Information Document
Facility Modelling Data and List of Electrical and Physical Parameters for Transmission System Model
ID #2010-001R

Information documents are not authoritative. Information documents are for information purposes only and are intended to provide guidance. In the event of any discrepancy between an information document and any authoritative document[1] in effect, the authoritative document governs.

1 Purpose

This information document relates to the following authoritative documents:

- Section 304.6 of the ISO rules, *Unplanned Transmission Facility Limit Changes* ("Section 304.6"); and
- Section 503.21 of the ISO rules, *Reporting Facility Modelling Data* ("Section 503.21").

The purpose of this information document is to provide the *List of Electrical and Physical Parameters for Transmission System Model* pursuant to subsection 2(1) of Section 503.21 and associated guidance information. Additionally, to provide contact information for the purposes of providing modelling data, records, written submissions or other information to the AESO in accordance with Section 503.21, and of notifying the AESO of an unplanned limit change to a transmission facility in accordance with Section 304.6.

2 The AESO's Modelling of the Interconnected Electric System

The AESO maintains:

(a) a transmission-system object model;

(b) a state-estimator model component to the energy management system; and

(c) a geographic transmission system mapping database.

Together these models constitute a comprehensive model of the interconnected electric system which is essential to the safe planning and operation of the interconnected electric system.

2.1 The List of Electrical and Physical Parameters

Pursuant to subsection 2(1) of Section 503.21, the AESO's List of Electrical and Physical Parameters for *Transmission System Model*, is included in this information document in Appendix 1.

Appendix 1 also includes guidance information that describes the objects in the list and the:

(a) attributes of and associations between those objects;

(b) terminology and nomenclature for referencing modelling objects;

(c) units of measure for expressing those attributes; and

(d) limitations on how objects and attributes are expressed.

The modelling data and records provided in accordance with the *List of Electrical and Physical Parameters for Transmission System Model*, support the AESO's maintenance of a comprehensive data model of the interconnected electric system.

[1] "Authoritative document" is the general name given by the AESO to categories of documents made by the AESO under the authority of the *Electric Utilities Act* and associated regulations, and that contain binding legal requirements for either market participants or the AESO, or both. Authoritative documents include: the ISO rules, the reliability standards, and the ISO tariff.

3 Modelling Data and Records Submission Process

Pursuant to subsection 2(2) of Section 503.21, the AESO expects that records associated with the modelling data include the provenance and effective dates of the data, and any other supporting documents.

A legal owner shall provide modelling data (e.g. power flow model, short circuit model, dynamic model, if applicable) and records as described in the *Project Data Update Package - Instruction Manual* ("PDUP IM"), for new facilities or modifications to existing facilities made pursuant to Section 503.21 and which relate to a connection project under the AESO's connection process or the AESO's market participant choice process. The PDUP IM is available on the AESO website.

In accordance with subsection 2(3) of Section 503.21 the forms to be submitted to the AESO are available on the AESO website. For increasing ratings of the existing equipment, the legal owner should not wait for the full 30-day period for the change to take effect if it can be implemented sooner and agreed upon by the AESO. However, for decreases in existing equipment ratings, the AESO expects the legal owner to adhere to the 30-day requirement.

For Electromagnetic Transients (EMT) model data submission, the legal owner should provide the modelling data and other supporting documents to the AESO using the *EMT Modelling Submission Checklist* published on www.aeso.ca.

4 Contact Information

4.1 Submitting Modelling Data

The AESO requests that the records described in subsections 2 and 3 of Section 503.21 be provided by the legal owner to the AESO at both of the following email addresses: PSMM@aeso.ca and OPTRAProjects@aeso.ca.

The AESO requests the records described in subsection 3 of Section 503.21 be provided by the legal owner to the AESO at the following email address: ops.coordination@aeso.ca.

4.2 Unplanned Transmission Facility Limit Changes

When notifying the AESO pursuant to subsection 2(1) of Section 304.6, the operator of a transmission facility is expected to contact the AESO's System Operations team using the phone number the AESO specifies.

When notifying the AESO pursuant to subsection 2(2) of Section 304.6, the operator of a transmission facility is expected to contact the AESO using the following email address: ops.coordination@aeso.ca.

Appendices

Appendix 1 – List of Electrical and Physical Parameters for Transmission System Model and Guidelines

Appendix 2 – Distributed Energy Resource Modelling Guideline

Appendix 3 – Electromagnetic Transients (EMT) Modelling Requirements

Appendix 4 – EMT Model Verification, Validation and Quality Testing Requirements

Revision History

Posting Date	Description of Changes
2024-04-19	Administrative amendments to align with Energy Storage ISO rule amendments. Clarification for submission of data related to re-rating an existing facility in Section 3.
2024-03-13	Added *EMT Model Package* for applicable generators and HVDC/FACTS equipment in Appendix 1, section 4.5.6, and sections 4.6 to 4.9 respectively. Added *EMT Modelling Requirements* in Appendix 3. Added *EMT Model Verification, Validation and Quality Testing Requirements* in Appendix 4. Revised ride-through requirements under Distributed Energy Resource in Appendix 1, section 4.5.5
2021-07-26	Combined the Guideline on the Electrical and Physical Parameters for Transmission System Model List and the List of Electrical and Physical Parameters for Transmission System Model into Appendix 1. Increased size from 4.5 to 5 MW for generating units, aggregated generating facilities, large motors and battery energy storage facilities to require submission of modelling data in Appendix 1, section 4.5. Added Appendix 2 Distributed Energy Resource Modelling Guideline and amended Appendix 1, section 4.5.5 Distributed Energy Resources. Administrative amendments to align with current AESO drafting principles, correct references, typographical errors and outdated information.
2018-12-20	Amended section 4.2 updated to include update of line data. Amended Appendix 1 section 5.2 to clarify modelling of voltage regulators. Amended Appendix 1 section 5.5 to clarify the applicability of various types of machines. Amended Appendix 1 sections to reflect adoption of FAC-008-AB-3, *Facility Ratings* (“FAC-008”).
2017-03-23	Appendix 1 updated to reflect revised List; Bus ranges added to Table 1 of Appendix 1; Overviews added to Appendix 1 for clarity; Glossary removed from Appendix 1; and Administrative amendments
2016-09-28	Administrative amendments
2016-07-26	Initial release

Appendix 1 – List of Electrical and Physical Parameters for Transmission System Model and Guidelines

This *List of Electrical and Physical Parameters for Transmission System Model* provides the modelling data and records associated with each type of transmission system object. Each section contains the following guidance information regarding each type of transmission system object:

(a) a short definition of the data categories covering that equipment type where necessary;

(b) a check list of the required data indicated by check boxes; and

(c) short paragraphs expanding on, or explaining, the check list items where necessary.

Changes to the nomenclature for some transmission system modelling objects have been made to align with International Electrotechnical Commission standard IEC 61970-301:2020, *Energy management system application program interface (EMS-API) - Part 301: Common information model (CIM) base*[2]. The former nomenclature is identified by an asterisk (*) and is included in parentheses after the standard nomenclature. Object nomenclature used in this guideline is identified in **bold underlined** print.

1 Measurement

1.1 Measurement Point

Overview: A "Measurement Point" is the point where electric power flows into or out from the transmission system into the facilities of the system access contract holder.

Checklist:

- ☐ Unique **MP_ID**

Explanation:

The Measurement Point identifier or **MP_ID** is defined by the Metering Services Provider. The data submitter obtains the **MP_ID** from the Metering Services Provider and forwards it to the AESO. The AESO may assign an interim, temporary **MP_ID** in consultation with the data submitter. In the case of "Behind-the-Fence" loads a unique **MP_ID** beginning with the letters "*BTF_*" will be assigned by the AESO. "Behind-the-Fence" loads are considered loads which are served by self-supply and; therefore, represent power both produced and consumed at the same site without passing through a revenue meter.

1.2 Load

Overview: A "Load" is an element of the electric system that consumes a measured amount of power of electricity consumption (MW).

Checklist:

- ☐ The bus to which load connects
- ☐ North American Industrial Classification System code
- ☐ Load response characteristic
- ☐ Load at energization

[2] International Electrotechnical Commission standard: IEC 61970-301:2020, *Energy management system application program interface (EMS-API) - Part 301: Common information model (CIM) base,* effective June 26, 2020, as amended from time to time, Available on www.iec.ch.

Explanation:

(a) Loads are to be aggregated to the first bus upstream of the physical loads.

(b) "Unmetered Volumes", which are also called "Behind-the-Fence" loads, are to be submitted in the same way as any other load.

(c) Every load is characterized by some industrial type, or group of industries, as identified in the North American Industrial Classification System.

(d) North American Industrial Classification System code is typically one of the codes listed in Table 1 for industry loads.

(e) Specify a separate energyConsumer.name (ELEMENT_CODE) for each different industry to be represented.

(f) If submitting a North American Industrial Classification System code of "99", specify the load response characteristic as a breakdown of constant power, constant impedance, and constant current, in percent for both real and reactive components, to a total of 100%, with a default value of 100% constant power if no other information is available. Submit unmetered volumes in the same way as any other load.

Table 1 North American Industrial Classification System Codes for Typical Industry Load Types

North American Industrial Classification System Code	Industry Type
11	Agriculture
32	Manufacturing – general
33	Heavy Manufacturing
40	Commercial and Services
71	Arts, Entertainment and Recreation
113	Forestry and Logging
211	Oil and Gas Extraction
486	Pipelines
814	Private Households
22131	Farming – Irrigation
99	Unspecified

(g) Specify a separate Element Code for each different industry to be represented.

(h) Load at energization is the estimate of peak load after reaching steady state on day 1 of energization.

2 Transmission Facilities

Overview: A "transmission facility" is a substation or transmission line.

Checklist:

- ☐ **FACILITY_CODE**
- ☐ Geographic location
- ☐ **operatorCompany** **(OWNER*)**

Explanation:

(a) The **FACILITY_CODE** is the unique identifier assigned to each transmission facility by the AESO. The identifier can be up to 20 characters consisting only of capital letters, the digits 0 through 9, periods, and hyphens. The data submitter may request a particular identifier. The preferred **FACILITY_CODE** is a simple, pronounceable, unambiguous word; or a short number optionally combined with one or more letters, for example:

- ROSSDALE
- D05
- 14.83L

(b) The AESO will issue one or more new **FACILITY_CODE**, as appropriate, when transmission facility is segmented or merged. The data submitter may consult with the AESO regarding any new **FACILITY_CODE**.

(c) Geographic location describes the detailed location of the transmission facility. A data submitter may submit geographic location data either as a shape file or as a 1:10,000 scale map showing the line route or substation polygon. The geographic location includes a GPS location for any substation; and GPS locations may be submitted for every structure of a transmission line, or for the line termination and for points where the line route significantly changes direction.

(d) ***operatorCompany*** is the legal corporate name of the entity that holds title to the transmission facility.

2.1 Substations and Switching Devices

Overview: A substation is a facility designed for transformation or switching operations. A switching device is a device designed to close, or open or both, one or more electric circuits.

