NETWORK CODE ON DEMAND CONNECTION (DCC) – SIMULATION MODEL REQUIREMENTS

ENERGINET

Energinet
Tonne Kjærsvej 65
DK-7000 Fredericia

+45 70 10 22 44
info@energinet.dk
CVR no. 28 98 06 71

Date:
22 August 2019

Author:
LAN/CFJ

Please note that this is a translation of the original Danish text.
In case of inconsistencies, the Danish version applies.

A	Public version	03-09-2018	03-09-2018	03-09-2018	03-09-2018
		LAN CFJ	FBN	HAB MPO CSH	SBN PHT
REV.	DESCRIPTION	PREPARED BY	CHECKED	REVIEWED	APPROVED

Revision view

NO.	TEXT	VERSION	DATE
1	Changes made following the Danish Utility Regulator's public consultation – categories specified.		18.01.2019

This memo comprises Energinet Elsystemansvar A/S' simulation model requirements for transmission-connected demand facilities and distribution systems. The memo is included as a background memorandum in connection with the implementation of Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection (DCC) [1], and consequently describes requirements for transmission-connected demand facilities and distribution systems, cf. the definition of these.

This memo describes:

- Functional requirements for the stipulated simulation models.
- Requirements for structural design and implementation of the stipulated simulation models.
- Documentation requirements for the stipulated simulation models.
- Accuracy requirements for the stipulated simulation models.
- Verification requirements for the stipulated simulation models.

CONTENTS

FIGURES

TABLES

1. Background

Due to the ongoing transition of the electricity system, with conventional generation facilities gradually being phased out, and the addition of more complex generation and demand facilities, Energinet Elsystemansvar A/S requires greater insight into these facilities' structural design and their systemic impact on the public electricity supply grid.

For analytical purposes related to planning and operation of the public electricity supply grid, Energinet Elsystemansvar A/S must be able to carry out grid and system analyses, e.g. when connecting new demand and generation facilities to the grid or when assessing interactions in the interface between transmission and distribution systems. This requires up-to-date and accurate simulation models of these facilities.

Naturally, the above-mentioned transition of the electricity system, with increased focus on electrification throughout the energy system, must be expected to result in future operation of the transmission system closer to the static and dynamic transfer limits. This places greater demands on modelling and analysis of the overall electricity system when setting these limits, including assessment of stability of the public electricity supply grid, etc.

Modelling of connected demand is a crucial factor in the simulation of electrical systems, where insufficient modelling of voltage and frequency dependencies of a given load model may cause an overestimation of stability limits for a power system, thus introducing a risk of voltage instability, etc. Similarly, an underestimation of stability limits may lead to a risk of non-optimum utilisation of the power system.

Against this background, Energinet Elsystemansvar A/S has defined requirements for simulation models for transmission-connected demand facilities and distribution systems.

Simulation models are used to analyse the transmission and distribution systems' static and dynamic states, including voltage, frequency and rotor angle stability, short-circuit ratio, exchange of reactive power in the interface between the two systems and harmonic conditions.

2. General simulation model requirements

The facility owner must submit simulation models to Energinet Elsystemansvar A/S [1]. These simulation models must properly reflect the transmission-connected demand facility or distribution system's steady-state properties. The facility owner must also submit a dynamic simulation model (RMS model) to Energinet Elsystemansvar A/S for time domain analyses. The facility owner must also submit a harmonic simulation model for analysis of the harmonic state of the public electricity supply grid, including the demand facility or distribution system's contribution to harmonic emissions in the point of connection (POC).

Please see Table 1 for information on requirements for simulation models and delivery scope for the respective types of transmission-connected demand facilities and distribution systems. The facility owner must ensure that models are delivered on time under current procedures for grid connection of transmission-connected demand facilities and distribution systems, and other provisions in the regulation.

Demand facility and distribution system types	Model requirements
Transmission-connected distribution system - Category 1	Static simulation model Dynamic simulation model
Transmission-connected demand facility - Category 3	Static simulation model
Transmission-connected demand facility - Category 4	Static simulation model RMS simulation model Dynamic simulation model
Transmission-connected demand facility - Category 5	Static simulation model
Transmission-connected demand facility - Category 6	Static simulation model

Table 1 Simulation model requirements for specific demand facility and distribution system types

The facility owner must ensure that simulation models are verified with the results of the compliance tests defined [1] as well as relevant test and verification standards and must submit the required documentation hereof.

If the transmission-connected demand facility or distribution system comprises external components, e.g. to ensure compliance with grid connection requirements, energy supply to the public electricity supply grid or for the provision of commercial ancillary services (e.g. automatic frequency or voltage control), the simulation model must incorporate the necessary representation of these components, applicable to all required model types.

From the transmission-connected demand facility and distribution system's design phase to the time of issue of the final operational notification (FON), the facility owner must keep Energinet Elsystemansvar A/S informed if preliminary plant and model data are no longer representative of the relevant demand facility or distribution system.

