**ANNEX 5 – GUIDE FOR WRITING ELECTRICAL INSTALLATION PROJECTS AND MODELLING REQUIREMENTS FOR ELECTRICAL INSTALLATIONS**

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# **1 Purpose**

1.1 The present document is a guide for creating electrical installation projects for Transmission System Operator (TSO), the cooperation simulation of power grid and generation equipment and modelling generation equipment and power plant. The guide is applicable together with the General Conditions for Connecting to the Transmission Grid (General Conditions).

1.2 The guide defines requirements for class 3 and 4 power-generating facility and consumer’s electrical installations which need to be coordinated with the TSO.

1.3 Chapter 3 of the guide defines the general structure of the electrical installation project considering the common elements of the transmission-connected demand facility and power-generating facility electrical installation.

1.4 Section 3.1 describes the structure of the transmission-connected demand facility electrical installation project to be connected to TSO.

1.5 Section 3.2 describes the structure of the power-generating facility electrical installation project to be connected to TSO.

1.6 Section 3.3 describes the Annexes to be submitted to the TSO by power-generating facility connecting to the Distribution System Operator (DSO).

# **2 General conditions for electrical installation projects**

2.1 Electrical installation project has to be set up in the scope that corresponds to Chapter 4 of the Conditions for connecting to the grid and Annex 5. It should enable to evaluate the compliance of the electrical installation to the Grid Code, standards given in Chapter 7 of the General Conditions, taking into account all aspects of specific requirements in Connection Contract.

2.2 Project design has to correspond to the standards effective in the Republic of Estonia, in the absence of these, relevant standards of other countries or harmonised standards can be considered, in which case the designer has to explain the compatibility of these standards.

2.3 If the installation includes both power-generating facility and transmission-connected demand facility, the customer can submit the power-generating facility and transmission-connected demand facility project as one project.

2.4 All figures, schemes, signal records, etc. have to include letterhead with the customer’s name, name of the project and name of the designer. SI-system has to be used in unit measurements and calculations.

2.5 The changes included during the coordination of the electrical installation project must be clearly indicated, with the date of change mentioned. The same procedure applies to any later changes made in project.

2.6 Electrical installation project has to be submitted electronically. The text documents submitted electronically must be in .docx, .doc or .pdf format; the tables and data tables in .xlsx or .xls format and the schemes and figures in .dwg and .pdf format. The TSO must be able to copy and print the electronically submitted documents.

2.7 Electrical installation project has to be submitted as a complete project. Single parts of the project have to be marked accordingly.

2.8 After receiving comments from the TSO, the customer has to include changes and/or amendments and submit the electrical installation project once again to the TSO for approval.

2.9 If agreed by the TSO, the electrical installation project can be divided and submitted in following sections:

2.9.1 transmission-connected demand facility grid connection project;

2.9.2 power-generating facility grid connection project.

2.10 The final approval will be given by the TSO to the complete electrical installation project.

2.11 All sections that have been submitted for approval have to include an informational/explanatory writing. If several sections are submitted together, one common informational/explanatory writing may be submitted.

2.12 The Factory Acceptance Test (i.e. FAT) for the transformers and generation units does not have to be included in the initially submitted electrical installation project, but has to be presented to TSO after the relevant tests have been performed.

2.13 FAT report is a pre-requisite for obtaining the final approval for the project. In case of incompatibility of electrical parameters based on the data given in FAT report, the TSO has the right to not give approval to the project and reject energising the electrical installation.

2.14 The power-generating module is according to Electricity Market Act § 3 sections 25 and 9 an electrical installation for producing electric power containing devices, drivers and accessories required for the production, transmission, transformation, measurement, sale and consumption of electricity.

# **3 Content of the electrical installation project**

3.1 The transmission-connected demand facility electrical installation project has to include (but not limited to):

3.1.1 Informational/explanatory writing, including:

3.1.1.1 Technical data table of the electrical installation;

3.1.1.2 Planned time of connection;

3.1.1.3 Initial planning data, e.g. technical conditions, conditions for

connecting the network and design requirements;

3.1.1.4 General technical description of the project, list of primary equipment and

the general operation description of the electrical installation.

3.1.2 Primary section has to include:

3.1.2.1.1 General information and short description;

3.1.2.1.2 Single line drawing(s) (SLD) from Clients facility to the point of common coupling (PCC) in the TSO substation;

3.1.2.1.3 Overhead conductors, earthing conductors and power cables data sheets including electrical data with short description;

3.1.2.1.4 Parameters of all transformers and a FAT reports;

3.1.2.1.5 A map with location coordinates (scale 1:200 or 1:500);

3.1.2.1.6 Intersections of 110 kV or 330 kV compartments and bus arrangements, in case the Customer’s electrical installation is connected to the TSO’s PCC directly;

3.1.2.1.7 Calculations of ground system, earthing calculations, touch voltage and step voltage (in case the ground loop of Customer’s electrical installation is electrically connected with TSO’s substation or line earthing conductor). TSO shall provide TSO’s side short-circuit current values required for calculations if requested;

3.1.2.1.8 Isolation coordination calculations;

3.1.2.1.9 In case connection to PCC in TSO’s substation is made with 110 – 330 kV cable the following information needs to be provided:

3.1.2.1.9.1 Length of cable;

3.1.2.1.9.2 Longitudinal profile drawing, incl. crossing with other installations/utilities (communications, fibre cable, electrical cables, water, gas etc);

3.1.2.1.9.3 Cable data sheet with electrical characteristics;

3.1.2.1.9.4 Cross section of cable line, connection point, cable layout drawings, joints etc.

3.1.2.1.10 In case of connection to TSO’s substation is made with 110 – 330 kV overhead line:

3.1.2.1.10.1 Length of line;

3.1.2.1.10.2 Mast locations;

3.1.2.1.10.3 Longitudinal profiles of the incoming line between Client’s end mast and TSO’s line portal;

3.1.2.1.10.4 Type of masts including drawings of the mast;

3.1.2.1.10.5 Phase conductor and ground-wire data sheets including electrical characteristics;

3.1.2.1.10.6 Ground-wire, specification and definition of lightning protective zones;

3.1.2.1.11 110 or 330 kV power transformer data:

3.1.2.1.11.1 Nominal voltages, minimum and maximum operating voltages;

3.1.2.1.11.2 Nominal apparent power;

3.1.2.1.11.3 Nominal frequency;

3.1.2.1.11.4 Calculated short-circuits and durations;

3.1.2.1.11.5 Mode of transformer earth connection.

3.1.2.1.12 Climatic and environmental conditions;

3.1.2.1.13 Description of electrical installation’s reactive power compensation;

3.1.2.1.14 Description of electrical installation’s ability to low-voltage ride through;

3.1.2.1.15 Describe the basis for calculations;

3.1.2.1.16 Calculations of quality indicators (flicker, current harmonics, voltage change caused by switchings), according to requirements of Chapter 4 of Conditions for Connecting to the network;

3.1.2.1.17 Electrical characteristics of consumption equipment.

3.1.3 Secondary section:

3.1.3.1 The secondary section should include at least:

3.1.3.1.1 General – short description of the protection conception;

3.1.3.1.2 An electrical installation main and backup protections layout diagram with instrument transformers, which also shows the connections between devices and their types.

3.1.3.1.3 The figures should present the main characteristics, marking and producer of the devices;

3.1.3.1.4 The settings of electrical installation’s all relay protection and automatics from the consumption equipment to the connection point will be presented in the form of table; the operation and automatics according to the requirements of Chapter 4 of the Conditions;

3.1.3.1.5 RTU data communication characteristics (IP addresses, etc.) in the direction of TSO’s operating centre (SCADA):

3.1.3.1.6 RTU data volumes (measurements, operation and position signals);

3.1.3.1.7 Guaranteed measurement accuracies.

3.1.4 Copies of confirmation letters in the form of table (if available).

3.1.5 Project folder should include copies of essential technical agreements.

3.1.6 Additional documents.

3.1.7 If available, any additional information concerning the project solution.

3.2 Power-generating facility electrical installation project will be presented as a complement to the existing transmission-connected demand facility project if generating sources are available and should include:

3.2.1 Upgraded explanation letter that addresses the differences compared to the priory presented transmission-connected demand facility project. If no technical amendments have been made, this should be explained in the explanation letter. The letter should include the planned synchronisation time of the production equipment;

3.2.2 Primary section:

3.2.2.1 Final data of the power-generating module:

3.2.2.1.1 Data sheets for power-generating modules.

3.2.2.1.2 Type testing protocols for every different type of generating unit of the power-generating module. In case of wind turbines the protocols should be in compliance with standard IEC61400-21, rotating electrical devices, the standard EN60034 has to be followed. In case of other type of production equipment relevant factory test reports have to be presented, where the main electrical characteristics, their behaviour in voltage dips, power quality and operation capacity have to be measured and calculated for every different type of generating unit. This requirement does not apply to technical projects of class 2 power-generating facility and with less than 5 MW (incl.) facilities of class 3;

3.2.2.1.3 PQ-characteristics of the power-generating module;

3.2.2.1.4 Description, measurement accuracy and location of the power-generating module’s control system; if the supervision, control and changing of settings and algorithms through the network has been planned. This requirement does not apply to technical projects of class 2 power-generating facility and with less than 5 MW (incl.) facilities of class 3;

3.2.2.1.5 In case of power-generating module with synchronous generator also the description of the excitation regulator has to be presented (application of ceiling voltage, excitation current, automatic and manual control of the excitation current, block diagram, characteristics) and the description of power system stabilizer (parameters, description of signals and settings for constraints). This requirement does not apply to technical projects of class 2 power-generating facility and with less than 5 MW (incl.) facilities of class 3;

3.2.2.1.6 In case of power-generating module with more than 5 MW nominal active power, the planned model(s) with parameters and descriptions; block diagrams of the production equipment operation and automatics (incl. PSS/E and PSCAD models in electronic format);

3.2.2.1.7 In case of production equipment with more than 5 MW nominal active power, the verified model(s) (incl. PSS/E and PSCAD models in electronic format) to be presented within 6 months after the all Grid tests have been carried out and results have been approved by TSO;

3.2.2.1.8 FAT report of generating units.

3.2.2.2 The descriptions of functions with settings. This requirement does not apply to technical projects of class 2 power-generating facility and with less than 5 MW (incl.) class 3 facilities. Please note that all power-generating facilities at least of 1 MW (nominal active power) generation have to be able participate in primary control:

3.2.2.2.1 Primary regulation;

3.2.2.2.2 Secondary regulation (regulation of active power with given speed and

range performed through remote control);

3.2.2.2.3 Regulation of active power;

3.2.2.2.4 Regulation of reactive power, automatic voltage regulation in reference to the connection point;

3.2.2.2.5 Transition to auxiliary load.

3.2.2.3 Cooperation imitation report of the network and production equipment according

to Chapter 4 of the current annex in case the PSS/E and PSCAD models are required;

3.2.2.3.1 Customer has to be present the cooperation imitation report of the network and the production equipment in both transient and stable operation. In case the production equipment will be constructed in stages, the report is required for each stage.

3.2.2.3.2 Describe the operation principles of the production equipment (type of equipment, load regime, an annual rated time of operation), present relevant tables, diagrams, equipment characteristics, etc. Describe the starting process of the production equipment. Describe the shutdown process of the production equipment.