Checklist:

- ☐ All component substation single-line diagrams, indicating for each switching device the:
- ☐ Type of equipment
- ☐ Type of control
- ☐ SCADA Communications block diagram in accordance with subsection 5(10) of Section 503.16 of the ISO rules, *SCADA Technical and Operating Requirements*
- ☐ ***substation.description*** (***SUBSTATION_NAME**)
- ☐ **LAND_LOCATION**
- ☐ ***subGeographicRegion*** (***AREA_CODE**)

Explanation:

(a) A single-line diagram shows all **ELEMENT_CODE**s, locations of switching devices with their switch numbers, electrical connectivity of all elements, and ratings of each component of the current path, metering and control current transformers and voltage transformers. Switching devices are identified on a single-line diagram using annotation or symbols for:

(i) equipment, such as circuit breakers, disconnects, circuit switches; and

(ii) controls, such as synchrocheck, synchronizer, motor operated, and supervisory controls.

The data submitter may submit multiple Single Line Diagrams to cover all required information.

(b) **substation.description** is included only where the owner assigns names to its substations. The AESO will, upon request, provide assistance in selecting a **substation.description** (***SUBSTATION_NAME**). **Substation.description** is a pronounceable text string of 50 characters or less, consisting only of the letters, digits 0-9, spaces, and hyphens. Substation names may not include corporate names. Substation names may not include variations on geographical names that are already used for other substations.

(c) **LAND_LOCATION** is the Dominion Land Survey designation at minimum resolution to the quarter-section, and preferably the legal sub-division.

(d) **LAND_LOCATION** is to conform to the following format: LL-SS-TT-RRWP, where:

(i) LL is the legal subdivision or quarter-section

(ii) SS is the section number

(iii) TT is the township

(iv) RR is the range

(v) P is the parallel

2.2 Transmission Lines

Overview: A transmission line termination point is where it connects to a substation bus or where it crosses into the territory of an adjacent owner of a transmission facility. A transmission line may have two or more terminals.

Checklist:

- ☐ Structure list or line survey
- ☐ Transmission line segment summary
- ☐ Structure drawings

Explanation:

(a) A structure list or line survey describe the line construction structure by structure.

(b) A transmission line comprises one or more line segments. The transmission line segment summary consists of a drawing or table showing how the segments connect.

(c) Structure drawings are comprised of dimensioned drawings of every tangent structure type mentioned on the structure list or line survey.

3 topologicalNode (*Buses)

Overview: A ***topologicalNode*** is a node that serves as a common connection for two or more circuits. A ***topologicalNode*** may comprise any number of zero-impedance equipment such as switches, ***connectivityNodes***, and busbars or physical bus segments which are subsumed into the ***topologicalNode***.

Checklist:

- ☐ Unique **topologicalNode.name** (*<u>**BUS_ID**</u>)
- ☐ **nominalVoltage** (*<u>**NOMINAL_VOLTAGE**</u>)
- ☐ **equipmentContainer.name** (*<u>**FACILITY_CODE**</u>)

Explanation:

(a) A new ***topologicalNode.name*** will generally follow the pattern used by existing ***topologicalNode***s in the same area. The ***topologicalNode.name*** is an integer assigned by the AESO consistent with the following:

Table 2 Standard Bus Ranges

BUS-RANGE DESCRIPTION	BUSRANGE BUSRANGE_HIGH	
	From_	To _
General transmission buses	1	999
	1000	1999
	540001	549999
Distribution buses	2000	4999
	15000	19999
	20001	29999
	30000	39999
	40000	49999
	550001	558999
Transformer midpoint buses	5000	8999
	10000	14999
	559001	559999
Temporary buses	9000	9999
Isolated system buses	50000	59999
Collector system buses	60000	69999
	560001	569999
Resource adequacy generation buses	70000	79999
	570001	579999
Unassigned	80000	99999
	580001	599999
Projects at Stage 1 of the connection process	990001	999001

(b) ***nominalVoltage*** on the transmission system is one of 500 kV, 240 kV, 138 kV, or 69 kV. ***nominalVoltage*** may differ somewhat from the actual operating voltage of the transmission system at any location. The owner of an electric distribution system will assign nominal bus voltage on the distribution-voltage bus.

(c) ***equipmentContainer.name*** (*__FACILITY_CODE__) is the exact ASCII text string previously assigned by the AESO for the facility containing the ***topologicalNode***.

4 Equipment (*ELEMENTS)

4.1 General requirements for conductingEquipment (*Elements)

Overview: A ***conductingEquipment*** is a current-carrying device that, by virtue of having inherent impedance, contributes to the admittance matrix of the power-flow model.

Checklist:

- ☐ **Equipment.name (*ELEMENT_CODE)**
- ☐ **equipmentContainer.name (*FACILITY_CODE)**
- ☐ **operatorCompany (*OWNER_NAME)**
- ☐ **normallyInService** (*__NORMALLY_INSERVICE__)
- ☐ Equipment or project in-service date
- ☐ Equipment or project decommissioning date, if known

Explanation:

(a) The ***equipment.name*** is the unique identifier assigned to each piece of conducting equipment. The identifier can be up to 20 characters consisting only of capital letters, the digits 0 through 9, periods and hyphens. The AESO may, upon request, provide assistance in selecting a unique identifier. Preferred identifiers are a simple, pronounceable, unambiguous word; or a short number optionally combined with one or more letters.

(b) ***equipmentContainer.name*** provides clarity in identifying which facility contains the element. The ***equipmentContainer.name*** is the exact ASCII string the AESO previously assigned as the ***FACILITY_CODE*** for the facility containing the equipment.

(c) ***operatorCompany*** is the legal corporate name of the entity that holds title to the element.

(d) ***normallyInService*** is identified as TRUE if the equipment is normally energized and able to carry current; and is identified as FALSE if the equipment is normally on standby or de-energized.

(e) If the equipment is put in service by a maintenance change-out, the data submitter is to submit the date on which the change-out takes effect. If the equipment is put in service by an AESO project, the AESO will associate the equipment with that project number and energization number. Note that one energization may cover a period no longer than 3 months.

(f) If the equipment is decommissioned by a maintenance change-out, the data submitter is to submit the date on which the change-out takes effect. If the equipment is decommissioned by an AESO project, the AESO will associate the equipment with that project number and energization number. Note that one energization may cover a period no longer than 3 months.

4.1.1 Element-to-Measurement Point Mapping

Overview: Each measurement point is cross-referenced to elements that either sink asset or supply asset the metered power. Every **MP_ID** serves one or more elements, either machines or loads.

Checklist:

- ☐ __**MP_ID**__
- ☐ **conductingEquipment.names** (*__ELEMENT_CODE__s)
- ☐ Portion of __**MP_ID**__ delivered to or from each **conductingEquipment**.

Explanation:

(a) **MP_ID** is the unique identifier assigned by the metering services provider

(b) ***conductingEquipment.name*** is the exact ASCII string the data submitter previously assigned for the equipment.

(c) The portions of the **MP_ID** summed over all the ***conductingEquipment*** that serve that **MP_ID** equal to one hundred percent (100%).

4.1.2 Applicable Dynamic Control Systems

Overview: A dynamic control system is an automated system that operates within a 0.01 second to 10.0 second timeframe, to achieve prescribed relationships between selected system variables by comparing functions of these variables to effect control of an identified element. For the purposes of this appendix, the transfer function inherent to a machine itself is considered a "control system".

Checklist:

- ☐ **conductingEquipment.name** (***ELEMENT_CODE**)
- ☐ Control system type
- ☐ Manufacturer
- ☐ Model
- ☐ Control system block diagram

Explanation:

(a) **conductingEquipment.name** is the exact ASCII string the data submitter previously assigned for the equipment.

(b) Control system type is one of those listed in Table 3 below:

Table 3 Standard Control Types

CONTROL_SYS	Applies to
Compensator	Large individual machines
Exciter	Large individual machines
Exciter limiter	Large individual machines
Generator/condenser	Machines
Synchronous/induction motors	Machines
Stabilizer	Large individual machines
Turbine governor	Large individual machines
Remedial action scheme	All element types
Load	Loads
Converter controls	Direct current converter
Other power electronics	All elements

(c) The equipment manufacturer generally provides the data submitter with the control system block diagram.

The AESO may identify the protection data that is to be provided to the AESO on a case-by-case basis through discussions with the legal owner. In general, underfrequency load shedding relays, under voltage load shed relays, synchrocheck relays, and synchronizers are essential to transmission modelling.

4.1.3 Applicable PSS/E or PSLF Software Model Data

Overview: Submit dynamic model data that accurately represents the element's dynamic behaviour and appears on the WECC list of accepted standard Siemens PTI Siemens Power System Simulation for Engineering ("PSS/E") and GE – Positive Sequence Load Flow ("PSLF") software library models[3]. A user-written model may be submitted along with the library model.

Checklist:

- ☐ **conductingEquipment.name** (***ELEMENT_CODE**)
- ☐ Model name
- ☐ Description of model
- ☐ Model block diagram
- ☐ Parameter names
- ☐ Parameter values
- ☐ Source-code or compiled object

Explanation:

(a) The **conductingEquipment.name** is the exact ASCII string that was previously assigned for the equipment.

(b) "Model Name" is the name of a standard library model on the WECC approved models list, to be submitted for every dynamic control system, regardless of whether a user-written model is submitted.

(i) In the case of power electronic control systems that the AESO determines cannot be adequately represented by a standard library model complete with its submitted parameters, an adequate detailed user-written model is to be submitted in addition to the standard library model.

(ii) This user-written model is to be adequate for dynamic study of the transmission system in the 0.01 seconds to 10 seconds timeframe and need not simulate proprietary detail of the flexible alternating current transmission system device. Any detailed user-written model submitted to the AESO may be distributed with the AESO dynamic data files.

(iii) Models are to be submitted for one or both of the PSS/E software and the PSLF software. The Institute of Electrical and Electronics Engineers ("IEEE") models may be submitted in addition to the PSS/E and PSLF models. If models are submitted in only one of PSS/E or PSLF the party responsible for submitting the data is to consult with AESO regarding converting the data to the other format.

(c) A description is to accompany each model, providing a high-level assessment of the model's accuracy and the scenarios under which it is applicable.

(d) A model block diagram is to be submitted for all user-written models, except for standard library models.

(e) Parameter names are to be the same as specified for the model in the relevant software documentation.

(f) All parameter values are to be provided; do not leave any parameter values blank.

(g) The source code is a text listing of programmatic commands that represent a control system model. The compiled object is the machine code produced by a compiling the source code, which

[3] The WECC list of accepted standard PSS/E and PSLF library models is available at www.wecc.org .

can then be called by the power system simulation program to simulate the control system behaviour and is often distributed as a ".dll" file type.

(h) Model source code or compiled object is to be submitted for all user-written models, except for standard library models.