If significant modifications are made to the properties of an existing transmission-connected demand facility or distribution system, the facility owner must submit an updated and documented simulation model of the modified system, in accordance with the following stipulations:

- For transmission-connected distribution systems - Category 1, permanent modifications to a given transmission-connected distribution system, e.g. restructuring, cable laying completed, disconnect (limit setting) changes, or *significant modifications* to connected demand or generation, require updates to relevant project parameters with an agreed update frequency. Significant modifications comprise grid and system modifications with decisive impact on coordinated planning and operation of the public electricity supply grid.

- For transmission-connected demand facilities - Categories 3-6, the necessary model update is only required to comprise replaced facility components or control, regulation or facility protection systems, as it is assumed that Energinet Elsystemansvar A/S is already in possession of a valid simulation model for the relevant transmission-connected demand facility. If the transmission system operator has not received such a model, a significant modification to a transmission-connected demand facility requires the submission of a complete and fully documented simulation model in compliance with present model requirement specifications.

Model delivery is deemed complete only when Energinet Elsystemansvar A/S has approved the simulation models and required documentation submitted by the facility owner.

2.1 General documentation requirements

2.1.1 Transmission-connected distribution systems – Category 1

When modelling transmission-connected distribution systems, Energinet Elsystemansvar A/S uses a generic grid equivalent to represent the distribution system in the interface between distribution and transmission systems. The requirement for simulation models for transmission-connected distribution systems primarily includes delivery/update of relevant grid data in accordance with the basic structure of the grid equivalent used.

For transmission-connected distribution systems operated as meshed grid areas, cf. the definition in section 3.1.1, model data must be submitted in the CGMES data format, version 2.4.15 or higher (IEC61970-600). If agreed with Energinet Elsystemansvar A/S, an alternative data format may be used that can be loaded directly into the DigSILENT PowerFactory simulation tool without loss of data.

For transmission-connected distribution systems operated as defined grid areas, cf. the definition in section 3.1.1, model data may be delivered in a specified spreadsheet format. If agreed with Energinet Elsystemansvar A/S, an alternative data format may be used that can be loaded directly into the DigSILENT PowerFactory simulation tool without loss of data.

Model-specific documentation requirements are described in the following sections.

2.1.2 Transmission-connected demand facilities – Categories 3-6

In order to ensure correct model application, the required simulation models must be documented in user guides with descriptions of the simulation models' structural configurations as well as descriptions of simulation model parameterization and valid boundary conditions in the form of operating points and any grid condition restrictions (short-circuit and R/X ratios) in the point of connection and fault location in connection with the simulation of external events in the public electricity supply grid. The user guide must also contain information about specific model-technical conditions, e.g. the maximum sample length for the equation solver used when carrying out dynamic simulations etc.

The user guide must also include descriptions of the control, protection and regulation functions implemented in the simulation model to be used when evaluating the demand facility's characteristics in the point of connection, where the following conditions should be in focus:

- Single-line representation of the simulation model's electrical main components up until the point of connection.
- Description of the simulation model's electrical input and output signals (electrical terminals), including relevant conditions in relation to measuring points used, their measuring units and base values.
- A comprehensive parameter list, where all parameter values must be stated in the enclosed data sheets for main components, block diagrams and transfer functions, etc.
- Description of structure and activation levels of protective functions used.
- Description of set-up and initialisation of the simulation model as well as any limitations to the application hereof.
- Description of how the simulation model can be integrated into a large grid and system model of the public electricity supply grid as used by Energinet Elsystemansvar A/S.
- Unique version control of simulation model and related documentation.

Model-specific documentation requirements are described in the following sections.

3. Model-technical requirements

3.1 Transmission-connected distribution systems – Category 1

3.1.1 Requirements for static simulation model (static conditions)

When modelling transmission-connected distribution systems, Energinet Elsystemansvar A/S uses a generic grid equivalent to represent the distribution system in the interface with the transmission system, i.e. demand and generation as well as reactive components at an aggregated level, connected at 60-10 kV for a given 150-132 kV substation and/or at 60-10 kV for a given 60-10 kV substation connected to the relevant distribution system, where this level of detail is required.

Energinet Elsystemansvar A/S regularly updates the grid and system model, implementing relevant model adjustments and aggregation of demand and generation facilities etc., at substation level based on updated data for the model elements described.

Despite differences in regional structures and modes of operation of transmission-connected distribution systems, this grid equivalent is used to represent the two basic grid topology types for distribution systems:

- Distribution systems operated as *meshed 60-10 kV grid areas*, i.e. with multiple sources of supply from several 150-132/60-30 kV substations, where the distribution system operates in parallel with the transmission system.
- Distribution systems operated as *defined 60-10 kV grid areas*, i.e. supplied by one 150-132/60-10 kV substation where parallel operation between the distribution and transmission systems does not occur during normal coupling state.