3.2.3 Secondary section project:

3.2.3.1 In case of presenting a power-generating facility project, the customer has to upgrade the content of the project in comparison to the transmission-connected demand facility project in all sections of the secondary section project. The upgrades have to be marked in comparison to the data presented in the transmission-connected demand facility project;

3.2.3.2 All relay protection and automatics settings have to be presented in the form of table with an added block diagram (required for systems with nominal voltage 1 kV and higher).

3.3 DSO and DSO’s client has to provide the following additional information for TSO:

3.3.1 The DSO confirms the electrical installation projects exceeding 1 MW with the TSO, and the following data in the sections 3.3.3, 3.3.4 and 3.3.5 will be added to the application;

3.3.2 The electrical installation project has to be set up according to the requirement given in sections 3.1 and 3.1.7; the unreasonable requirements will be agreed with the TSO based on specific case.

3.3.3 For power-generating facility, equipment with nominal active power of 1-5 MW, the folloring additional information will be required:

3.3.3.1 A connection project for transmitting required measurement results in compliance with Chapter 4 of the conditions for connecting to the network and Annex 4 of the connection conditions;

3.3.3.2 Single line diagram from the connection point in the DSO where the production equipment has been connected to the connection point in grid of the TSO. Single line diagram should present transformer ratings, lengths of lines and cross-sections, short-circuit voltages, etc.);

3.3.3.3 The settings of relay protection between the connection point of the DSO and

the TSO;

3.3.3.4 PQ-characteristics of the production equipment.

3.3.4 In case of production equipment with nominal active power between 5 MW and 10 MW:

3.3.4.1 A connection project for transmitting required measurement results in compliance with Chapter 3 of the conditions for connecting to the network and Annex 4 of the connection conditions;

3.3.4.2 Single line diagram from the connection point in the DSO where the production equipment has been connected to the connection point in grid of the TSO. Single line diagram should present transformer ratings, lengths of lines and cross sections, short-circuit voltages, etc.);

3.3.3.3 The settings of relay protection between the connection point of the DSO and

the TSO;

3.3.3.4 PQ-characteristics of the production equipment.

3.3.4.5 PSS/E model in compliance with the requirements given in Chapter 5 of the current annex;

3.3.4.6 The report of the cooperation simulation in the section that concerns the ability

transmit voltage dips in compliance with Chapter 4 of the current annex.

3.3.5 In case of production equipment with more than 10 MW nominal active power:

3.3.5.1 A connection project for transmitting required measurement results in compliance

with Chapter 3 of the conditions for connecting to the network and Annex 4 of

the connection conditions;

3.3.5.2 Single line diagram from the connection point of the DSO where the production equipment has been connected to the connection point in grid of the TSO. Single line diagram should present transformer ratings, lengths of lines and cross-sections, short-circuit voltages, etc.);

3.3.5.3 The settings of relay protection between the connection point of the DSO and

the TSO;

3.3.5.4 PQ-characteristics of the production equipment.

3.3.5.5 PSS/E and PSCAD models in compliance with the requirements given in Chapter 5 of the current annex;

3.3.5.6 The report of the cooperation simulation in the section that concerns the fault-ride-through ability in compliance with Chapter 4 of the current annex.

# **4 Requirements for the cooperation simulation report between the network and the production equipment**

4.1 The cooperation simulation report has to be included in the electrical installation project documentation. The cooperation simulation report has to be submitted for all types of production equipment to be connected to the network.

4.2 In order to evaluate the interaction between the electrical installations and the power system, a consumer has to submit a summary report on the technical studies of the electrical installation with the aim to analyse the behaviour of the electrical installation and to evaluate if the installation is in compliance with the established requirements. All customers have to submit the report if the power-generating facility power increases or the nominal active power of the production equipment exceeds 5 MW. The report should provide an understanding how the electrical installation will behave, so that its impact to the power system and in reverse can be estimated.

4.3 Generally, network calculation software of PSS/E and PSCAD have been allowed to be used for setting up the parts of technical studies connected with network calculations, and for the electrical installation models submitted to the TSO. At the same time, if agreed, the use of other well-known network calculation software is also acceptable. The use of the latter has to be agreed with the TSO that evaluates the results, determining how exactly and in which manner the electrical installation will be modelled and how will the research be carried out.

4.4 The present document proceeds mainly from the synchronous stations to be connected to the network, production equipment connected through inverter (wind or solar power station) and bigger consumers. IN case of HVDC and FACTS devices the requirements can be somewhat different and the exact amount of analyses will be agreed separately in each case.

4.5 The aim of technical studies report:

4.5.1 The summary of the technical studies report provides the TSO information about the interactive impact of the electrical installation to the power system during the steady and transient operation. The report should give a picture of the behaviour of the electrical installation and has to include at least:

4.5.1.1 The behaviour of electrical installation in different network situations;

4.5.1.2 P/Q curves of the electrical installation;

4.5.1.3 The limits of electrical installation’s power exchange with the network (min, max P);

4.5.1.4 The limits and the behaviour of the electrical installation to regulate voltage during the changes in voltage setting value and the network voltage;

4.5.1.5 The power quality indicators of the electrical installation and their compliance with the technical conditions and marginal values;

4.5.1.6 To present the nature of the electrical installation’s dynamic behaviour and compliance to the established requirements;

4.5.1.7 To present the cooperation and impact of the electrical installation to other close electrical installations (the exact content of the studies depends on the location of the installation in the power system and will be agreed separately with the TSO);

4.5.1.8 To provide an evaluation on the behaviour of different control functions (e.g. primary regulation, voltage and reactive power control, etc.) and their compliance to the requirements.

4.6 The models used during the studies:

4.6.1 The technical studies of cooperation have to use mathematical models that enable most precisely to describe the given electrical installation. The used models have to be agreed with the TSO before the studies have been performed. Also, the suitability of used models according to e. g. factory test protocols has to be shown before the studies. It is assumed that prior to the studies, already some factory tests have been performed and it is possible to obtain more detailed information compared to information available during the compilation of initial models.