4.2 Transformers

Overview: "Transformer" refers to a voltage transformer, phase-shifting transformer, voltage regulator or grounding transformer. Transformers have significant scope for variation from one transformer to the next. The data is requested in a standard format that can accommodate both common transformers and their variations; and more unusual transformers. Voltage regulators are modelled as the transformer tap changer of the associated power transformer. Test reports are not required for regulators.

Checklist:

- ☐ Transformer nameplate
- ☐ Test report

Explanation:

(a) A ***powerTransformer*** contains multiple windings and optionally tap-changers. A single name-plate describes all the ***conductingEquipment*** that the ***powerTransformer*** contains.

(b) Test data in the test report is defined in C57.12.00, IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers. Test data is to be provided for both positive and zero sequence. If the transformer has a tertiary delta winding, test data is provided for the tertiary delta winding closed and for the tertiary delta open circuited. Transformer impedances are not required for regulators.

4.2.1 Transformer Windings

Overview: Refer to the AESO's *Transformer Modelling Guide* for derivation of the transformer equivalent circuit and windings.

Checklist:

- ☐ **equipment.name** (*__ELEMENT_CODE__)
- ☐ Winding identifier
- ☐ Connection (delta/wye)
- ☐ Neutral grounding status
- ☐ Grounding impedance
- ☐ Ratings
- ☐ Rated voltage
- ☐ Identification of the bus to which winding connects

Explanation:

(a) ***equipment.name*** is the exact ASCII string previously assigned to the ***powerTransformer*** that contains this winding.

(b) Provide the 2 seasonal normal ratings and 4 seasonal emergency ratings, as well as the terminations for each winding identifier consistent with the methodology documented in accordance with FAC-008-AB-3.

(c) Submit the winding connection as either wye or delta for each winding. For other connections, please contact the AESO at PSMM@aeso.ca.

(d) For each winding, neutral grounding status is "TRUE" if the winding is grounded and "FALSE" if the winding is ungrounded. The grounding impedance shall be resistance and reactance values expressed in ohms. Indicate solidly grounded windings by a grounding impedance of zero.

(e) The ratings of the windings may be:

  (i) Identical, for example, in a 2-winding transformer, primary and secondary windings are equally rated;

  (ii) Related, for example, the 2 secondaries of a split-secondary are each half the rating of the primary;

  (iii) Arbitrary, for example, the windings of a 3-winding transformer may all be differently rated.

  Each winding may have one or more ratings, expressed in MVA. Provide all ratings for each winding, including provisional ratings. For each rating, indicate the condition under which the rating is valid. Clearly indicate which ratings are available and which are provisional. If the transformer capacity is limited by separate equipment, then also provide the limiting condition and its rating.

4.2.2 Transformer Tap Changers

Overview: Windings may be associated with tap-changers. For each tap-changer on a winding, provide all of the following information:

Checklist:

- ☐ Tap points
- ☐ Tap-changing strategy (manual, automatic)
- ☐ On-load tap changing (True/False)
- ☐ Control band
- ☐ Actual tap

Explanation:

(a) The voltage rating of each tap, for a voltage controlling tap-changer, the phase shift for each tap, for a phase-shifting transformer, or indicate that no tap-changer exists for this termination; and

(b) the tap-changing strategy used, by choosing on of the strategies provided below in Table 4.

Table 4 Standard Tap-Changing Strategies

TAP_CHANGING_CODE	TAP_CHANGING_DESCR
OFF	Off-load tap changing (having external controls on the transformer tank but requiring de-energization)
OLTC-M	On-load tap changing, manual-local
OLTC-S	On-load tap changing, supervisory (i.e., manual-remote)
OLTC-A	On-load tap changing, automatic (i.e., under-voltage regulation)
FIXED	Fixed taps that have no external control
PHASE-P	Phase shifting, controlling MW
PHASE-Q	Phase shifting, controlling MVAr

(i) Indicate which transformer termination is intended to be controlled by the tap-changing action, usually the “X” bushing of a distribution load transformer. If a remote bus is intended to be controlled, enter the bus number. Provide the voltage range for tap-changer control, in per-unit of the system nominal voltage.

(ii) For a voltage controlling tap-changer, specify the control band as the maximum and minimum allowed voltage at the controlled bus. For a phase-shifting tap changer specify the control band as the power flow into the termination.

(iii) Model the voltage regulator as a tap-changer on the directly connected winding.

4.2.3 Transformer Impedances

Overview: Refer to the AESO’s *Transformer Modelling Guide* for derivation of the transformer equivalent circuit. The equivalent circuit is to include positive and zero sequence resistance and reactance for every series branch in the equivalent circuit. The equivalent circuit is to include conductance and susceptance to ground for every shunt branch in the equivalent circuit.

Checklist:

- ☐ Transformer equivalent circuit
- ☐ Positive and zero-sequence real and reactive impedances
- ☐ Positive and zero-sequence real and reactive shunt admittances
- ☐ Short-circuit impedances and load losses
- ☐ Open-circuit excitation currents and no-load losses
- ☐ Phase angle shift
- ☐ Significant off-neutral impedance of tap-changing transformers

Explanation:

(a) The equivalent circuit impedances are expressed in per-unit based on rated voltage of the transformer and on the MVA rating that was used to establish impedances.

(b) Express short-circuit impedance in % and load loss in kW.

(c) Express open-circuit excitation in % and no-load loss in kW.

(d) If the transformer is a voltage transformer, submit the phase angle shift as a fixed value. If the transformer is a phase-shifting transformer, submit the phase angle limits. If the impedance of a transformer with taps differs by 15% or more from the impedance at the rated tap, then the tested impedance shall be submitted at the maximum and minimum taps in addition to the neutral tap, and at enough of the intervening taps so that the total difference from one submitted impedance to the next is always 25% or less.

(e) The AESO will assign a 2-character circuit identifier for each impedance branch in the equivalent circuit.

4.3 Reactor and Capacitor Shunt Device

Overview: A "Reactor and Capacitor Shunt Device" is a simple switched or fixed shunt device.

Checklist:

- ☐ Bank nameplate
- ☐ Capacitance (Farads)
- ☐ Inductance (Henrys)
- ☐ Rated MVA (Capacitive)
- ☐ Rated MVA (Inductive)
- ☐ Rated voltage
- ☐ Control strategy
- ☐ Control bus
- ☐ Maximum control-band voltage
- ☐ Minimum control-band voltage
- ☐ Connection (delta/wye)
- ☐ Neutral grounding status
- ☐ Grounding impedance

Explanation:

(a) Express the rated MVA at the reactive or capacitor bank rated voltage.

(b) Express the control strategy as one of the strategies provided below in Table 5:

Table 5 Standard Shunt-switching Strategies

Strategy	Explanation of Strategy
Fixed	The shunt cannot be switched
Manual	The shunt can be switched on or off by personnel on site
Supervisory	The shunt can be switched on or off remotely
Automatic	The shunt switches on or off under control of an automated control system

(c) The "Control Bus" is the bus at which the voltage is monitored for the purpose of controlling this shunt device. Refer to the bus by the **BUS_CODE** assigned to the bus by the AESO.

(d) Express maximum and minimum voltages of the control band in per-unit of the system nominal voltages in kV at the control bus.

(e) Express grounding resistance and reactance in ohms, with zero indicating a solidly grounded bank.

4.4 Line Segments

4.4.1 Line Segments Construction

Overview: A "Line Segment" is a portion of a transmission line that has consistent physical attributes of conductor and cross-section throughout the length of the segment.

Checklist:

- ☐ **conductingEquipment.name**
- ☐ Line segment length (km)
- ☐ Conductor type
- ☐ # of conductors per bundle
- ☐ Bundle spacing (m)
- ☐ Average sag (m)
- ☐ Typical tangent structure
- ☐ Typical structure height (m)
- ☐ Positive-sequence real and reactive impedances and susceptances
- ☐ Zero-sequence real and reactive shunt admittance

Explanation:

(a) A tap off a line that enters a substation, irrespective of length, is to be designated as a separate line segment. However, if a line segment is:

(i) less than 500 metres and less than 20% of the line's total length from substation to substation;

(ii) less than 50 metres; or

(iii) less than 5% of the line's total length from substation to substation,

it can be considered part of the adjacent line segment.

(b) Conductor type is defined by name as shown in Table 6. If using a different conductor type, the conductor data sheet is to be submitted.

Table 6 Conductors

CONDUCTOR_NAME
CHICKADEE
COCHIN
COREOPSIS
COSMOS
CROWSNEST
CURLEW
DOVE
DRAKE
HADDOCK
HAWK
HORNBILL
IBIS
LINNET
MERLIN
OSPREY
PARTRIDGE
PELICAN
PENGUIN
PIGEON
RAVEN
SPARROW
TRILLIUM
WAXWING

(c) The tangent structure is designated with a reference to the relevant structure drawings.

(d) The structure height is measured from the ground to the lowest conductor.

(e) Submit line segment impedance in ohms.

(f) Submit line segment susceptance and terminal-shunt admittance in Siemens.

(g) The submission includes the assumed ground resistivity (ohm-m) on which the values are calculated.

4.4.2 Line Segment Ratings

Overview: None

Checklist:

- ☐ Conditions
- ☐ Ratings
- ☐ Limiting factors

Explanation:

(a) The ampere ratings of the line segment for each of summer normal, summer emergency, winter normal and winter emergency conditions consistent with the methodology documented in accordance with FAC-008-AB-3.

(b) The line segment rating as limited by the unconstrained line conductor thermal rating is identified for each condition. If the line segment has a more limiting rating, then identify the most limiting factor that limits the rating of the line segment. The line segment is considered to terminate at the breaker or breakers. Submit the rating corresponding to that limiting factor for each condition. Describe all applicable limiting factors as one of the factors that are provided below in Table 7:

Table 7 Capacity-limiting Conditions

CONDITION_DESCR
Circuit breaker
Current transformer
Line conductor thermal rating
Ground clearance
SLAPAC dampers
Underbuild
Disconnect Switch
Jumpers
Buswork
Protection setting
Connectors

If some other factor limits the capacity of the line segment, then describe the factor in detail in a letter to the AESO.

4.4.3 Line Mutuals

Overview: None

Checklist:

The following is submitted for each line segment branch in the pair of line mutuals:

- ☐ **conductingEquipment.names** of the 2 line segment branches
- ☐ Real and reactive mutual impedances (ohms)
- ☐ Start-of-parallel distance (m)
- ☐ End-of-parallel distance (m)
- ☐ Assumed direction of flow for the mutual calculation

Explanation:

(a) When 2 line segments form any part of a parallel between 2 transmission lines, where:

(i) the length of the cumulative parallel is greater than 20% of the length of either line, from substation to substation; and

(ii) the separation of the parallel is less than 500 m,

the mutual impedances are submitted on a line segment-by-line segment basis.

(b) Direction of flow is indicated by reference to the ***topologicalNode***s at the line ends by declaring which ***topologicalNode*** current is presumed to be flowing from.

(c) Start-of-parallel is the distance from the “from” end of the line segment branch to the point where the mutual coupling begins. If the entire length of the line segment branch parallels the other line segment branch this value will be 0.