The grid equivalent's basic structure at 60-10 kV appears from Appendix 1 - Grid equivalent for meshed 60-10 kV grid areas and Appendix 2 - Grid equivalent for defined 60-10 kV grid areas and consists of the following model elements:

- Maximum connected consumption (aggregated level):
  - Conventional demand – active power [MW].
  - Centralised heat pumps[1] – active power [MW].
  - Central electric boilers[1] – active power [MW].
- Installed generation capacity (aggregated level):
  - Old wind turbines (commissioned before 2004) – active power [MW].
  - New wind turbines (commissioned after 2004) – active power [MW].
  - Local CHP facilities (aggregation of small facilities) – active power [MW].
  - Local CHP facilities (individual facilities ≥ 10 MW) – active power [MW].
  - PV power facilities (aggregation of small facilities) – active power [MW]
  - PV power facilities (individual facilities ≥ 10 MW) – active power [MW].
- Equivalent[2] for autogeneration of reactive power, originating from completed cable laying in the distribution system – reactive power [Mvar].
- Rated power and rated voltage for installed reactive components (reactors and capacitor banks) – reactive power [Mvar].

[1] This electricity demand comprises only large central units connected at the 60-10 kV level. Small units are assumed to be included in the aggregated conventional electricity demand.

[2] This equivalent is calculated using information about the total amount of cables connected at the 60-10 kV level.

- The following additional information is required for reactive components:
  - Is the component connected to a cable system (YES/NO)?
  - Is the component switchable (YES/NO)?
  - Is the component's output variable (YES/NO) and, if YES, within which interval [Mvar]?
  - Criteria for connection and disconnection, e.g. hysteresis applied for allowable exchange of reactive power in the reference point, or other local criteria?

3.1.1.1 Model requirements for transmission-connected distribution systems operated as meshed grid areas

For transmission-connected distribution systems operated as meshed grid areas, the grid equivalent used contains both the relevant 150-132/60-10 kV substations and a full representation of the 60-30 kV connections and 60-30/10 kV substations with matching model elements, cf. section 3.1.1, which form part of the relevant grid area. This extended level of detail for the model is necessary to ensure a correct representation of voltage and Mvar regulation in the interface between the transmission and distribution systems as well as load distribution between the transmission and distribution systems. This is relevant to the identification of any operational limitations owing to the above parallel operation under normal operating conditions as well as in connection with operational restructuring of the transmission or distribution systems.

For transmission-connected distribution systems operated as meshed grid areas, the following additional data is required for 60-30 kV distribution systems:

- Data for 60-30 kV connections (cables/overhead lines)
  - Unambigious naming using the following syntax:
    - Substation abbreviation[3] (substation A/node A[4] – connection starting point) = XXX
    - Substation abbreviation (substation B/node B – connection endpoint) = YYY
    - Voltage level = ZZ
    - System number = W
    - Example: XXX_ZZ_YYY-W/HEL_60_LYK-2
  - Electrical data for each section[5]:
    - Unambiguous ID[6]: "section 1", "section 2", ...
    - Conductor type (cable, overhead line, conductor material and conductor type/cross section).
    - Resistance [Ohm/km] at 20 °C – synchronous and zero sequence component.
    - Inductance [Ohm/km] – synchronous and zero sequence component.
    - Capacitance [µF/km] – synchronous and zero sequence component.
    - Rated transmission capacity[7] [A] for each section.

[3] Station abbreviations used must be approved by Energinet Elsystemansvar A/S.

[4] The "Substation/node" concept is also used when naming branching points.

[5] The "section" concept is used for 60-30 kV connections with transitions between different conductor types, for example between cables and overhead lines, and different cable types or tower types, where electrical properties may vary for the individual sections.

[6] Thus, section 1's starting point is in substation A/node A, cf. the above syntax.

        - Length [km] of each section.
- Topology map (diagram) with a clear indication of normal switching state, including information on the breaker (limit) for the connected distribution system.
    - 60-30 kV substations connected to a grid area must appear from the topology map:
        - 60-30 kV ring and radial structures must appear from the topology map.
- Information about auxiliary supply conditions for a given 150-132/60-10 kV substation:
    - Is a 60-10 kV substation auxiliary supply required (YES/NO)?
    - Is a 60-10 kV grid auxiliary connection required (YES/NO)?
        - 60-30 kV auxiliary connections must be specified, cf. section 3.1.1.4.1.

3.1.1.2 Model requirements for transmission-connected distribution systems operated as defined grid areas

For transmission-connected distribution systems operated as defined grid areas, the following additional data is required for 60-30 kV distribution systems:

- Topology map (diagram) with a clear indication of normal switching state, including information on the breaker (limit) for the connected distribution system.
    - 60-30 kV substations connected to a grid area must appear from the topology map:
        - 60-30 kV ring and radial structures must appear from the topology map.
- Information about auxiliary supply conditions for a given 150-132/60-10 kV substation:
    - Is a 60-10 kV substation auxiliary supply required (YES/NO)?
    - Is a 60-10 kV grid auxiliary connection required (YES/NO)?
        - 60-30 kV auxiliary connections must be specified, cf. section 3.1.1.4.1.