4.7 Requirements for the documentation:

4.7.1 Research results have to be submitted in the form of report, which covers the starting point of the research and the used models. The report should also include the overview of the electrical installation and all of its used control functions with references to documents where these functions have been more precisely described. The report should present the research results in a clear and understandable manner, all figures and tables shown in the report have to be explained in the text and the analysis of the results should provide comparisons to previously agreed technical conditions and requirements given in the Grid Code. Information (models, technical parameters, principles of the control system, etc.), that contribute to the analysis of the report results should be given in the report annex(es).

4.7.2 The report has to be submitted to the TSO in electronic version (pdf). If there are colours used in the report, the paper printable copy has to be printed out in colour.

4.8 The scope of research:

4.8.1 The technical studies report should consider the physical content of the given problem and proceed from the most difficult cases of the given situation. Generally, the impact of the electrical installation to the power system and on the contrary has to be analysed in borderline cases, if necessary, the operation in other working sections will be shown. Selection the borderline cases has to include an overview and explanations on the capability of that particular installation and the criteria how these borderline cases have been selected.

4.8.2 While carrying out the studies, the behaviour of the installation in case of all control functions (voltage control, reactive power control, primary regulation, etc.) has to be analysed. The aim is to optimise the operation of the electrical installation and to minimise possible side impacts, and to improve the operation of the network and the electrical installation. The results of the studies should provide an understanding that all technical requirements set to the electrical installation, have been met and the installation is capable to cooperate with the network.

4.8.3 The scope of research to be carried out for the connection of electrical installation depends on the type of electrical installation, its location, voltage level of the connection, the existence and principles of control systems and other factors. Depending on all that, the concrete studies will be agreed between the TSO and the customer to be carried out in the framework of technical studies already during the connecting contract. A list of possible studies that can be required depending on the electrical installation:

4.8.4 The studies connected with the operation and interaction of the installation:

4.8.4.1 Loading possibility of the electrical installation (active and reactive power) depending on the external temperature or other temperatures;

4.8.4.2 Capability of reactive power regulation and compliance to requirements (the study

will show the capability of reactive power regulation and the compliance to technical agreements and the requirements of the Grid code; the report has to analyse the issues of both reactive power and voltage regulation);

4.8.4.3 PQ characteristics (PQ curve of one production unit and the PQ curve of the installation’s connection point have to be presented);

4.8.4.4 Coordination of relay protection and automatics (the study should present the nature of the relay protection and automatics of the installation to be connected and the principles for the selection of settings and show their impact to the functions used in the power). The results of the studies have to be submitted together with the electrical installation project. The final settings have to be agreed at least 30 days before the energisation.

4.8.4.5 the analysis of electrical installation’s dynamics (the study should present the suitability of the electrical installation for parallel operation with the power system; it should cover the behaviour of the installation during the short-circuits occurring in the network (both asymmetric and symmetric short-circuits with different duration and length should be considered, evaluating the results on at least three curves given in the Grid code (one of these should be the most difficult case with voltage dip *U* = 0 p.u. in the connection point)), analysis has to considered the changes in both active reactive power; in case of synchronous equipment the excitation and its components have to be considered, including PSS (*Power system stabilizer*), impact on the network operation, also the capability of primary and secondary regulation and voltage and reactive power control and compliance with the set requirements has to be evaluated. In evaluating the operation of different regulators their behaviour in different extreme and typical conditions has to be presented. The study of dynamic processes should show the impact depending on the connection point and if necessary, also the behaviour of one particular production unit should be presented);

4.8.4.6 The evaluation and analysis of sub synchronous oscillation processes (depending on the used technology, the study and the evaluation of possible counteractions would be analysed);

4.8.4.7 the studies of power quality (this study should enclose and analyse the impact of electrical installation to the harmonics and flicker level after the connection, also analyse the impact of fast voltage change values and the asymmetry caused by the switching activities. In case of wind turbines, the methodology of standard EVS-EN 61400-21, section 8 has to be followed);

4.8.4.8 analysis of harmonics (the study should proceed from the network impedance curves provided by the TSO which should be used for analysing the impact of the electrical installation to the harmonics transformation and the possibility of resonances; if necessary, the limiting technical measures will be stipulated);

4.8.4.9 The analysis of ensuring the black start (the study will examine the capability of the electrical installation to participate in the re-energising of the power system and the concurring processes; the possible scenarios will be provided by the TSO).

4.8.5 The studies connected with the design and planning of the installation:

4.8.5.1 The calculations of the equipment selection and the compliance with set requirements (the report should present the selection criteria of all main equipment components and their technical boundaries);

4.8.5.2 Network frequency overvoltages (the study should calculate possible overvoltage levels and present the principles for limiting the overvoltages, and the main parameters and suitability of the equipment used for overvoltage protection);

4.8.5.3 Transient and temporary overvoltages and their levels (the study should present the levels of this type of overvoltages and their impact to the TSO’s equipment (if necessary, to the equipment of the proximate substations). Analysis should cover the suitability and compatibility of circuit breaker, overvoltage limiters and the other equipment connected by the TSO);

4.8.5.4 Isolation coordination (the principles for isolation coordination have to evaluated from the standpoint of connecting installation and the TSO’s installation);

4.8.5.5 The selection and technical compatibility of filter parameters and their impact analysis (this study will be performed in case the installation uses filters for suppressing harmonics);

4.8.6 Other studies:

4.8.6.1 noise studies (the study should show that the acoustic noise caused by the customer’s electrical installation does not exceed the limits determined in the Regulation of Minister of Social Affairs No. 42 of 04.03.2002 “Noise limit values in residential and recreational areas, residential and public buildings, and the noise level measuring methods” both separately and in concurrence with the installations of the TSO in case the installations are located in close proximity. The common diagrams have to be used for showing the noise distribution and the preventive factors. The necessity for this study occurs general in cases the connecting electrical installation is located in close proximity of the TSO’s electrical installation and it can be suspected that the noise level of the TSO’s electrical installation may be influenced);

4.8.7 The studies should provide an understanding of the possibility of the cooperation of electrical installation and the power system and its limiting factors. In case the studies show that technical requirements have not been met, the necessary measures have to be taken to improve the situation. After the technical principles have been update, both models and research has to be also updated and submitted again to the TSO.