(d) End-of-parallel is the distance from the “from” end of the line segment branch, to the point at which the parallel ends. If the entire length of the line segment branch parallels the other line segment branch, this value will be the same as the line segment branch length.

(e) Direction of flow is indicated by reference to the ***topologicalNode***s at the line ends by declaring which ***topologicalNode*** current is presumed to be flowing from.

4.5 Generating Units, Aggregated Facilities, Large Motors, and Energy Storage Resources

Overview: A “Machine” is defined as a rotating generator, motor, or large power electronic converter set for the purposes of facility modelling. In the case of a collector-based generating facility, “collector” such as wind, or mini-hydro; “Machine” means the aggregated equivalent machine representing the power plant.

Table 8 summarizes the pertinent subsections of this section 4.5 for each type of machine.

Table 8 Summary of Relevant Sections for Generation or Machine Types

Relevant Section	Machine Type	Interconnected Electric System Connection	Applicable maximum authorized real power size (MW)
4.5.1	Generating unit	Directly connected to the transmission system or an industrial complex	Greater than or equal to 5 MW for individual unit
4.5.2	Aggregated facility		Greater than or equal to 5 MW for each aggregated facility
4.5.3	Battery energy storage facility	Directly connected to the transmission system or an industrial complex	Greater than or equal to 5 MW
4.5.1	Motors	Directly connected to the transmission system	Greater than or equal to 5 MW for each individual unit
4.5.1 and 4.5.4		In an industrial complex	Greater than or equal to 1 MW for each individual unit and greater than or equal to 5 MW for the aggregated motors at each point of delivery
		Connected to an electric distribution system at greater than or equal to 1 kV	
4.5.1 and 4.5.5	Generating unit	Connected to an electric distribution system	Greater than or equal to 5 MW at each point of delivery
4.5.2 and 4.5.5	Aggregated facility		

4.5.1 Large individual machines

Overview: "Large individual machines" are generating units or large electric motors of greater than or equal to 5 MW directly connected to the transmission system or directly connected to an industrial complex.

Checklist: (as applicable to the specific machine or converter type)

- ☐ Nameplate
- ☐ Manufacturer's datasheet, including at a minimum:
  - ☐ Rated machine capacity (MVA)
  - ☐ Rated voltage (kV)
  - ☐ Maximum authorized real power (MW)
  - ☐ Minimum stable generation (MW)
  - ☐ Reactive power capability curve
  - ☐ Inertia constant
  - ☐ Positive-sequence saturated and unsaturated subtransient reactance
  - ☐ Positive-sequence saturated and unsaturated subsynchronous reactance
  - ☐ Positive-sequence saturated and unsaturated synchronous reactance
  - ☐ Transient time constant
  - ☐ Subtransient time constant
  - ☐ Negative sequence resistance
  - ☐ Negative sequence synchronous reactance
  - ☐ Zero-sequence resistance
  - ☐ Zero-sequence synchronous reactance
  - ☐ Station service load (MW required when generation output is 0 MW)
  - ☐ Unit service load (incremental load (MW) per unit of generation (MW))
  - ☐ Saturation
  - ☐ "G" for "generator or "M" for "Motor"
  - ☐ The bus to which machine connects
  - ☐ The "D" curve (for generators)
  - ☐ The "V" curve (for generators)
  - ☐ Power variation curve as a function of temperature
  - ☐ Nameplate of exciter (for synchronous generators)
  - ☐ Model validation test report
  - ☐ EMT model, if applicable

Explanation:

(a) Machine inertia constant is the combination of the generator and driver (or for the motor and the connected load).

(b) Express machine impedances in per-unit on machine power (MVA) rating and machine voltage (kV) rating.

(c) For synchronous machines, submit both direct-axis and quadrature-axis impedances and time constants.

(d) Express saturation either as saturation factors or as a saturation curve.

4.5.2 Aggregated Facility

Overview: It is expected that the data associated with an aggregated facility, that has a total aggregated capacity of greater than or equal to 5 MW and is either directly connected to the transmission system or connected to an industrial complex, is provided separately for each collector group in accordance with Figure 1 as an example.

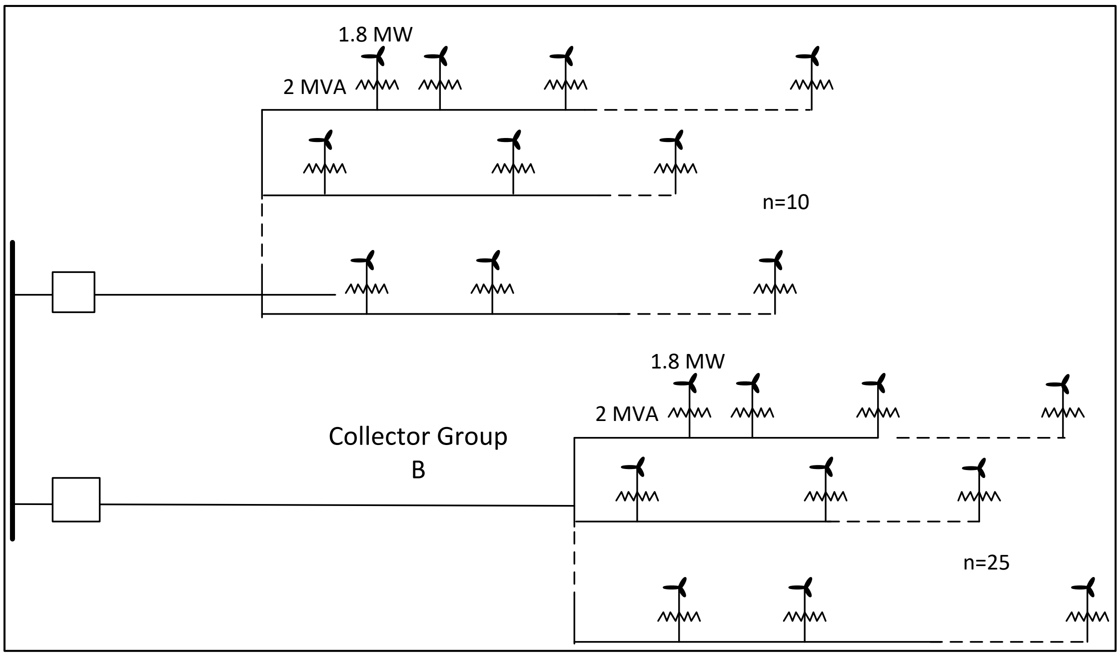

Figure 1: Typical Collector System Generators

Checklist: (as applicable to the specific machine or converter type)

- ☐ Reduced representation diagram of collector system
- ☐ Positive-sequence total real and reactive impedance of the collector system
- ☐ Zero-sequence total real and reactive impedance of the collector system if grounded
- ☐ Positive-sequence real and reactive shunt admittance of the collector system
- ☐ Zero-sequence real and reactive shunt admittance of the collector system if grounded
- ☐ Step-up transformer Impedances
- ☐ Typical generator nameplate
- ☐ Count of individual generators
- ☐ Maximum authorized real power at collector bus (MW)
- ☐ Generator's manufacturer's data sheet, including at a minimum:
  - ☐ Generator type

- ☐ Maximum real power output
- ☐ Minimum real power operation
- ☐ Maximum reactive power output
- ☐ Minimum reactive power output
- ☐ Equivalent positive-sequence impedance for three-phase fault calculations
- ☐ Equivalent zero-sequence impedance for single-phase fault calculations
- ☐ Houseload
- ☐ Generator impedance
- ☐ Generator step-up transformer data
- ☐ Shunt device nameplate for shunt devices residing within turbine units
- ☐ Shunt device manufacturer's data for shunt devices residing within turbine units
- ☐ Count of individual shunt devices
- ☐ EMT model, if applicable

Explanation:

(a) The reduced model represents each collector group as the equivalent impedance of the collector network, a single aggregate generator and a single aggregate step-up transformer representing the sum of the individual generator and unit step-up transformers on that collector group. Figure 2 below shows the reduced model of the collector systems shown above in Figure 1.

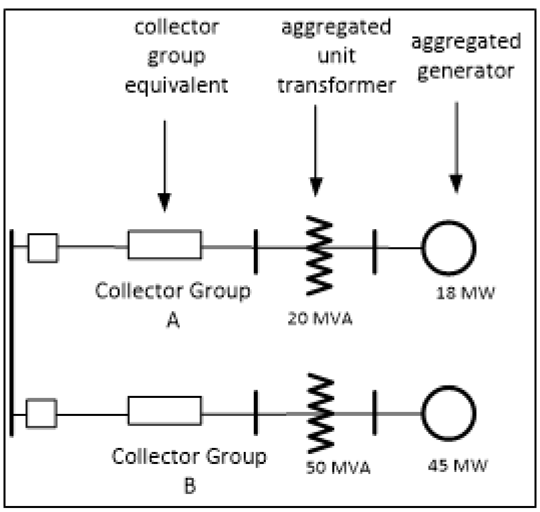

Figure 2 Equivalent Collector System

(b) Collector equivalent impedances are expressed per-unit on collector nominal voltage and a 100 MVA base.

(c) The individual data for a single wind turbine generator, and a typical generator nameplate, is to be submitted for each group of identical generators. If all wind turbine generators in a wind aggregated facility are identical, only one nameplate and one set of manufacturer's data need be submitted.

(d) Generator type will be one of: conventional synchronous, conventional induction, wound rotor induction with variable rotor resistance, doubly fed induction, or full converter.

(e) Generator impedances are expressed in per-unit on the machine rated MVA base

(f) Include with the collector-system generator data only those shunt devices that are distributed throughout the collector system within or at the turbine generator locations. Refer to section 4.3 of this Appendix to submit data for any shunt devices.

(g) Refer to section 4.2 of this Appendix to submit the data for the generator step-up transformer. If all wind turbine generators in a wind aggregated facility are identical, only one set of data need be submitted.

(h) The requirements to submit controls system data and dynamic modelling data apply to equivalent collector-system generators.

4.5.3 Battery Energy Storage Facility

Overview: The AESO expects data to be submitted by a legal owner of battery energy storage facility that is governed by Section 5032 ISO rules that have a maximum authorized real power and a maximum authorized charging power greater than or equal to 5 MW. The AESO expects that this data will be submitted separately for each collector group in accordance with Figure 3.