On request, the facility owner must provide Energinet Elsystemansvar A/S with data for the model elements described in section 3.1.1.

3.1.1.3 Accuracy requirements

No accuracy requirements have been defined. The facility owner shall ensure that required data exchange is based on consolidated data.

3.1.1.4 Other model requirements for transmission-connected distribution systems

3.1.1.4.1 Status of 60-30 kV auxiliary connections

The simulation report must include information about existing 60-30 kV auxiliary connections between any 150-132/60-10 kV substations for which the auxiliary supply is actually based on these auxiliary connections. The purpose is to facilitate the assessment of options for maintaining regional/local security of supply, cf. Energinet's grid dimensioning criteria for grids above

[7] If varying transfer capacities apply to a given 60-30 kV connection, e.g. factoring in of wind allowance for overhead lines, this must be stated in the form of specified spreadsheet format load tables.

100 kV [2], including an assessment of the need to establish a substation auxiliary supply for any given 150-132/60-10 kV substation.

3.1.1.4.2 Relay protection used at 150-132/60-10 kV substations

Data is required for the expected fault disconnection time in case of a correct fault disconnection via primary relay protection systems and, correspondingly, the fault disconnection time for disconnection via auxiliary protection systems for analyses of critical fault[8] disconnection times in the interface between the transmission system and the distribution system, including selectivity studies.

Specifically, the following data is required for relay protection systems used at any given 150-132/60-10 kV substation:

- Maximum protection operating time (time for disconnection of any faulty grid component) [s] via primary relay protection systems.
- Maximum protection operating time (time for disconnection of any faulty grid component) [s] via auxiliary protection systems.

3.1.1.4.3 Load shedding

Data is required for defined load shedding for total demand connected to any 150-132/60-10 kV station for analysis of dynamic events in connection with large frequency variations in the public electricity supply grid, including activation of required load shedding in reference to technical regulation TR 2.1.2, automatic and manual electricity load shedding [3].

Specifically, information is required about the principle behind the defined load shedding, divided into point of connection and voltage level:

- Demand disconnection – power [MW] disconnected in each step activated.
- Activation level – frequency [Hz] setting for each step activated.
- Time delay – time [s] setting for each step activated.

For transmission-connected distribution systems operated as meshed grid areas the above information is submitted for the 60-10 kV substations that form part of load shedding.

3.1.1.4.4 System protection

Data on system protection measures installed must be submitted for dynamics analyses in the public electricity supply grid, for example in connection with regional or local system disturbances that activate system protection schemes or other supplementary facility protection in the transmission-connected distribution system for e.g. disconnection or downward regulation of local production.

8 This only comprises faults in busbars only or faults in grid components (transformers, cables and overhead lines etc.) connected to a 150-132/60-10 kV substation.

Specifically, information about the principle applied for system protection installed is required, divided into point of connection and voltage level:

- Production capacity – power [MW] covered by system protection.
- Activation criteria for the system protection installed – for example, relay and circuit breaker logic or SCADA initiation.
- Activation level [9] – e.g. overcurrent [A].
- Time delay – time [s] for activation of system protection.
- Ramp rate – power gradient [MW/s], at which generation changes.

The above information is stated for 60-10 kV stations with system protection in transmission-connected distribution systems operated as meshed grid areas

3.1.2 Requirements for dynamic simulation model (RMS model)

Not required.

3.1.3 Requirements for harmonic simulation model

Harmonic simulation models are only required for transmission-connected distribution systems in which identified distribution-connected facilities with significant impact on the transmission grid are connected, see the grid connection process for facilities at DSO level. It is mandatory for grid operators to provide harmonic simulation models for these significant distribution-connected facilities.

The simulation model must represent the distribution-connected facility's emission of harmonics and passive harmonic response (harmonic impedance) in the 50-2500 Hz frequency range at the facility's point of connection in the distribution system. The model must include all relevant positive, negative and zero-sequence impedance within the specified frequency range at a resolution of 1 Hz.

If a fully detailed simulation model is submitted, a method must be specified for summing up emissions from harmonic sources present in the demand facility. This can be done either by specifying requirements for setting the angle of the Thévenin voltage for each harmonic frequency specifically for each harmonic source, or by using a summation law such as IEC 61000-3-6: Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems [4].

If a summation law is applied, α coefficients must be specified by the facility owner. Explanations must be given for the selected α- coefficient values for all harmonics. In both cases, it must be substantiated that the method applied results in a correct representation of the transmission-connected demand facility's total emissions.

