adopted in the elaboration of the required analysis. Later on, the approved models shall be attached to the study report.

6.10.4. The performance of the electrical system equipment and components as affected by a particular transient event shall be assessed. This is achieved by comparing the output voltage waveforms across the terminals of such equipment and components with the overvoltage withstand capabilities described in IEC 60034-15, 62271-100, 60076-3 etc., IEC/IEEE 62271-37-013 and ANSI/IEEE C37.04, C37.011, C37.96, C57.12.01 etc. standards.

6.10.5. The analysis shall consider if the short-circuit current limiter device supports the electrical system electromagnetic transients to avoid its spurious actuation and the respective results shall be validated with the device manufacturer.

6.10.6. The Energization of power transformers analysis shall consider the transfer function models made available by manufacturers to represent the dynamics of machines (synchronous generators, gas turbines and engines) and their controllers (speed governors and voltage regulators) to evaluate the system response.

6.10.7. The model used to simulate arc reignition in medium-voltage circuit-breakers and contactors shall consider the possibility of multiple reignition in order to predict the voltage escalation and then to properly evaluate the need of surge protection in the electrical equipment.

6.11. Delayed Current Zeros Analysis

6.11.1. Depending on machine parameters, currents arising from a near-to-generator short-circuit may present delayed zero-axis crossing. If there are no zero-crossings during the time the circuit-breaker is attempting to interrupt the fault current, it may overheat and fail. This study shall investigate whether all medium-voltage circuit-breakers are capable of dealing with such a phenomenon.

6.11.2. Required modelling

6.11.2.1. Equivalent generator stator time constant (Ta) shall be estimated considering the stator DC resistance at 70ºC.

6.11.2.2. All medium-voltage induction motors and their corresponding outgoing feeders shall be individually included in the study. Dynamic models of motors shall be employed, in order to allow the representation of the decaying effect of the AC and DC components of each machine contribution to the fault.

6.11.2.3. The influence of initial stator and rotor fluxes of induction motors and synchronous generators on the delayed zero current phenomenon shall be investigated. This is achieved by calculating the amount of load associated to each machine immediately before the moment of the fault inception.

6.11.2.4. The arc resistance of circuit-breakers shall be included in the study during the length of time needed for the fault current to be interrupted.

6.11.2.5. The effect of generator saturation shall be considered in the study. This is accomplished by modelling the "No Load characteristic" obtained from Factory Acceptance Tests.

6.11.2.6. The effect of automatic voltage regulators of generators shall also be considered in case the length of time elapsed between the fault inception and clearing is higher than 120 ms.

Note:

The fault is only deemed to be cleared if every phase current waveform crosses the x-axis after the circuit-breaker opening.

6.11.3. Additional information

6.11.3.1. Bidder shall also address the short-circuit current limiter device tripping situation by islanding the main switchgear busbar soon after the inception of a three-phase short-circuit fault on the corresponding system. Faults at all sections of the main switchgear busbar shall be investigated. The operational conditions related to this assessment shall be defined at the meetings specifically convened for such purpose, as required in item 4.7.

6.11.3.2. The short-circuit current waveforms resulting from the simulations shall be presented in scaled graphics.

6.11.3.3. This study shall be subjected to the manufacturer of the medium-voltage circuit-breakers for analysis and comments. After that, Bidder may be requested to take part on discussions along with the circuit-breaker manufacturer and issue a final revision of the report including the outcomes of such discussions.

6.11.3.4. Bidder shall be reminded that recommendations laid down in intermediate and final reports of the present study may require revision in the protection study.

Possible impacts arising from that shall have already been foreseen and included in the contractual scope of work.

6.12. PWM Switching Overvoltages

6.12.1. The PWM Switching Overvoltages analysis aims to evaluate the overvoltage at induction motors fed by PWM (pulse width modulation) voltage source converters through the feeder cable. The overvoltage is caused by the successive reflections of the fast-rising PWM pulses generated by the converter and may lead to damages to the insulation of the converter-fed motor.

6.12.2. The calculated overvoltage at the induction motors subjected to fast rising PWM pulses shall be compared with the withstand capabilities described in IEC 60034-25.

6.12.3. In case a calculated motor terminal voltage happens to exceed the levels which the motor insulation is qualified, Consultant shall either review the corresponding simulation to seek for a possible solution capable of keeping the voltage within acceptable limits or a motor with the insulation system qualified for these calculated overvoltages shall be used.

6.12.4. The acceptable possible solutions to keep the voltage within acceptable limits are presented in technical specifications I-ET-3010.00-5140-700-P4X-009 [3] and ET-3010.00-5140-772-P4X-001 [4].