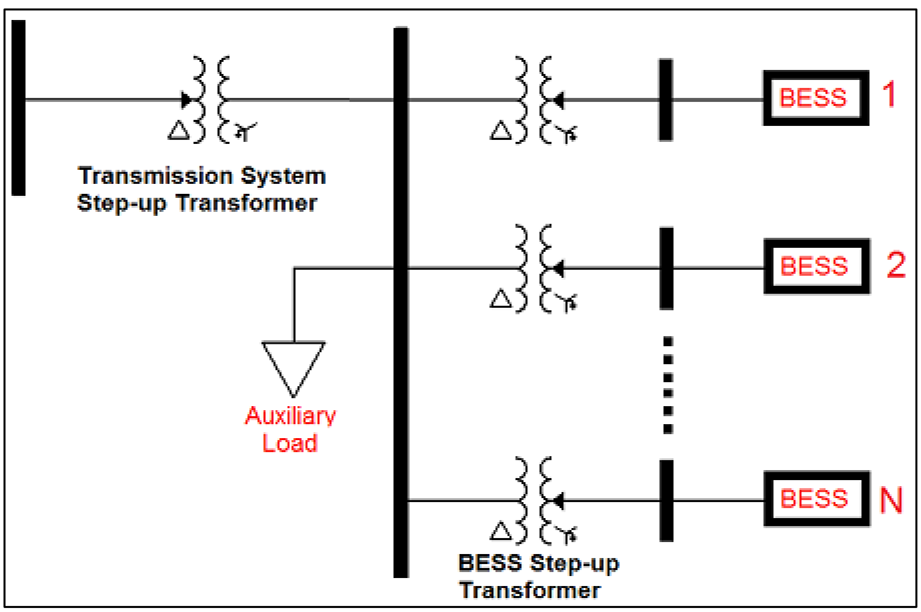

Figure 3 Typical Battery Energy Storage Facility

Checklist:

- ☐ Reduced representation diagram of collector system
- ☐ Maximum authorized charging power (MW)
- ☐ Maximum authorized discharging power (MW)
- ☐ Generator's manufacturer's data sheet, including at a minimum:
  - ☐ Number of battery energy storage system converter units
  - ☐ Unit converter rating (MVA)

- ☐ Rated terminal voltage (kV)
- ☐ Maximum temporary ratings and time characteristics
- ☐ Minimum real power operation
- ☐ Maximum reactive power output
- ☐ Minimum reactive power output
- ☐ Equivalent positive-sequence impedance for three-phase fault calculations
- ☐ Equivalent zero-sequence impedance for single-phase fault calculations
- ☐ Converter type
- ☐ Equivalent converter series impedance
- ☐ Battery type
- ☐ step-up transformers

☐ Auxiliary load characteristics

☐ Maximum continuous operation under maximum authorized discharging power (hours)

☐ Model validation report

☐ EMT model. Refer to the EMT Model Submission Checklist published on www.aeso.ca

Explanation:

(a) Maximum authorized charging power and maximum authorized discharging power are defined in the AESO's *Consolidated Authoritative Document Glossary*.

(b) Maximum reactive power output and minimum reactive power output are calculated based on the maximum authorized charging power and maximum authorized discharging power.

(c) The equivalent positive-sequence impedance is the impedance of the converter filter behind the converter step-up transformer. The total impedance of this equivalent impedance and converter step-up transformer determines the three-phase fault level at the point of connection.

(d) Each battery energy storage converter unit consists of a step-up converter transformer, a converter, and a set of battery racks.

(e) The auxiliary load consists of the converter cooling load and the substation base load. The cooling load, which is the major part of the auxiliary load in the battery energy storage facility, is usually a motor load and is a function of the power converted by the converter. When the converter operates at its maximum capacity, the cooling load and consequently the auxiliary load is maximum. The auxiliary load may have non-linear characteristics when compared to a converter load; however, for the purpose of modelling a simplified liner model as described in the following equation is preferred.

$$P_{Auxiliary} = m \times P_{Converter} + P_{Base\ Load}$$

Where
$P_{auxiliary}$ = Auxiliary load power (MW)
m = slope
$P_{converter}$ = Converter unit power (MW)
$P_{base\ load}$ = Base load power (Mw)

Figure 4, provided below, shows the characteristics of this simplified load relationship.

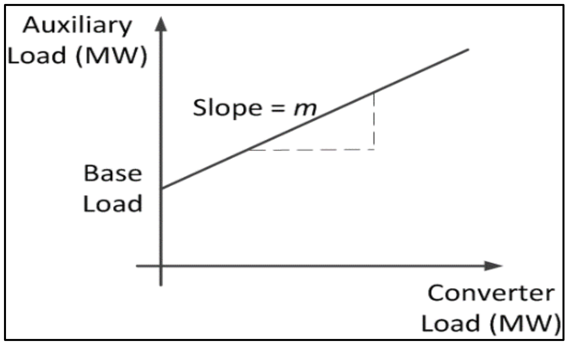

Figure 4 Auxiliary Load Characteristics Versus Converter Load (MW)

(f) The auxiliary load may have a low power factor because it is a motor load. The load power factor or the reactive power at the auxiliary load value should be provided.

4.5.4 Industrial Complex Aggregated Machines and Distribution Connected Motors

Overview: Aggregated machines are modelled as a totaled MVA equivalent for each type of machine such as induction motors, synchronous motors, and motors controlled by a power electronic drive that are located on the load side of a point of delivery where:

(a) the individual machines are connected at a voltage of greater than or equal to 1000 V;

(b) the individual machines have a capacity that is greater than or equal to 1 MW; and

(c) the total connected capacity is greater than or equal to 5 MW.

If any of the previous 3 conditions are not true, the aggregated machine data does not need to be submitted.

Checklist:

The checklist includes all applicable items of large individual machines or an aggregated facility and:

- ☐ ½-cycle fault contribution on the high voltage side of the Point of delivery
- ☐ 3-cycle fault contribution on the high voltage side of the Point of delivery
- ☐ Aggregate low-voltage induction motors ratings in MVA
- ☐ Aggregate medium-voltage induction motors ratings in MVA
- ☐ Aggregate medium-voltage synchronous motors ratings in MVA
- ☐ Aggregate synchronous generators ratings in MVA
- ☐ Aggregate induction generators ratings in MVA
- ☐ EMT model, if applicable

Explanation:

(a) ½-cycle fault contribution is the asymmetric fault current, in amperes, coming from the industrial complex for a fault on the transmission system side of each of the supply transformers.

(b) 3-cycle fault contribution is the symmetrical fault current, in amperes, coming from the industrial complex for a fault on the transmission system side of each of the supply transformers.

(c) Where multiple transformers supply a site, the faults are to be applied simultaneously to all supplying transformers.

(d) Aggregate MVA is the sum of the rated MVA of all induction motors or generators in the specified class.

(e) Low-voltage motors are those motors directly connected at a voltage of less than or equal to 1000 V, excluding all motors connected through variable-frequency drives.

(f) Medium-voltage motors are those motors directly connected at a voltage of greater than 1000 V, excluding all motors connected through variable-frequency drives.

(g) It is expected that aggregate MVA values include any machine that is also modelled as a large individual machine.

4.5.5 Distributed Energy Resources

Overview: Aggregated distribution energy resources have a totaled MVA equivalent to distribution-connected generators located on the distribution side of a point of delivery, where the total distribution-connected capacity is greater than or equal to 5 MW.

The AESO has established the following two approaches for modelling distributed energy resources:

(a) Legal owner provides detailed model of the distributed energy resources; or

(b) Legal owner selects one of the typical parameter sets and includes the recommended typical parameters provided in Appendix 2.

Refer to Appendix 2 of this information document for further details about these approaches.

Checklist:

<u>Data common to both approaches</u>:

☐ Generic Prime Mover Type.

☐ Provide generation general characteristics as listed in Table 9 in accordance to the Prime Mover Type.

Table 9 Required Data by Prime Mover Type

<table>
<tr><th>Generation Type</th><th>Indicate the Machine type</th><th>Indicate if it is inverter-coupled</th><th>Indicate if the Heat Recovery System is installed</th><th>Indicate the Reactive Power Control Method</th></tr>
<tr><td>Solar</td><td rowspan="3">N/A</td><td rowspan="2">Yes</td><td>No</td><td rowspan="7">Voltage Control or Power Factor Control</td></tr>
<tr><td>Storage</td><td>Yes/No</td></tr>
<tr><td>Wind</td><td rowspan="5">Yes/No</td><td rowspan="2">No</td></tr>
<tr><td>Hydro</td><td rowspan="4">Synchronous or Induction</td></tr>
<tr><td>Gas</td><td rowspan="3">Yes/No</td></tr>
<tr><td>Diesel</td></tr>
<tr><td>Biomass</td></tr>
</table>

- ☐ Maximum authorized real power (MW)
- ☐ Minimum stable generation (MW)
- ☐ Reactive power capability (MVAr)
- ☐ Positive-sequence resistance and subtransient reactance
- ☐ Frequency control mode
  - ☐ No frequency control; or
  - ☐ Droop mode and droop setting
- ☐ Type of Exciter (for synchronous generators)
  - ☐ Power factor and power factor setpoint; or
  - ☐ Voltage control and voltage control set point.
- ☐ Generator interconnection ride-through requirement
  - ☐ IEEE 1547-2003 IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
  - ☐ IEEE 1547-2014 IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems - Amendment 1
  - ☐ IEEE 1547-2018 IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. Ride-Through: Abnormal Operating Performance Categories, Category I or II
- ☐ Impedance of feeder from distributed energy resource to transmission point of delivery
- ☐ Distribution Feeder Data
  - ☐ Equivalent or reduced representation diagram of distribution feeder
  - ☐ Positive-sequence total real and reactive impedance of the distribution feeder
  - ☐ Zero-sequence total real and reactive impedance of the distribution feeder, if grounded

- ☐ Minimum load on the feeder
- ☐ Total generation capacity installed on the same feeder

☐ EMT model, if applicable

Additional Data requirement for Approach 1:

Synchronous Generation Data: The same requirements provided in section 4.5.1 of this appendix for large synchronous generating unit applies

Inverter-based Generation Data: The same requirements provided in section 4.5.2 of this appendix for aggregated facilities applies

Step-Up Transformer:

- ☐ Transformer impedances
- ☐ Transformer equivalent circuit
- ☐ Positive and zero-sequence real and reactive impedances
- ☐ Positive and zero-sequence real and reactive shunt admittances
- ☐ Short-circuit impedances and load losses
- ☐ Open-circuit excitation currents and no-load losses
- ☐ Phase angle shift
- ☐ Significant off-neutral impedance of tap-changing transformers

4.5.6 EMT Model Package

Overview: The AESO requests that all inverter-based resource (IBR) facilities (at both transmission and distribution levels) with an in-service date after January 1, 2021 submit the EMT model data using the Power Systems Computer Aided Design (PSCAD) software provided by Manitoba Hydro International (MHI). Refer to Appendix 3 for a comprehensive outline of the EMT modelling requirements pursuant to Section 503.21 of the ISO rules, *Reporting Facility Modelling Data*.

The AESO may also request EMT modelling data for the following facilities on a case-by-case basis:

(a) Synchronous and induction generators, which include combustion turbine generators, steam turbine generators, hydro generators, and Type 1 and Type 2 wind turbines. This may be required for special studies such as sub-synchronous oscillation.

(b) Facilities participating in the system restoration plan; and

(c) IBR facilities with energization date prior to January 1, 2021.

The AESO will specify the EMT modelling requirements for such facilities in functional specifications or connection study scope during the connection process as needed. For facilities that are already energized and in operation, the AESO will contact facility owners directly to request EMT modelling data as needed.