If the distribution-connected facility's emissions or impedances are dependent on the facility's operating point, the model must be submitted for three power levels at nominal voltage and zero reactive power: P = 0.0, P = 0.5 p.u. and P = 1.0 p.u. In addition, a description of the reactive effect's impact on harmonic emissions and impedances must be included. The facility

[9] If step-by-step activation and downward regulation is used, this must be stated and described.

owner shall document any dependencies on the operating point and ensure correct implementation in the model.

The grid operator must also provide data for grid components and other components that form part of the distribution system infrastructure between the distribution-connected facility and the point of connection between Energinet Elsystemansvar A/S and the grid operator. Data must be of an extent and level of detail that makes it possible to create a complete frequency-dependent simulation model in the 50-2500 Hz frequency range. The scope of delivery will be agreed between Energinet Elsystemansvar A/S and the grid operator.

3.1.3.1 Accuracy requirements

The method used for computation of the simulation model for the transmission-connected distribution system must be specified and approved by Energinet Elsystemansvar A/S. If model parameters are set based on measurements, a measurement report must be enclosed as documentation. In addition, an account must be given of how model parameters are set using the results in the measurement report. If model parameters are set based on calculations or simulations, the method used must be specified and supported by examples of the deduction of model parameters.

3.1.4 Requirements for transient simulation model (EMT model)

Not required.

3.1.5 Special conditions for distribution systems with multiple facility owners or operating in multiple licence areas

In cases of transmission-connected distribution systems that have multiple facility owners or operate in multiple license areas and are connected to a given 150-132/60-10 kV substation, the owner of the point of connection[10] shall submit any model data required to Energinet Elsystemansvar A/S.

3.2 Transmission-connected demand facilities – Categories 3-5

3.2.1 Requirements for static simulation model (static conditions)

The simulation model must include information about the power consumption mix broken down by main categories (e.g. UPS-connected consumption, engine load and inverter-connected consumption). An important main category accounts for more than 20% of nominal active power consumption.

The simulation model must include information about consumption in the point of connection of the overall demand facility, cf. Table 2Fejl! Henvisningskilde ikke fundet.. Active power (P) must be stated in p.u. based on the demand facility's nominal active power as a function of voltage (U) and frequency (f) in the point of connection. Corresponding values for reactive power (Q) are stated in p.u. of the demand facility's nominal active power.

[10] The point of connection is defined as the 60-10 kV terminals for a 150-132/60-10 kV transformer, cf. defined limits of ownership.

U [p.u.]	P [p.u.]	Q [p.u.]		f [Hz]	P [p.u.]	Q [p.u.]
1.3				51.5		
1.2				51.0		
1.1				50.5		
1.0	1.0			50.0	1.0	
0.9				49.8		
0.7				49.5		
0.6				49.2		
0.5				49.0		
0.4				48.5		
0.3				48.0		
0.2				47.5		

Table 2 Voltage and frequency dependency for connected demand

3.2.2 Requirements for dynamic simulation model (RMS model) - Category 4

The grid and system analyses described in section 1 are performed in the RMS time domain (Root Mean Square), where the simulations mentioned typically involve analyses of system responses in connection with short-circuit faults or voltage and frequency deviations in the public electricity supply grid. The simulation model is intended for analyses of scenarios covering all states of the system of the public electricity supply grid as described in Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL) [5]. This includes normal, alert and emergency state operation as well as restoration after an extensive contingency situation. Simulations typically have a duration of 60 seconds.

The simulation model of the transmission-connected demand facility must represent the facility's static and dynamic properties in the point of connection, applicable to the defined normal operation range [1] and in all relevant static grid conditions under which the demand facility must be operational. The simulation model must be representative of the transmission-connected demand facility's static and dynamic properties in connection with the following external incidents, or combinations of these external incidents, in the public electricity supply grid:

- Short circuit in the point of connection. A short circuit here can either be:
  - A phase-to-earth short circuit with any impedance in the fault point.
  - Phase-to-phase-to-earth or phase-to-phase short circuit with any impedance in the fault point.
  - A three-phase short circuit with any impedance in the fault point.
- Voltage disturbances of a duration of less than the required minimum simulation period, cf. section 3.2.2.3, and as a minimum within the transient sequence for the demand facility's transition to a new static state.
- Frequency disturbances of a duration of less than the required minimum simulation period, cf. section 3.2.2.3, and as a minimum within the transient sequence for the facility's transition to a new static state.

3.2.2.1 Voltage dependency

The simulation model must include the following information about the transmission-connected demand facility's voltage dependency:

a) Voltage dependency in case of a voltage change in the POC from 1.0 p.u. to 0.5 p.u.
b) Voltage dependency in case of a voltage change in the POC from 0.9 p.u. to 1.1 p.u.
c) Voltage dependency in case of an overvoltage sequence in the POC as indicated by the blue graph in Figure 1 - Overvoltage and undervoltage sequences in the POC.Fejl! Henvisningskilde ikke fundet..
d) Voltage dependency in case of an undervoltage sequence in the POC as indicated by the pink graph in Figure 1.