6.12.5. Prior to the beginning of this transient study, Consultant shall submit to Owner for approval a report containing the modelling approaches intended to be adopted in its elaboration. Later on, the approved models shall be attached to the study report.

6.13. Dynamic Motor Starting

6.13.1. The dynamic motor starting is an evolution of static motor starting analysis, since it considers dynamic models of machines (generators and motors), regulators (speed and voltage) and loads. Hence, the evaluation scope, acceptance criteria and possible corrective measures defined on section 6.5 shall be also considered for this study.

6.13.2. This study aims to assess the dynamic behaviour of the electrical system when subjected to large motor starting. Requirements of IEEE Std 141, IEEE Std 399, IEC 61892-1 and technical specification I-ET-3010.00-5140-700-P4X-009 [3] shall be followed.

6.13.3. For the large motor starting analysis, according to electrical design specification I-ET-3010.00-5140-700-P4X-001 [1], it is allowed application of generators’ voltage regulators field forcing function. In the study recommendations it shall be indicated the generators’ voltage regulators field forcing function voltage set points and durations.

6.13.4. The dynamic models used to represent equipment, controllers and components of the electrical system shall follow the applicable IEEE Standards.

6.13.5. Consultant shall validate the transfer function models made available by manufacturers to represent the dynamics of machines (synchronous generators, gas turbines and engines) and their controllers (speed governors and voltage regulators).

6.13.6. Also included in the scope of this study is the optimal tuning of the PID loops associated with speed governors and voltage regulators, which shall be achieved by adjusting the gains of such controllers.

6.13.7. If dynamic models of generators voltage regulator and speed governors are not readily available when Consultant is called upon to begin the intermediate studies, it is acceptable to perform a static motor starting analysis (refer to 6.5) at the beginning of intermediate studies.

6.13.8. This study shall also investigate the maximum load that can be delivered by each main generator prior to the starting of the largest motors, so that the capability limits (stator and rotor) of the generators are not violated during the starting process and after its completion.

6.13.9. For a proper evaluation of the dynamic motor starting results, it shall be presented for each motor starting simulation at least the following graphic results:

a) Voltage and frequency dynamic response curves at the feeder panel of the starting motor, the voltage at the starting motor's terminals and at the most affected panel.

b) Active and reactive power dynamic response curves at starting motor terminals.

c) Stator current, speed and terminal voltage dynamic response curves of the starting motor.

d) Stator current and excitation voltage dynamic response curves of the running generators.

6.14. Electrical System Stability

6.14.1. This study aims to assess the dynamic behaviour of the electrical system when subjected to the following abnormal transient events: three-phase short-circuit faults, load rejection, sudden application of load, reacceleration of motors and loss of generation. Requirements of IEEE Std 399 shall be followed.

6.14.2. Transient stability studies shall determine:

a) The transient power limits between different bus bars in case of system disturbances;

b) The required critical clearing times for faults (three-phase short-circuits) in the system;

c) The system response to sudden rejection of loads (e.g., a shutdown of the process plant);

d) The system response to sudden application of loads (e.g., a large motor starting);

e) The system response to the loss of a large amount of generation;

f) Load shedding requirements (needed to keep the system stable after the loss of a large amount of generation).

g) Loads to be inhibited by the starting load inhibition function.

6.14.3. Simulations of three-phase short-circuit faults in the system shall consider the fast actuation of the short-circuit current limiter device at the main switchgear busbar and the consequent islanding scenario.

6.14.4. In case of an unfavourable critical clearing is obtained from the simulations of three-phase short-circuit faults, Consultant shall review the protection study to seek for a possible solution capable of speeding up relay actuation. Any costs arising from this requirement shall have already been included in the contractual scope of work.

6.14.5. The dynamic models used to represent equipment, controllers and components of the electrical system shall comply with the applicable IEEE Standards.

6.14.6. Consultant shall validate the transfer function models made available by manufacturers to represent the dynamics of machines (synchronous generators, gas turbines and engines) and their controllers (speed governors and voltage regulators).

6.14.7. Also included in the scope of this study is the optimal tuning of the PID loops associated with speed governors and voltage regulators, which shall be achieved by adjusting the gains of such controllers.

6.14.8. The following quantities shall be plotted as a function of time:

a) Rotor angles, torques and speeds of synchronous machines;

b) Currents and voltages of excitation systems of synchronous machines;

c) Real and reactive power flows throughout the system;

d) Voltage magnitudes of the bus bars;

e) System frequency;

f) Torques and slips of induction motors.

6.15. Lightning Protection sizing

6.15.1. This study has two main aims: to indicate the parts of the platform structure most likely to be struck by lightning and to protect such parts and associated equipment from the undesirable effects of the lightning discharges.