Checklist: The AESO’s EMT Model Submission Checklist is published on www.aeso.ca.

4.6 High-voltage Direct Current Converter Terminals

Overview: Data requirements are to be established through discussion with the AESO.

4.7 Series Compensation

Overview: Series compensation is a series component, typically a reactor or capacitor, which modifies the series reactance of a line. Refer to Appendix 3 for a comprehensive outline of the EMT modelling requirements.

Checklist:

- ☐ Nameplate
- ☐ Reactive power (MVAr) rating
- ☐ Rated voltage
- ☐ Rated current
- ☐ Control strategy
- ☐ EMT model. Refer to the EMT Model Submission Checklist published on www.aeso.ca.

Explanation:

Discuss the control strategy with the AESO to identify which details are to be submitted.

4.8 Static VAr Compensators

Overview: A "Static VAr Compensator" is a shunt-connected capacitive or inductive conducting equipment whose output is automatically and rapidly adjusted to maintain or control some parameter of the electrical power system, typically voltage. Refer to Appendix 3 for a comprehensive outline of the EMT modelling requirements.

Checklist:

- ☐ Nameplate
- ☐ Maximum/minimum MVA (Capacitive)
- ☐ Maximum/minimum MVA (Inductive)
- ☐ Rated voltage
- ☐ Control strategy
- ☐ Control bus
- ☐ Maximum control-band voltage
- ☐ Minimum control-band voltage
- ☐ Connection (Delta/Wye)
- ☐ Neutral grounding status
- ☐ Grounding impedance
- ☐ EMT model. Refer to the EMT Model Submission Checklist published on www.aeso.ca

Explanation:

(a) Reactive power (MVAr) rating is to be expressed at the shunt-connected equipment rated voltage.

(b) The control strategy is one of the strategies summarized in Table 10.

Table 10 SVC-Switching Strategies

☐ Strategy	☐ **Explanation** of Strategy
Manual	The SVC output can be adjusted by personnel on site
Automatic	The SVC output is adjusted under the control of an automated control system
Supervisory	The SVC output can be adjusted remotely via a supervisory control and data acquisition system

(c) The "Control Bus" is the bus at which the voltage is monitored for the purpose of controlling this shunt device. Refer to the bus by the (**BUS_CODE**) assigned to the bus by the AESO.

(d) The maximum and minimum voltages of the control band are expressed in per-unit of the system nominal voltage (kV) at the control bus.

(e) Grounding resistance and reactance, expressed in ohms, with 0 indicating a solidly grounded bank.

4.9 Other FACTS Devices

Overview: "FACTS Devices" or "Flexible AC Transmission System Devices" refer to power electronic based systems and their associated static equipment that provide control of one or more alternating current transmission system parameters to enhance controllability and increase power transfer capability. Refer to Appendix 3 for a comprehensive outline of the EMT modelling requirements.

Checklist:

☐ Nameplate

☐ Component single-line diagram

☐ Manufacturer's test report

☐ Manufacturer's data Sheet

☐ Details established by discussion with the AESO

☐ Description of operation

☐ EMT Model Submission Checklist published on www.aeso.ca.

Explanation:

(a) A component single-line diagram is used to show all the main circuit components of the FACTS installation, including transformers, line segments, capacitors, and reactors.

(b) Provide a text description of the operation of the FACTS installation, to a level of detail to be discussed with AESO.

(c) Submit the data for any transformers, line segments, capacitors, reactors, or dynamic control systems associated with the FACTS device as detailed in the relevant section of this appendix.

Appendix 2 – Distributed Energy Resource Modelling Guideline

This Appendix 2 provides information for legal owners of distributed energy resources and other market participants on the modelling of these distributed energy resources in power flow and dynamics simulations and provides a set of typical data for the purpose of a connection project.

The AESO is focused on the impact of distributed energy resources on the reliability of the interconnected electric system. This impact is defined in part by the distributed energy resource capabilities such as voltage support, fault current contribution, the incremental losses to the transmission system, and to a lesser degree, frequency support through inertia and governor controls.

As such, the AESO requests legal owners to provide a specific set of distributed energy resource modelling data for each resource type when the distributed energy resource with Maximum Capacity (MC) is greater than or equal to 5 MW or in the AESO connection process.

1 Power Flow Models

For modelling purposes, a set of identical generators can be aggregated into a single equivalent generator for a pool asset. The AESO expects that if there is more than one type of generator, the market participant can aggregate each generator type separately into a single equivalent generator. The gross onsite load associated with the distributed energy resources facility may be modelled separately.

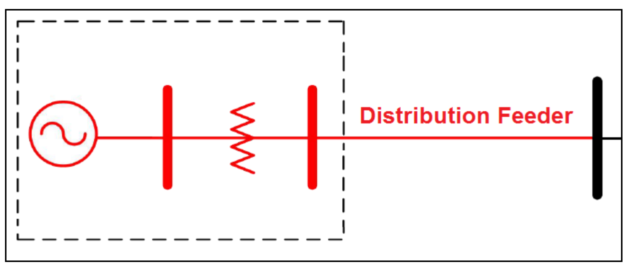

Figure 1 Power Flow Model of a Distributed Energy Resources Connection with One or More Identical Generating Units

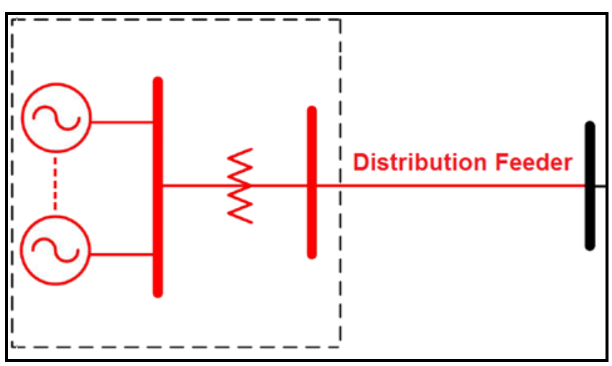

Figure 2 Power Flow Model of a Distributed Energy Resources Connection for Non-identical Generating Units

The AESO recommends market participants provide the AESO with the power flow model data in Table 1 for each equivalent generator described above.

Table 1 Distributed Energy Resource Power Flow Data

Generator Power Flow Data		
	Maximum Power (Pmax)	Minimum Power (Pmin)
	Maximum Reactive Power (Qmax)	Minimum Reactive Power (Qmin)
Machine Base (Mbase)	Source Impedance (Resistive) R Source [pu]	Source Impedance (Reactive) X Source [pu]
Power Factor Set Point	Reactive Control Mode Set to "**3-Fixed Q based on WPF**" for power factor control mode	
Voltage Control Set Point	Reactive Control Mode Set to "**0- Not a wind machine**" or "**1 – Standard QT, QB Limits**" for power factor control mode	
Distribution Feeder Power Flow Data		
Feeder Name or ID	Minimum load on the Feeder	Total installed distributed energy resources capacity on the same feeder
Positive Sequence Line R, X & B [pu]	Zero Sequence Line R, X & B [pu] if grounded	Applicable summer and winter ratings

2 Dynamic Models

The AESO understands that creating a dynamic model for distributed energy resources is challenging due to the level of support along the supply chain for these small units. As such, to assist market participants, the AESO has developed 2 suggested approaches for market participants to provide dynamic modelling data to the AESO.

Approach 1

A legal owner or project proponent may request, from the manufacturer, the relevant generating unit modelling information including generator, excitation and electrical control, prime mover governor or real power controller and voltage and frequency protection settings. The legal owner and project proponent may submit this information directly to the AESO. Please note, this information is typically not available from the manufacturer until the project is in a later stage (i.e., stage 3 or 5) of the AESO's Connection Process. The AESO applies this information to the model.

Approach 2

The legal owner or project proponent may use Approach 2 when no project-specific data for a distributed energy resource is available at earlier stages of the connection process. In this Approach 2, the AESO applies pre-defined typical parameters for the distributed energy resource modelling. Approach 2 is intended to assist market participants when establishing a set of reasonable assumptions prior to obtaining manufacturer data.

As per the NERC, *Reliability Guideline: Distributed Energy Resource Modeling*[4], at a minimum, the following information related to the distributed energy resource may be provided to the AESO[5].

(a) Type of generating resource, such as, reciprocating engine, wind, solar photovoltaics, gas unit, or battery energy storage;

(b) Distribution bus nominal voltage level and control where the distributed energy resource is connected;

(c) Feeder characteristics for connecting distributed energy resource to the distribution bus, if applicable;

(d) Capacity of each distributed energy resource including: maximum power output, reactive power capability, apparent power rating, rated power factor, capability curve of distributed energy resource reactive output with respect to different real power outputs down to Pmin;(e) The version of the IEEE Standard 1547, *Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces,* such as, -version 2003, version -2014, version -2018 Cat I/II, version UL1741-SA/SB, version CA Rule 21, or other relevant interconnection standard requirements that is related to the utility scale distributed energy resource;

(f) Actual or projected plant control modes in operation;

(i) reactive power control mode:

(A) voltage control with control bus and voltage setpoint; or

(B) power factor control with control bus and power factor setpoint; and

(ii) presence of frequency response and droop; and

(g) The prime-mover type classification of the utility scale distributed energy resource. Prime-mover types include:

(i) Reciprocating engines with or without co-generation;

(ii) Gas turbine with or without co-generation;(iii) Steam turbine with or without co-generation;

(iv) Small synchronous hydro; and

(v) Inverter-based distributed energy resources such as wind, solar photovoltaics, or battery energy storage systems.

The AESO applies this information to the model.

[4] NERC, Reliability Guideline: Distributed Energy Resource Modeling, Dated September 2017, Available on www.nerc.com.

[5] NERC, *Reliability Guideline: Distributed Energy Resource Modeling*, refers to a Transmission Planner and a Planning Coordinator. In Alberta, these functions are performed by the AESO.

2.1 Synchronous Generating Units Connected to an Electric Distribution System[6]

As per NERC, *Reliability Guideline: Distributed Energy Resource Modeling*[7], synchronous generating units connected to the electric distribution system are expected to be modelled using the GENTPJ model with Kis = 0. If modelling information is provided from the generating unit, that data may be used by the market participant to develop the GENTPJ model parameters. Otherwise, the AESO recommends the market participant apply best engineering judgment when developing reasonable modelling parameters based on the type of synchronous generating units.

Note, synchronous generating units connected to the electric distribution system prior to the IEEE Standard 1547-2018 Cat II are not required to have frequency response capability. Furthermore, frequency response is typically not required for synchronous generating units connected to the interconnected electric system. Therefore, the assumption of using only a generator model would represent the most conservative assumption for frequency and reactive power support from the synchronous generating units.

Synchronous generating units typically operate in constant power factor control mode with no droop control mode. To implement the constant power factor control mode, the market participant may model these synchronous generators in power flow as a wind machine code =3. In dynamics simulation the study engineer may convert the unit back to code 0 to accept the GENTPJ model.

Table 2 below sets out a sample set of typical data provided by market participants to the AESO for the modelling synchronous generating units.