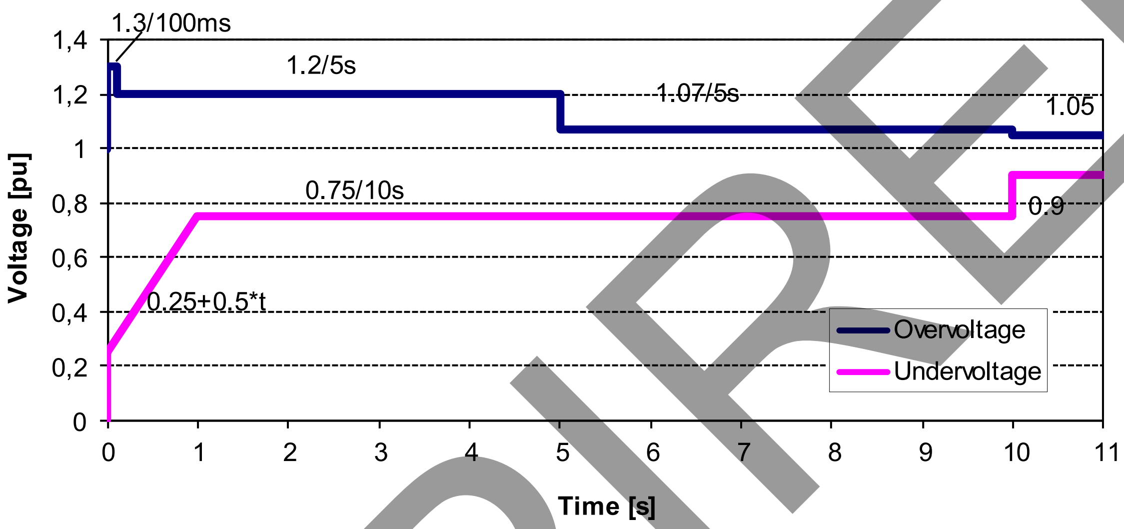


Figure 1 - Overvoltage and undervoltage sequences in the POC.

Simulations must be documented with graphs showing active and reactive power over 60 seconds. Voltage in the POC can be simulated with a controlled voltage source.

3.2.2.2 Frequency dependency

The simulation model must include the following information about the transmission-connected demand facility's frequency dependency:

a) Frequency dependency in case of frequency changes in the POC within the 47.5-51.5 Hz range in steps of 0.5 Hz.

Simulations must be documented with graphs showing active and reactive power over 60 seconds. Frequency in the POC can be simulated with a controlled voltage source.

3.2.2.3 General model requirements

The dynamic simulation model must:

- Represent main demand categories in-house separately if these main categories react significantly different to external incidents.
- Include relevant protective functions, which can be activated, and is able to fully or partially disconnect the transmission-connected demand facility in case of external incidents and faults in the public electricity supply grid.

- Include relevant in-house control functions, e.g. tap changers for the grid connection transformers used for voltage control of the demand facility's internal infrastructure, including relevant blocking criteria (i.e. undervoltage and overvoltage).
- Include reclosing criteria and restoration time following demand disconnection or transition to local supply (e.g. UPS or reserve power supply).
- Allow simulation of root-mean-square (RMS) values in the individual phases during symmetrical incidents and faults in the *public electricity supply grid*.
- Allow simulation of RMS values in the individual phases during symmetrical incidents and faults in the *public electricity supply grid*.
- As a minimum, cover the 47.5-51.5 Hz frequency range and the 0.0-1.4 p.u. voltage range.
- Allow initialisation in a stable operating point based on a single load flow simulation without subsequent iterations. Show a time-derivative value (dx/dt) on initialisation for any of the simulation model state variables of less than 0.0001.
- Allow description of the demand facility's dynamic properties for at least 60 seconds after any of the above external incidents in the public electricity supply grid.
- Be numerically stable through a simulation of minimum 60 seconds without application of a sequence of events or changes to boundary conditions with simulated values for active power, reactive power, voltage and frequency remaining constant throughout the simulation.
- Be numerically stable through an instantaneous voltage vector jump of up to 20 degrees in the point of connection.
- Be capable of utilising numerical equation solvers with variable sample lengths in the 1 to 10 ms range.
- Not contain encrypted or compiled parts (unacceptable), as Energinet Elsystemansvar A/S must be able to quality assure the results of the simulation model and maintain this without the restrictions of software updates, etc.

It is accepted that the simulation model may return a limited number of non-convergence error messages relating to the applied external incident when running a simulation sequence.This will, however, generally be perceived as imperfections related to model implementation, and cause and mitigation proposals must appear from the relevant model documentation. If it can be documented that aspects of the simulation model's non-convergence will adversely impact the application of Energinet Elsystemansvar A/S' overall grid and system model, the simulation model in question will be rejected.