# **5 Requirements for modelling production equipment**

5.1 TSO is responsible for the operation of the power system and providing quality power to the customers at all times. A natural part of power system development is the inclusion of new customers, including producers and consumers. The complete analysis of possible interaction of the installations of the new customers and the power system is done using mathematical models and power system software programs. This enables to model and analyse the impact of possible network reinforcements, different network regimes, consumers and producers in an integral manner and guarantee the reliability of the network.

5.2 TSO uses the models to examine the impact of the new customer to the power system and to other customers and gives an initial estimation if the installation to be connected is suitable and complies with the set requirements. The examination of the electrical installation’s impact, mostly the different operation borderline situations are considered to make sure that particular installation is capable of cooperating with the network, and if some shortcomings do exist, to evaluate their extent and study the possibility for eliminating them. Before real connection of electrical installation, this allows to identify conditions TSO and new customer face during the connection process.

5.3 TSO carries out different studies using the mathematical models provided by the network and new customers, the most important of these are:

5.3.1 The studies connected with the steady-state operation, electromechanical and electromagnetic transient processes of the network operation and planning;

5.3.2 The studies connected with adding new customers and possible network tests and compliance to technical requirements, including Grid Code;

5.3.3 The studies connected with operative planning of the network;

5.3.4 The studies connected more general system disturbances, including short circuits, and disturbances between different installations.

5.3.5 Other case-based studies

5.4 The current chapter describes the requirements to the models submitted by new customers and gives an overview of the content of the submitted models at different stages during the connecting process.

5.5 General requirements for the models submitted by new customers:

5.5.1 New customers have to present network calculation models in PSS/E software program (for examining the steady operation and electromechanical processes or dynamics) and PSCAD software program (for examining the electromagnetic processes and power quality effects).

5.5.2 In presenting the models one has to proceed from the principle that network calculation software programs (PSS/E and PSCAD) present the models as seen from the connection point with TSO as follows:

5.5.2.1 The aggregated model, if the electrical installation consists of several similar production units;

5.5.2.2 a detailed installation model in addition to the aggregated model in the case of production equipment exceeding 50 MW nominal active power and direct current systems and flexible alternating current transmission systems (FACTS);

5.5.2.3 Simulation results of all presented models have to be in compliance with each other.

5.5.3 It is permitted to aggregate only the same type of production units, e.g. production equipment consisting of wind turbines produced by two different companies. In that case, the aggregated model of the installation has to be presented with two wind turbines, and each describes the wind turbine of that particular company in the given installation.

5.5.4 The model of the electrical installation has to enclose all electrically important elements of the installation. Only elements that have an impact on the behaviour and impact of the electrical installation in different network calculations and dynamic processes have to be modelled. The model should include at least the following elements:

5.5.4.1 Transformers; in the aggregated model the same type of equipment can be equivalented;

5.5.4.2 Lines, in the aggregated model the same type of equipment can be equivalented;

5.5.4.3 Compensation equipment (reactors, capacitors, etc.), in the aggregated model the same type of equipment can be equivalented;

5.5.4.4 Generator, in the aggregated model the same type of equipment can be equivalented;

5.5.4.5 Turbine;

5.5.4.6 Exiter (regulator, limiters):

5.5.4.7 Power system stabilizer (if required);

5.5.4.8 Governor;

5.5.4.9 Relay protection (generally voltage and frequency protection);

5.5.4.10 control systems (depending on the type of station);

5.5.4.11 filters, in case of aggregated models the same type of equipment can be equivalented.

5.5.5 The final content of the model depends on the type of installation and used technologies.

5.5.6 It is important that the presented model should reflect the characteristics of the elements included in the installation as exactly as possible, proceeding from the purpose of the model and the requirements for the electrical installation. When composing the models, all different factory test protocols and other documents should be considered which could convince that the model is suitable.

5.5.7 It should also be considered that the models composed using PSS/E and PSCAD network calculation software programs have to be comparable and the modelling results of the similar processes should be close. In case of larger differences the models has to be complemented.

5.5.8 The model has to be presented together with the content and explanatory documentation, which enables to evaluate the model contempt and its suitability. Also, the other documents presented during the connecting process should be available for the evaluation of the model suitability (factory test protocols, block diagrams, e. g. technical documents relevant in evaluating the content and behaviour of the model).

5.5.9 In case of direct current and flexible transmission systems, in order to examine electromechanical and electromagnetic processes, next to complete models also the simplified models have to be presented, with longer calculation steps compared to the exact model. The author of the model has to show the conditions in which the models are compatible and which restrictions have to be considered in case of the simplified model. Also, it has be examined at which conditions the simplified model can not be used. The relevant evaluation has to be presented as a separate report, which includes the general description of the models and the calculations and their results on which the relevant evaluations have been based.

5.5.10 In composing the models, the standard models of the network calculation software programs should be used. This enables to simplify the analysis of the models and transfer the models to the newer versions of these software programs. In case this approach is not possible, the model using only standard model components should be presented next to the closed (black box) model given by the producer. Generally, these cases will be considered separately and the final decision on the presentation of the model is done after the discussion and possible confidentiality agreement between the TSO and the author of the model. This process should involve the agreement on subsequent model support, which is extremely important in case of closed models.

5.5.11 In determining the calculation conditions of the models it is important that in the PSCAD software program the simplified model must be used with calculation time step of 25 μs and in the PSS/E software programs the standard models have to be usable with calculation time step of 5 ms. The basic values used in PSS/E models have to coincide with the values used by the TSO.