[6] All instances of the use of synchronous generating units in subsection 2.1 of Appendix 2 refer only to those synchronous generating units connected to an electric distribution system.

[7] See footnote 5.

Table 2 Reciprocating Engine Generators

	GENTPJ Model					
	High Voltage reciprocating	**Medium Voltage reciprocating**	**Low Voltage reciprocating**	**Steam Turbine**	**Small Hydro**	**Gas Turbine**
Generator Voltage Range	7.2-13.8	4.16	380-690	Any	Any	Any
T'_{d0}	4.478	2.967	2.214	6	6	6.5
T'_{q0}		0.313		1	0	1
T''_{q0}		0.2		0.035	0.0650	0.03
H	1.2	1.2	1.2	3	1.7	4.2
D	0	0	0	0	0	0
X_d	2.242	2.227	2.647	1.8	1.45	1.6
X_q	1.62	1.217	1.71	1.7	1.05	1.5
X'_d	0.188	0.284	0.167	0.2	0.47	0.2
X'_q		1.217		0.4	1.05	0.3
X''_d	0.139	0.179	0.123	0.18	0.33	0.13
X''_q	0.261	0.197	0.262	0.18	0.33	0.13
X_l	0.101	0.13	0.1	0.12	0.28	0.1
S(1.0)	0.2	0.2	0.2	0.2	0.2	0.1
S(1.2)	0.6	0.6	0.6	0.6	0.6	0.4
K_{is}	0	0	0	0	0	0
K J=K*VA		0.029	0.027			

Note: “VA” is on the machine rating.

2.2 Inverter-Based Distributed Energy Resources

A performance-based modelling approach may be used by a market participant to model the large number of inverter-based distributed energy resources. As some of inverter-based distributed energy resource are small with difficulties accessing modelling data, the AESO recommends the use of standardized model parameters in accordance with the distributed energy resource control and protection standard vintage.

A performance-based modelling approach for inverter-based distributed energy resources is the modelling method described in NERC, *Reliability Guideline: Parameterization of the DER A Model*[8],. For specific distributed energy resource projects, the parameters can be found in Chapter 2 of the document.

[8] NERC, *Reliability Guideline: Parameterization of the DER A Model,* Dated September 2019, Available on www.nerc.com.

3 Distributed Energy Resource Representation in Base Cases

The purpose of this section is to inform study engineers how the AESO models distributed energy resource in the base cases.

The AESO base cases form the basic assumptions common to most transmission system studies on the interconnected electric system. Some studies require additional details or different representation of the interconnected electric system, including generating units in isochronous mode, inverter-base resources in weak grid operation, detailed high voltage direct current controls, dynamic load characteristics, voltage and frequency protections, inclusion of non-market participating distributed energy resources, and detailed electric distribution system characteristics. These additional modelling characteristics are not part of the base cases as they are not applicable to the majority of transmission system studies.

The AESO has the following principles as it relates to distributed energy resource modelling in base cases:

(a) that the model is suitable to assess any impact on transmission facilities;

(b) that the transmission facilities and electric distribution system are represented appropriately;

(c) the representation of observable physical electrical quantities; and

(d) to simplify data manipulation as much as possible.

3.1 Existing System

The AESO base cases will represent the system topology support for these forecasted points. Thus, the base case model can be simplified to the system shown in Figure 3 for the simplest representation while maintaining all elements needed to allocate forecast load and generation.

Distribution feeder loss, electric distribution system load, distributed generation onsite load, micro-generation and onsite load are all implicitly included in the single load model. The inclusion of the distribution feeder loss also means that feeder impedances are also implicitly included in the single load model. Therefore, explicitly modelling the distribution feeder without removing the actual feeder loss would duplicate the effect of the losses.

While the feeder impedance has important impact on the voltage level and power flow on the feeder, the purpose of the AESO base case is to study the transmission system and the observable quantities at the transmission and distribution interface and ensure that it has accounted for the impact from feeder.

3.2 Connection Studies

Connection studies examine the effect of connecting new resources to the system. In such cases, either the physical system is new or there is an additional flow of energy not currently observed, thus the incremental impact is not included in the base case.

In the case of the feeder, in order to capture the effect of a new feeder or new energy flow on an existing feeder, the impacted feeder is modelled explicitly with the expected load and generation provided by the distribution facility owner. Once energized, this new feeder or new energy flow on an existing feeder would be part of observable quantities, thus, the feeder modelling is no longer required and forecast provided by the AESO.

3.3 Observable physical electrical quantities

Distributed energy resources may be installed in Alberta with or without interconnection to interconnected electric system in a number of ways. Table 3 provides a summary of the interconnection options for distributed energy resource in Alberta and how each type of market participation is represented in models.

Table 3 Distributed Energy Resource Characteristics by Market Participation

Market Participation Type			Characteristics	AESO Registration	Modelling Representations
Non-parallel operation			Do not synchronize with the electric distribution system for more than 150 ms. (i.e., Back up generation)	No Pool Asset ID No MPID No SCADA No settlement with AESO	
Parallel operation	Non-exporting		Load always exceeds distributed energy resource output and no power is exported to the grid.	No Pool Asset ID No MPID No SCADA No settlement with AESO	
	exporting	Small Micro-Generation	Renewable or low emission distributed energy resource less than 150 kW and only has cumulative metering. Designed to offset annual energy consumption.	No Pool Asset ID No MPID No SCADA AESO settles with retailer	Aggregated model provided by AESO if required
		Large Micro-Generation	Renewable or low emission distributed energy resource greater than 150 kW or less than or equal to 5 MW site equipped with interval metering. Designed to offset annual energy consumption.	Pool Asset ID MPID No SCADA AESO settles with retailer	Aggregated model provided by AESO if required
		Distribution Connection Generation	Any energy source and any size including small scale generation and community generation	Pool Asset ID MPID AESO settles directly with the GFO SCADA and Offering if greater than 5 MW	Modelling Data from market participants: Asset location greater than 5 MW or Locations subject to the AESO Connection Process

3.4 Supervisory Control and Data Acquisition Data and Revenue Meters

Figure 3 shows a simplified typical electric distribution system with supervisory control and data acquisition data[9] points, mostly on the transmission system and to a limited extent on the electric distribution system, and revenue meters[10] on both transmission system and electric distribution systems.

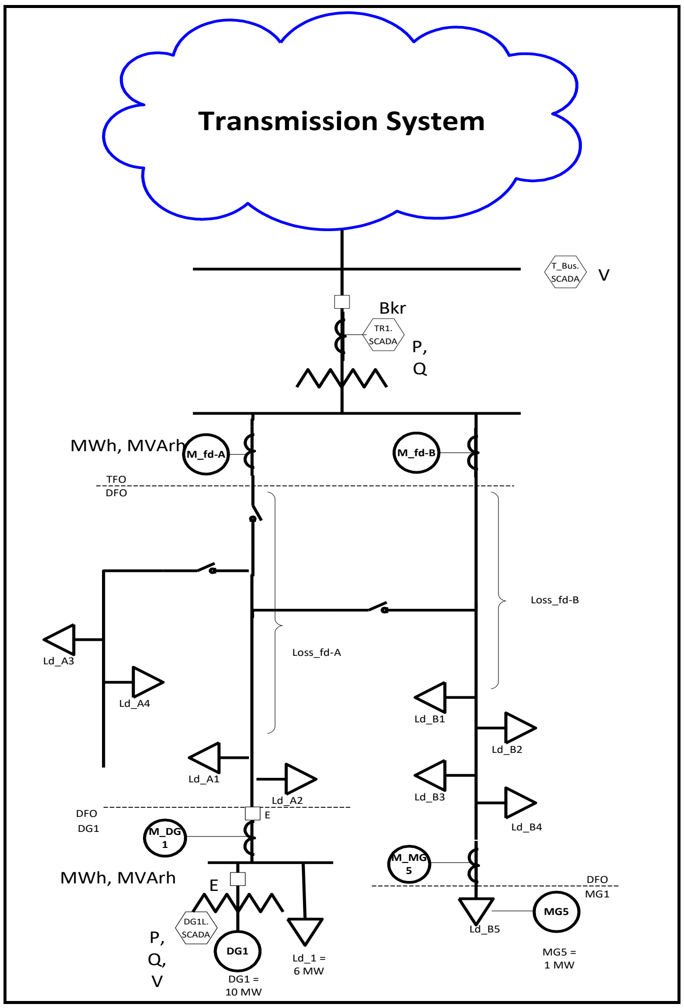

Figure 3 Simplified Conceptual Diagram of an Electric Distribution System with Distributed Energy Resources

The AESO's load forecast uses inputs from substation load revenue meters to forecast future loads. The AESO's generation forecast uses inputs from generating units participating in the energy markets. Generating units that do not participate in the energy market are implicitly forecast as a reduction in substation load. This is represented in Figure 4, where the yellow highlighted points are used.

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[9] Refer to Section 503.16 of the ISO rules, *SCADA,* available on www.aeso.ca for supervisory control and data acquisition data requirements.

[10] Refer to AUC Rule 021, Settlement System Code Rules, available on www.auc.ab.ca for details regarding what information a revenue meter is required to measure for settlement purposes.