If the transmission-connected demand facility comprises several parallel units, the simulation model must be representable of the demand facility's characteristics at the point of connection, as described above.

The simulation model submitted must be implemented in the most recent version of the DIgSILENT PowerFactory simulation tool, using built-in grid component models and standard programming features, which must be reflected in the model structure used, etc.

The scope and level of detail of data for grid components and other electrical equipment that form part of the demand facility infrastructure must enable the construction of a fully operational simulation model as required in section 2.

If the static simulation model is identical to the dynamic simulation model described, the requirement for a separate static simulation model no longer applies.

3.2.2.4 Accuracy requirements

The simulation model must represent the transmission-connected demand facility's static and dynamic properties in the point of connection. The simulation model must thus respond sufficiently accurately in reflection of the physical demand facility's static response for an actual operating point and similarly for the dynamic response in connection with an external incident in the public electricity supply grid.

The facility owner shall ensure that simulation models have been verified, e.g. using measurements from similar transmission-connected demand facilities or measurements from the main components that make up the greater part of the demand facility.

3.2.3 Requirements for harmonic simulation model

The simulation model for the overall transmission-connected demand facility must represent the facility's emission of harmonics and passive harmonic response (harmonic impedance) in the 50-2500 Hz frequency range in the point of connection, applicable to the defined normal operation range of the demand facility [1] and in all relevant static grid conditions under which the demand facility must be operational.

If the transmission-connected demand facility is composed of individual units, which all contribute to the emission of harmonics, an aggregated simulation model must be submitted which is representative of the demand facility's total emissions as well as the passive harmonic response seen from the point of connection. As an alternative to the aggregated simulation model, a fully detailed simulation model may be submitted, that includes all relevant sources of harmonic emissions and all components that affect harmonic impedance. Both model types must be representative of the transmission-connected demand facility's total emissions of integer harmonics, stated as RMS voltages, as well as the demand facility's passive response in the 50 Hz-2500 Hz frequency range seen from the point of connection. Both model types must include all relevant positive, negative and zero-sequence impedance within the specified frequency range at a frequency resolution of 1 Hz.

If a fully detailed simulation model is submitted, the facility owner shall specify a method for summing up emissions from harmonic sources present in the demand facility. This can be done either by specifying requirements for setting the angle of the Thévenin voltage for each harmonic frequency specifically for each harmonic source, or by using a summation law such as specified in IEC 61000-3-6: Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems [4].

If a summation law is applied, α coefficients must be specified by the facility owner. Explanations must be given for the selected α- coefficient values for all harmonics. In both cases, the facility owner shall substantiate that the method applied results in a correct representation of the transmission-connected demand facility's total harmonic emission.

The scope and level of detail of data about grid components and other components of the plant infrastructure must enable the creation of a complete, frequency-dependent simulation model in the 50 Hz-2500 Hz frequency range. This includes infrastructure cables, transformers, filters etc. The scope of delivery must be approved by Energinet Elsystemansvar A/S.
If the transmission-connected demand facility is expanded over time, a simulation model must be submitted for each expansion stage or a description must be included, detailing the use of an overall model to represent the individual expansion stage. The scope of this must be agreed between the facility owner and Energinet Elsystemansvar A/S.

If the transmission-connected demand facility's emissions or impedances are dependent on the facility's operating point, the model must be submitted for three power levels at nominal voltage and zero reactive power: P = 0.0, P = 0.5 p.u. and P = 1.0 p.u. In addition, a description of the reactive effect's impact on harmonic emissions and impedances must be included. The facility owner shall document any dependencies on the working point and ensure correct implementation in the models.

3.2.3.1 Accuracy requirements

The method used for computation of the simulation model for the transmission-connected demand facility must be specified and approved by the transmission system operator. If model parameters are set based on measurements, a measurement report must be enclosed as documentation. In addition, an account must be given of how model parameters are set using the results in the measurement report. If model parameters are set based on calculations or simulations, the method used must be specified and underpinned by examples of the deduction of model parameters.

3.2.4 Requirements for transient simulation model (EMT model)

Not required.

3.3 Transmission-connected demand facilities – Category 6

3.3.1 Requirements for static simulation model (static conditions)

When modelling transmission-connected demand facilities in category 6, the facility owner must provide load profiles for all points of connection where the demand facility is connected to the transmission system.

If changes are made to operational schedules or overhead line installations are expanded, Energinet Elsystemansvar A/S may require updated load profiles for the relevant transmission-connected demand facilities in the category concerned.

Load profiles submitted must include an indication of the transmission-connected demand facility's absorption of active and reactive power with a one second time resolution. Energinet Elsystemansvar A/S and the facility owner must agree on the periods that the load profiles are to cover. Load profiles for all points of connection must be synchronised to ensure that power consumption concurrency is correctly represented.