5.5.12 The size and voltage of the installation to be connected has to be considered in determining the model scope. The sections 5.5.2 and 5.16 describe the scope of different new customers in more detail.

5.6 The description and requirements for the models used for network calculations:

5.6.1 The modelling of power system components has to proceed from the purpose of modelling. The models are composed for the calculation of normal operation, electromechanical an electromagnetic transient processes.

5.6.2 The present section provides an overview of the math and content of the models that the models composers have to follow. The models and their composition will be considered separately in the context of the requirements for modelling normal operation, short-circuit currents, electromechanical and electromagnetic transient processes.

5.7 The calculations of power system’s normal operation (power flow and voltages) and short-circuit currents:

5.7.1 The purpose of analysing the power system’s normal operation is to investigate the regimes limiting the production unit and the measures to clear the limits. As the result, the production unit should be able to develop (within its power limits) whatever power in all possible load situations of the power system without the application of power system’s operational limitations. During the analysis special attention will be paid for examining the impact of different disturbances (e.g. N-1, N-1-1 situations), in order to determine the possible operational limitations caused to the production units.

5.7.2 The following effects will be identified during the analysis of the normal operation:

5.7.2.1 over and under voltages;

5.7.2.2 overloads;

5.7.2.3 the sufficiency of active and reactive power reserves;

5.7.2.4 operational limitations;

5.7.2.5 necessary precaution measures for controlling the power system, etc.

5.7.3 The following data has to be provided for the analysis of power system’s normal operations required for the power system:

5.7.3.1 the equivalent circuit of the network, with the following data:

5.7.3.1.1 the most important power transformers and other consumption points;

5.7.3.1.2 network nodes (substation bars);

5.7.3.1.3 overhead and cable lines;

5.7.3.1.4 reactive power compensation equipment and other major power equipment (e. g. large motors);

5.7.3.1.5 connection points with other networks or systems;

5.7.3.1.6 the symbols and nominal voltages of network elements;

5.7.3.1.7 connection point with the transmission system;

5.7.3.2 data of the most important parameters of the modelled network elements

(e. g. active and reactive resistances);

5.7.3.3 power and operational limits of the production units;

5.7.3.4 nominal currents and working voltages of existing and planned equipment;

5.7.3.5 active and reactive load of the installation;

5.7.3.6 voltage control equipment data (including step-changers).

5.7.4 The purpose of short-circuit current calculations is:

5.7.4.1 to most precisely determine the application settings of relay protection;

5.7.4.2 to guarantee the withstand of network equipment to short-circuits;

5.7.4.3 to provide the starting information for planning earth-connection.

5.7.5 The following data has to be presented for the calculations of short-circuit currents:

5.7.5.1 all data necessary for the calculation of steady-state operation of the

power system;

5.7.5.2 zero sequence impedances of all network equipment units (in case of ground short-circuits);

5.7.5.3 subtransient and transient reactances of the production equipment and loads;

5.7.5.4 earth connection data of transformers, production units and other equipment (e. g. type of earth connection and earth impedances);

5.7.5.5 the settings of relay protection of the electrical installation (voltages, currents).

5.7.6 The aggregated and detailed model of the electrical installation should be able to present the impact of the electrical installation’s power distribution, voltage profiles, considering the following aspects and functionalities:

5.7.6.1 the impact of different voltage control operations on the behaviour of the production equipment;

5.7.6.2 the relation of active and reactive power efficiency of the electrical installation to the network mains supply voltage (compliance with PQ-diagram of the production units);

5.7.6.3 the existence of specific discharge of voltage control and regulation and

their functionality.

5.7.7 The presented model should enable to adjust at least these main control settings that can be changed or activated through local user interface or distant control system (e.g. SCADA).

5.8 Electromechanical processes of the power system

5.8.1 The analysis of electromechanical processes of the power system, generally its dynamic stability helps to detect operational deviations of the power system and its components in case of different disturbances. One of the most common purposes is to find out the times of effect and switching times of the critical protection equipment during the disturbance before the production unit (and the surrounding component of the power system) becomes unstable. The analysis of dynamic stability helps to precisely tune the control system of the electrical installation. The possible problems that need solutions discovered during the analysis:

5.8.1.1 insufficient time to eliminate the disturbance;

5.8.1.2 the capability of the electrical installation to cope with network disturbances, e.g. voltage dips;

5.8.1.3 the capability of the electrical installation to cope with network disturbances, e.g. disconnections of other electrical installations and the redistribution of power flow in the system;

5.8.1.4 unwanted and insufficiently supressed power flow fluctuations and oscillations caused by the settings of the control system;

5.8.1.5 excessive frequency fluctuations;

5.8.1.6 insufficient voltage recovery after the transient process.

5.8.2 The following data is necessary for the analysis of dynamic stability:

5.8.2.1 data describing the steady-state operation and short-circuit power;

5.8.2.2 subtransient reactance, time constants and other values of production units and loads;

5.8.2.3 mechanical constants of the generators and loads and the values describing their physical characteristics;

5.8.2.4 block diagrams describing the active and reactive power control algorithms of the production units;

5.8.2.5 a complex model of the electrical installation describing the production unit and its control system compatible with modelling software of the TSO;

5.8.2.6 control system and parameters of the main drive (turbine in case of heating plants);

5.8.2.7 characteristics and settings of the relay protection models (voltage, current, frequency).

5.8.3 In case the electrical installation uses several production units, in addition to the complete model an aggregated model has to be presented, which should be able to describe the dynamic behaviour of the whole electrical installation and include the control system of the installation. The presented models should be able to perform the analysis of electromechanical processes of the power system. The modes have to be capable of reflecting the behaviour of the equipment in the electrical installation in case of different level disturbances.