6.15.2. The Lightning Protection study may be carried out by either or both Bidder and Consultant, as stated in item 5.3.

6.15.3. The “Rolling Sphere Method” (RSM) as presented in NFPA 780, and IEC 62305 shall be used to determine those parts of the platform structure most likely to be struck by a lightning discharge. A striking distance of 30 m shall be applied to achieve LPL II.

6.15.4. The RSM shall be applied with the aid of a 3D computer engineering design tool. The sphere shall be rolled over the surface obtained by superposing the 3D approaches for the hazardous area classification and for the installation. The resulting geometry shall be forwarded to Owner with all parts exposed to lightning discharges, as well as those naturally protected by surrounding structures, clearly identified. Vents and valves exposed to direct strikes or secondary arcing shall also be indicated.

6.15.5. The parts of the installation most likely to receive a lightning strike shall be protected by a Lightning Protection System (LPS), unless they may be proven to comply with the requirements of inherently self-protecting structures as presented in NFPA 780.

6.15.6. The LPS shall be comprised by a system of strike termination devices, down conductors, interconnecting conductors, isolation transformers, surge protective devices (SPD), and other connectors and fittings required to complete the system.

6.15.7. All activities under the scope of items 6.15.3 and 6.15.4 shall be carried out in two stages: initially without the LPS components (strike termination devices, down conductors and so on) and afterwards by including them.

6.15.8. The requirements of NFPA 780, IEC 60092-401 and IEC 61892-6, as well as those presented below, shall apply to the design of the lightning protection system (LPS):

a) Metallic structures less than 4.8 mm thick, if exposed to lightning discharges, shall be protected by a system of air terminals and down conductors. The same holds for non-metallic structures, regardless of their thickness;

b) Structures that are electrically continuous and have a metal thickness of 4.8 mm or greater may replace the system of down conductors. In this case, the said structures shall be bonded to the platform main structure;

c) The structures as mentioned in paragraph “b)” may also replace the strike termination devices, unless otherwise required elsewhere in this specification (e.g., paragraph “e)”) or in the applicable standards;

d) The protection of helidecks against direct lightning strikes shall follow the corresponding requirements in NFPA 780 and NORMAM 27;

e) The following elements shall be protected by an air terminal if they fall inside a region exposed to lightning discharges: vents that give off flammable gases or vapours (including those provided with flame arrester device), valves for oil and gas process, telecommunication antennas and meteorological instruments;

f) Air terminals shall be installed at least 2 m above the top of flammable gases or vapours vent outlets according to IEC 60092-401;

g) LPS materials shall follow the requirements of I-ET-3010.00-5140-700-P4X-002 [3].

6.15.9. Bidder shall issue a comprehensive report, including at least:

a) A chapter addressing the measures to be provided to protect the installation against lightning strikes and their undesirable effects.

- The installation as a whole shall be assessed with regard to the need for protection by an LPS and appurtenances (SPDs, isolation transformers, equipotential bonding and so on, in accordance with the requirements laid down in item 6.15.8).
- The following parts shall be individually addressed (in dedicated items of the chapter): flare stack, telecom towers, helideck, cranes and process plant.

b) 3D and 2D drawings (such as isometrics, perspectives, plans, sections and views) showing both the parts of the structure exposed to lightning discharges and the naturally protected ones.

- The drawings shall also show those vents, valves and instruments exposed to direct strikes;
- All drawings shall be extracted from the 3D geometry as requested in item 6.15.4;
- The number of drawings to be provided shall be such as to allow a complete evaluation of the lightning protection system;
- The drawings shall be provided initially without the LPS components (strike termination devices, down conductors and so on) and afterwards by including them.

c) Conclusions and recommendations.

6.15.10. After the final Lightning Protection study issuance, Bidder shall issue a general LPS arrangement plan (plan, sections and views) encompassing the entire unit with indication of the LPS components' locations.

7. ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
ANSI	American National Standards Institute
ATP	Alternative Transient Program
AVR	Automatic Voltage Regulator
CT	Current Transformer
ETAP	Electrical Transient Analyzer Program
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
LPL	Lightning Protection Level
LPS	Lightning Protection System
MCC	Motor Control Centre
NFPA	National Fire Protection Association
PES	Power & Energy Society
PID	Proportional, Integral and Derivative
PPE	Personal Protective Equipment
PSCAD	Power System Computer-Aided Design
PTW	Power Tools for Windows
PWM	Pulse Width Modulation
RGf	Fictitious Resistance of Synchronous Generator
RSM	Rolling Sphere Method
SPD	Surge Protective Device
TCC	Time Current Curve
TRV	Transient Recovery Voltage
UPS	Uninterruptible Power Supply