For transmission-connected demand facilities in category 6, model data may be submitted in a defined spreadsheet format.

3.3.2 Accuracy requirements

No accuracy requirements have been defined. The facility owner shall ensure that required data exchange is based on consolidated data.

3.3.3 Requirements for dynamic simulation model (RMS model)

Not required.

3.3.4 Requirements for harmonic simulation model

Not required.

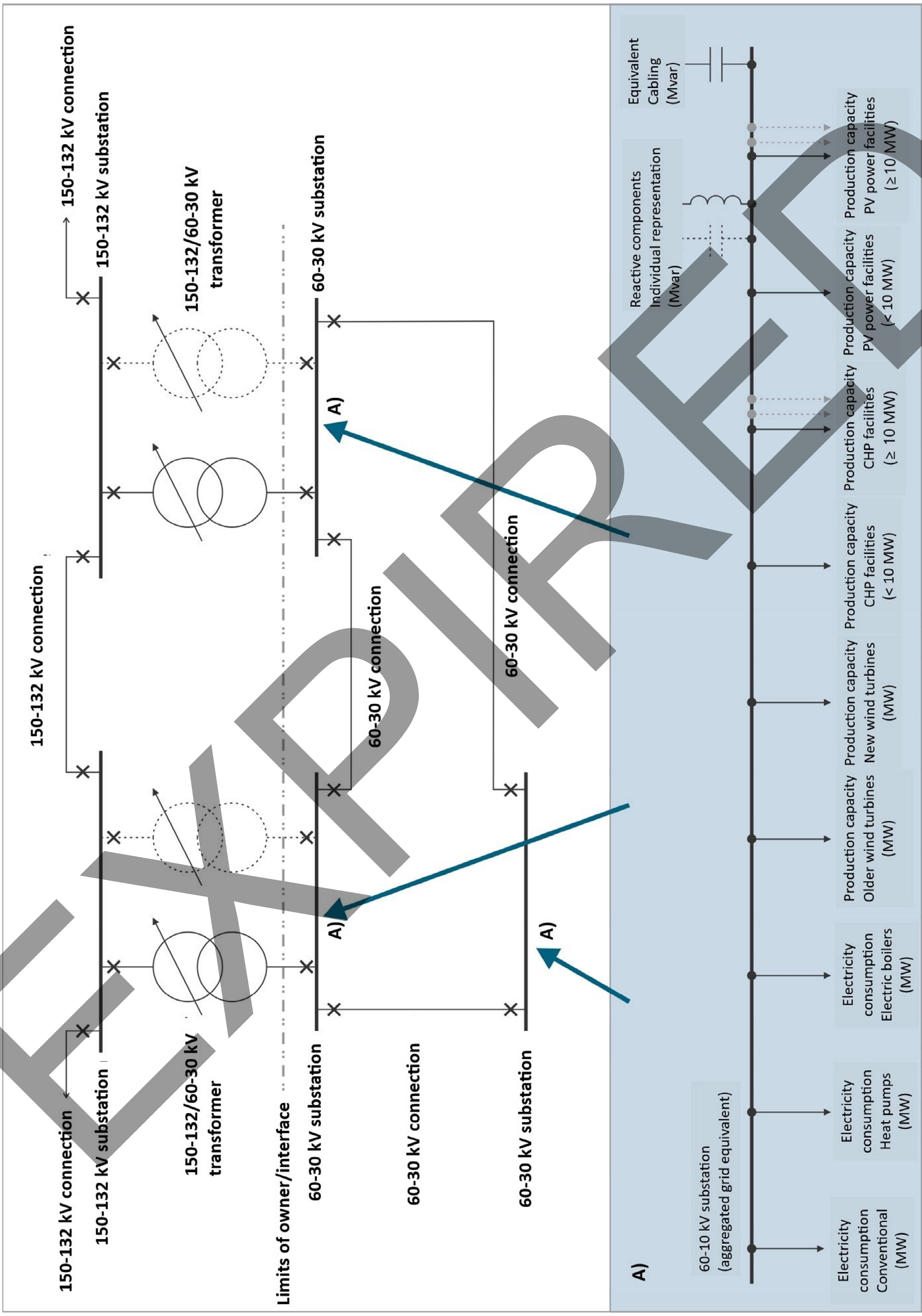
3.3.5 Requirements for transient simulation model (EMT model)

Not required.

4. References

1. Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection (DCC).
2. Grid dimensioning criteria for grids above 100 kV, Energinet, May 2013 (Danish only)
3. Technical regulation TR 2.1.2 Automatic and manual electricity load shedding, Energinet, June 2014 (Danish only).
4. IEC 61000-3-6: Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems.
5. Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL).

Appendix 1 - Grid equivalent for meshed 60-10 kV grid areas



Appendix 2 - Grid equivalent for defined 60-10 kV grid areas