5.8.4 The presented models have to cover all essential control systems and their components and to describe different regimes of the electrical installations which influence or are influenced by the following electromechanical processes:

5.8.4.1 all voltage and reactive power control regimes (including power system stabilizer);

5.8.4.2 all frequency and active power control regimes;

5.8.4.3 relay protection, control systems and other equipment directly connected, influenced or installed in compliance with technical requirements.

5.8.5 The dynamics models presented for the investigation of electromechanical processes should be capable of describing processes connected with basic frequency and also the working conditions at which the rotor oscillating frequency is 0,1…3,0 Hz.

5.8.6 The duration of analysed transient processes are determined by the equipment/components/controllers of the electrical installation depending of the time and time constants or their operation. According to the given scope the models presented for the dynamic stability analysis must be capable of covering the following transient operation intervals after the disturbance:

5.8.6.1 the first 30 seconds (short-term) and;

5.8.6.2 900 seconds (long-term).

5.8. The models of electrical installation’s synchronous equipment to be connected to the network consist of at least generators, governor and excitation system. In addition, other control systems required for describing the behaviour of the equipment during the electromechanical processes and transient operation are included. The model should consider the following:

5.8.7.1 the used generator model has to consider the impact of saturation, i.e. the generator model that considers saturation characteristics has to be used;

5.8.7.2 the excitation system has to include terminal voltage transducer, load compensator, excitation control elements, exciter, power system stabilizer (PSS), V/Hz limiter under- and over-excitation limiter;

5.8.7.3 turbine/prime mover model should be capable to describe its behaviour during frequency and load changes;

5.8.7.4 hydro turbine models have to consider inelastic water column in the pressure pipe without the impact of the reservoir;

5.8.7.5 the modelling of steam turbines and its control presumes constant vapour pressure in the inlet. It is not required to model the boiler and its control system in case it is not included in the model of the turbine and its speed controller.

5.8.8 In the case of production equipment consisting of wind turbine(s), the models describing its dynamic behaviour have to be presented. The model for wind turbine(s) connected through converter has to include the converter and its control systems that describe its behaviour in regular and emergency system operation, including different functions of active power, reactive power and voltage control. In case of DFIG solutions in addition to converter and the control systems, the model has to include the generator model to be used.

5.8.9 For all other production equipment connected through converter (solar panels, fuel cells, etc.) have to follow similar principles that has been described under the section for wind turbines connected through converter.

5.8.10 For the auxiliary loads of the electrical installation a description and types have to be presented, modelled using relevant models.

5.8.11 The presented model should enable to adjust at least these main control settings that can be changed or activated through local user interface or distant control system (e.g. SCADA).

5.9 Electromagnetic processes of the power system

5.9.1 Electromagnetic transient processes are processes that last from microsecond (overvoltage) to second (subsynchronous resonance, relay protection). Relevant models have to be used for modelling and evaluating these processes and their specific features and principles have to be used for the compilation of these models. The TSO uses network software PSCAD for modelling these type of processes.

5.9.2 The most important investigation objects are connected with the interaction of resonances and control functions caused by power quality, isolation coordination and harmonics and issues connected with relay protection and automatics. In addition, the models are used for studying all possible interactions that can arise between the electrical installation to be connected and other installations connected to the network, i.e. interactions of FACTS equipment and direct current connections, production equipment connected through inverter (wind and/or solar power station), etc.

5.9.3 The models composed using PSCAD software have to reflect the characteristics of the electrical installation according to the planned usage area. All elements of the installation, their control and protection systems have to be modelled in the model (e. g. frequency control, active and reactive power control, voltage control, etc.) and it should be possible to directly change the controllable values (e g. front page or a special module should present all controllable values).

5.9.4 In PSCAD model composition it is preferable to use the module based approach, where every control function and installation component is modelled in a separate module. This provides a better overview of the model and it can be more easily connected with the TSO’s own model. The front page of the model should be the module of the installation and it should include all necessary parts and elements.

5.9.5 In the composition of the model, the software version agreed with the TSO in the connecting contract has to be used. The TSO has to be consulted before starting to compose the initial model.

5.10 Modelling and analysis of torsional oscillations

5.10.1 The necessity for modelling the interaction between the electrical installation and direct current connections or series compensation might occur during the analysis of the power system operation. Modelling and analysis of torsional oscillations is a part of that analysis. In order to perform the analysis, the stations equipped with synchronous equipment over 10 MW have to present following data to the TSO:

5.10.1.1 number of different masses in the model (in the shaft);

5.10.1.2 inertia H of every mass [kgm2];

5.10.1.3 intermass stiffnesses K [Nm/rad];

5.10.1.4 logarithmic attenuations D of different mechanical modes;

5.10.1.5 number of generator poles;

5.10.1.6 relative power S of different turbine parts [p.u.];

5.10.1.7 mechanical oscillation frequencies between different masses calculated by

the producer.

5.10.1.8 The abovementioned data has to be present on paper after the calculations provided by the producer.

5.11 Presenting the models

5.11.1 The models have to be presented in electronic format and have to consist of proper clarifying model documentation. Models presented on paper format are not accepted.

5.11.2 The presented model should enable to perform studies on steady-state operation, electromechanical and also electromagnetic effects, depending on the size of the electrical installation. The models presented in this phase of connection application are considered as simplified models and the electrical installation can be modelled proceeding from the principle of aggregation, using the models of any other similar installation or technology.

5.11.3 If the electrical installation uses reactive power compensation equipment or includes large motors, also these have to be modelled.

5.11.4 If the new customer has submitted an application to increase or change the application (e. g. one additional wind turbine is added or one existing wind turbine is replaced, except in cases the type of added wind turbine and the model is exactly identical with the replaced one and a relevant model has been submitted earlier), the total model of the existing installation has to be submitted or the previously submitted model has to be upgraded.

5.11.5 The models of electrical installation required in section 5.5 have to be submitted together with the electrical project. At this stage the specific solutions and the initial parameters of the control systems have appeared and it is assumed that the precise model to describe the connected object as exactly as possible can already be submitted. In addition to the data submitted with connection application the synchronous generator model has to include all components of the excitation system (limiters, etc.) and also the submodels of all control systems and the submodels of relay protection functions (voltage and frequency protection) essential from the system’s standpoint. In case of equipment connected through converters, the model has to include all control system supplements and the models of relay protection functions (voltage and frequency protection) essential from the system’s standpoint. The models have to enclose all control functions used in the installation, e. g. P control, Q control, U control, etc. These functions should also enable modelling and analysis of values connected with power quality (harmonics, flicker) and their impact on the power system. The models have to be submitted in electronic format together with all documentation.

5.11.6 The third stage of the activities connected modelling electrical installations is the verification of models. During this stage, the results received through the submitted models are compared with the test results of the electrical installation with the purpose of imitating the test conditions, tests and the results with network calculation software and to evaluate and compare the results with the results received in real conditions. If necessary, the upgrading of models will be performed. Also, the similarity of the model results of different network calculation software have to be compared.

5.12 Verification of models

5.12.1 The aim of model verification is to ensure the compatibility of models to the real electrical installation. The verification is based on the successfully performed tests of the electrical installation, as their results are used directly to evaluate the suitability and compatibility of the model. Model verification is generally performed by the model designer and the compatibility of all designed models have to be evaluated.

5.12.2 The scope of verification has to be agreed, but it generally consists of checking all control functions and comparing with real test results (active power primary and secondary control, Q/U control, voltage dip transit, in special cases technology-based control functions can be added) and it can differ depending on the type of the station and its control principles. Depending on the principles of performed voltage dip transit test it might not be possible to verify all models and in that case the results received using another network calculation software can be used as the starting point.

5.12.3 The scope of verification will be proposed by the customer, having acquainted with the test results report and using the report to show specific test results will be verified. Verification is usually started after the TSO’s relevant approval.

5.12.4 Generally the model verification encloses voltage reactive power control, active power control (primary and secondary regulation), voltage dip transit test and other comparisons depending on the installations.

5.12.5 A separate verification report will be presented for the model verification which shows the scope of verification and explains the background and reasons for the changes made into the model. The verification report has to include the comparison of results of the model and the tests and also between the PSS/E and PSCAD models (aggregated and detailed model).

5.13 Requirements for model documentation

5.13.1 A correct model documentation has to be submitted together with the models, including an overview of the electrical installation, description of important nodes, model design principles, used models (standard, specific solutions, etc.), an overview of control functions and other necessary information for using the model.

5.13.2 The documentation has to reflect all control functions of the installation and explain their impact on the model behaviour and how the control function parameters can be changed during the modelling.

5.13.3 The documentation has to also separately provide the descriptions and parameters of all model components applicable in the case of particular electrical installation. The results of most characteristic calculations and functionalities of control functions form a part of model documentation which is usually presented in the end of the report. If different standard models / solutions (blocks) are used in different models, the conversion principles between different solutions have to be presented.

5.14 Management of models

5.14.1 Management of models have to follow the principle that different model components have to be modelled using standard models of the network calculation software databases. That improves the probability that the model of the connected electrical installation can be used also in updated version of the calculation software.

5.14.2 If the principle of using only standard models is not followed, the issue of model support in the future has to be explained to the TSO. It has to be guaranteed that updating the model after the next software update has to be paid by the customer and hereinafter the updates can be ordered directly from the model designer.

5.14.3 It is a common approach in the management of models for the TSO to conclude a contract with the model producer considering both confidentiality and the model support.

5.15 Recommendations for the model design

5.15.1 Designing and submitting correct and reliable models is of essential importance to the TSO in the process of connecting the electrical installation. The prerequisite of designing such models is the existence of correct and suitable data. Also, it is important to realise that designing the models takes time and the scope and content of the models depends substantially on selected technology and the existence and content of the installation’s control functions.

5.15.2 It is advisable to agree on the design and verification of models already in the initial stage of the project development and to include this in the contracts. That rules out the situation when the customer contract lacks this section and additional information has to be submitted to the TSO. The model design framework has to consider total scope of modelling and models, including the obligation to verify the models after performing the network tests.

5.15.3 For making the discussion related to models faster and more transparent, it is recommended to agree on a relevant meeting with TSO, model designer and the customer’s representatives.

5.15.4 A correct and compatible model of the electrical installation requires the existence of correct data and a competent designers. Therefore, it is required that the models should be designed by persons having previous experience in designing models for electrical installations and who have licenced software necessary for performing such work. The relevant licences have to be presented to TSO on their request.

5.16 The scope of models depending on the connection

5.16.1 The following principles have to be followed when designing models for electrical installations:

5.16.1.1 Production equipment to be connected with the network have to submit electrical installation models in both PSS/E and PSCAD software programs (for power-generating facility with nominal active power starting from 10 MW).

5.16.1.2 Large demand facility connecting to the network (with a single connected device using 10 MW or more, with the exception of DSOs), whose equipment has major impact on the network have to submit electrical installation models in both PSS/E and PSCAD software programs.

5.16.1.3 In case of power-generating facility connecting into distribution networks it is important to consider nominal active power. The following should be considered:

5.16.1.3.1 the models in both PSS/E and PSCAD software programs have to be submitted for production equipment with nominal power exceeding 10 MW;

5.16.1.3.2 only the PSS/E model has to be submitted for production equipment with the nominal power between 5 MW and 10 MW;

5.16.1.3.3 no models have to be submitted for production equipment with nominal power up to 5 MW, only the main data and parameters of the production equipment (power, voltage, cos φ, power source, technology, etc.) and the factory tests have to be submitted.

5.17 In designing the models the principles described in the connection conditions have to be followed.