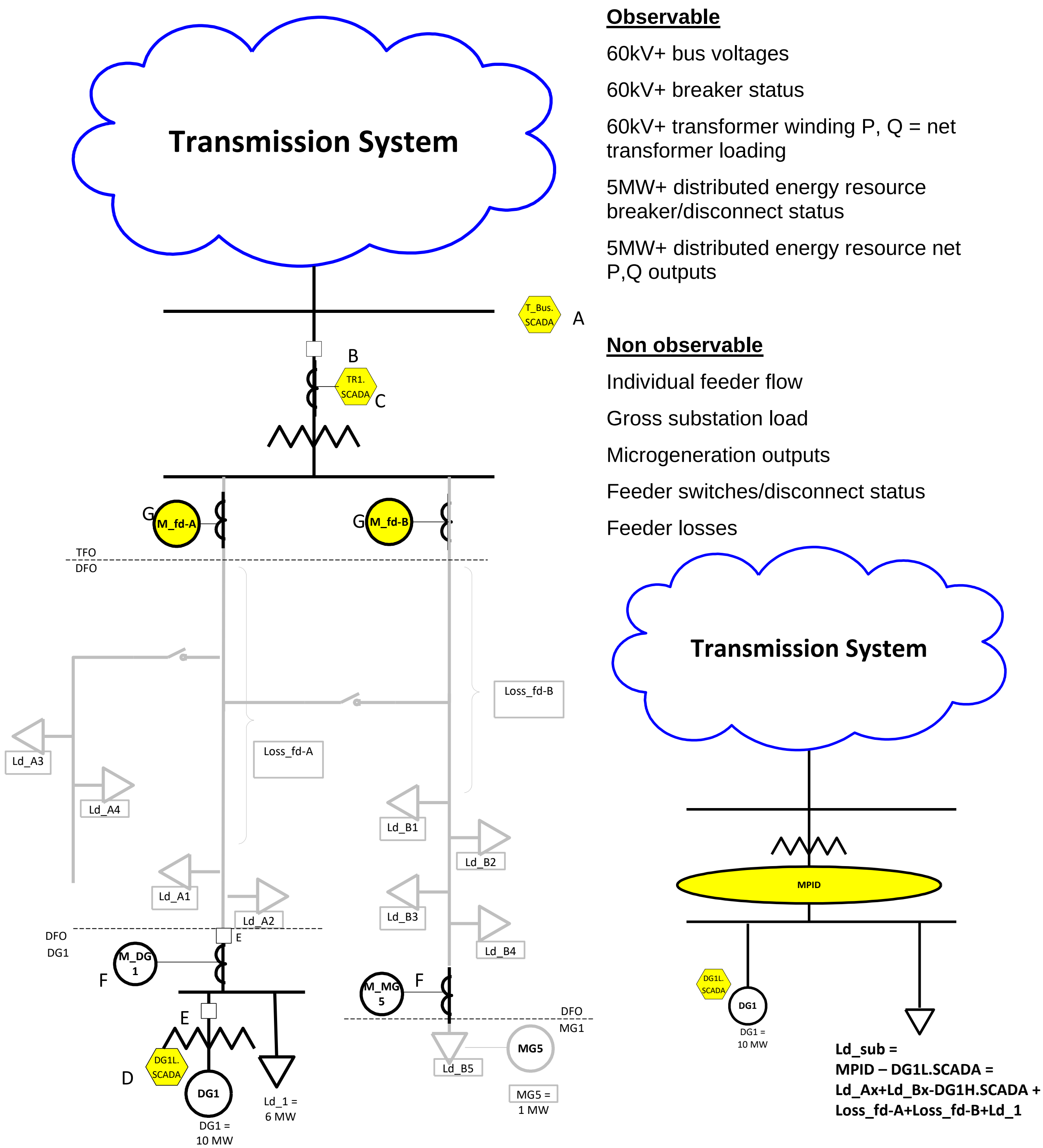

Figure 4 Observable Quantities and Simplified Distribution Modelling in AESO Base Cases

Appendix 3 – Electromagnetic Transients (EMT) Modelling Requirements

A3.1 EMT Software

Submitted EMT models shall be compatible with the PSCAD version and Intel Visual Fortran compiler version outlined in Section A3.3.2. Occasionally, it may be necessary for the AESO to move to new versions of PSCAD/EMTDC. Ideally, the new versions of these simulation tools will be backwards-compatible with existing models. However, if the AESO deems it necessary that a new version of the simulation tool is required to undertake studies, and an existing model no longer functions correctly in the simulation tool, an updated model compatible with the new version might be required. These updates may be required at any point in the life of the facility.

A3.2 Documentation and Model Attestations

Supporting documentation is required when submitting the EMT model. The following information should be included in the EMT Model Submission Checklist published on www.aeso.ca:

- Manufacturer name, the version of the model, and the version equipment installed in the field.
- List and description of the PSCAD files being submitted.
- Instructions for setup and running the model and any limitation of the models, including the lowest grid strength the model is designed for.
- Indication that the model is implemented using Real-Code[11].
- Facility single line diagram.
- List and description of all the control functions and associated parameters, and identification of those accessible to the user.
- List and description of all the protections (both AC and DC protections), and identification of associated settings accessible to the user.
- Description of the test case, which must be configured according to the site-specific real equipment configuration up to the point of interconnection. This would include (for example): aggregated generator model, aggregated generator transformer, equivalent collector branch, main plant transformers, gen tie line, power plant controller, and any other static or dynamic reactive resources.
- Specific modelling requirements for inverter-based facilities as per Section A3.3.2 in Appendix 3
- Authenticated model validation report as per the requirements in Section AA4.1 in Appendix 4.
- Authenticated model verification report as per the requirements in Section A4.2 in Appendix 4.
- Authenticated model quality test report per the requirements set out in Section A4.3 in Appendix 4.

A3.3 EMT Model Requirements

A3.3.1 General Requirements

The AESO requests that all submitted models be site specific and represent the whole facility including all the components necessary to study the specific phenomenon under consideration. As a minimum, the following equipment shall be included in the submitted plant model:

[11] Actual code implemented in the inverter and plant controller firmware.

- The generating unit and any other primary or relevant secondary plant within the generating system that may affect the overall interaction of the generating system with the power system (e.g., reactive power compensation plant).
- All automatic changes to operating modes that occur should happen automatically within the model. Where automatic mode switchover cannot occur, operating mode changes must be based on configuration file or variable changes. It is not acceptable to require a separate model for each operating mode.
- Linearized models that are accurate only for a single operating point are not acceptable.
- All transient models provided must define the site-specific electromechanical and control system performance of components comprising the plant under steady state, set-point change, and disturbance conditions for all levels of system strength and energy source availability that the plant is rated to operate.

A3.3.2 Inverter Based Facilities EMT Model Requirements

All the power electronic based facilities (Type 3 and Type 4 wind turbines, HVDC, STATCOM, Solar PV, BESS, and etc.) shall satisfy the applicable requirements:[12]

General requirements

- For generation facilities identified as inverter based resources, if the facility holds both Grid Forming (GFM) and Grid Following (GFL) capability, two sets of models shall be submitted each representing the facility in GFL or GFM mode. Models shall represent the associated controls and characteristics.

Model Accuracy Requirements

In order to be sufficiently accurate, the AESO requests that the model provided for each facility:

1. Include the collector system including generator step-up and main interconnection transformers, and collection system including cables and capacitor banks, etc.[13]
2. Represent the full detailed inner control loop of the power electronics. The model cannot use the same approximations classically used in transient stability modelling, and should fully represent all fast inner controls, as implemented in the real equipment. The model shall embed the actual hardware code into a PSCAD component. If the model is assembled using standard blocks available in the PSCAD master library, approximations are usually introduced, and specific implementation details for important control blocks may be lost. In addition, there is a risk that errors will be introduced in the process of manually assembling the model.
3. Incorporate a full Insulated-gate bipolar transistor (IGBT) representation (preferred), or use a voltage source interface that mimics IGBT switching (i.e., a firing pulse based model). A three-phase sinusoidal source representation is not acceptable. Models manually translated from MATLAB (i.e., block-by-block) or control block diagrams are often unacceptable because the method used to model the electrical network and interface to the controls may not be accurate, or portions of the controls (such as protection) are omitted. Note, that Matlab may be used to generate C code which is used in the real control hardware. If this approach is used by the

[12] The AESO acknowledges the Electranix memo and ERCOT PSCAD Model Submittal Guidelines, which were used to develop the AESO's PSCAD model requirements in this section.
[13] Equivalent or aggregated representations of the collection collector system, step-up transformer, and inverter systems are acceptable as long as they accurately represent the facility and its response characteristics.

developer, the same C code may be used to create an extremely accurate PSCAD model of the controls. The controller source code may be compiled into dynamic link libraries (DLLs) or binary if the source code is unavailable due to confidentiality restrictions.

4. Represent plant level controllers as they are implemented in the real controls, such as automatic voltage regulation. Parameters typically requiring site-specific adjustment should be user-accessible. For example, the plant level controller should provide access to regulation gains and droop settings. Generic Power Plant Controllers (PPC) representations are not acceptable unless the final PPC controls exactly match the generic PPC model. If multiple plants are controlled by a common controller, or if the plant includes multiple types of IBRs (e.g., Hybrid BESS/PV) this functionality must be included in the plant control model. If supplementary or multiple voltage control devices (e.g., STATCOM) are included in the plant, these should be coordinated with the PPC. Any delays, such as communication or measurement delays in the actual control and protections, are to be accurately represented in the model.
5. Represent all pertinent control features as they are implemented in the real controls e.g., customized phase-locked loops (PLLs), ride-through controllers, sub-synchronous control interaction (SSCI) damping controllers, etc.
6. Represent machine slip of Type III, Doubly Fed Induction Generator (DFIG), wind generation as appropriate for the power dispatch.
7. Represent sub-synchronous oscillation (SSO) mitigation and/or protection including the ability to enable and disable SSO mitigation/protection, if applicable.
8. Represent dynamic reactive devices including automatically controlled capacitor and reactor banks, if applicable.
9. Represent all pertinent electrical and mechanical configurations, such as filters and specialized transformers. Mechanical features (such as gearboxes, pitch controllers, etc.) should be included if they impact electrical performance. Any control or dynamic features of the actual equipment which may influence behavior in the simulation period that are not represented, or are approximated, must be clearly identified.
10. Have all pertinent protections modeled in detail for both balanced and unbalanced fault conditions. Typically, this includes various over-voltage (OV) and under-voltage (UV) protections (individual phase and root mean square (RMS)), frequency protections, DC bus voltage protections, converter overcurrent protections, and other inverter specific protections. Any protections that can influence dynamic behavior or plant ride-through in the simulation period must be included.
11. The model should reasonably represent the DC side dynamics to replicate different operating conditions such as transient ride-through during disturbances.
12. Accurately reflect behavior throughout the valid (MW and MVAr) output range from minimum power through maximum power.
13. Be configured to match expected site-specific equipment settings. Any user-tunable parameters or options in the model must match the equipment at the specific site being evaluated. Default parameters are not appropriate unless they match the configuration in the installed equipment.

Model Usability Requirements

To allow study engineers to perform system studies and analyze simulation results, the AESO requests that the model provided for each facility:

14. Have control or hardware options pertinent to the study accessible to the user. Although the plant must be configured to match site specific settings, parameters pertinent to the study must be accessible to the model user. Examples include protection thresholds, real power recovery ramp rates, frequency or voltage droop settings, voltage control response times, or SSCI damping controllers. Diagnostic flags to show control mode changes or which protection has been activated should be visible.
15. Be capable of running at timesteps larger than 10 µs. Most of the time, requiring a smaller time step means that the control implementation has not used the interpolation features of PSCAD, or is using inappropriate interfacing between the model and the larger network. Lack of interpolation support introduces inaccuracies into the model at higher time steps.
16. Be capable of operating at a range of simulation time steps. The model must not be restricted to operating at a single time step.
17. Include model documentation and instructions as per section A3.2 and a sample implementation test case.
18. Have an identification mechanism for configuration. The model documentation must provide a clear way to identify the specific settings and equipment configuration which will be used in any study, such that during commissioning the settings used in the studies can be checked. This may be controlling revision codes, settings files, or a combination of these and other identification measures.
19. Be capable of self-initializing. Models shall initialize and ramp to full output without external input from simulation engineers. Any slower control functions included, such as switched shunt controllers or power plant controllers, must also accept initial condition variables if required. Note that during the first few seconds of simulation (e.g., 0-2 seconds), the system voltage and corresponding terminal conditions may deviate from nominal values due to other system devices initializing. The model must be able to tolerate these deviations or provide a variable initialization time.
20. Accept external reference values. This includes real power reference (for active power control mode) or frequency reference (for frequency control), and reactive power reference values (for Q control mode), voltage reference values (for V control mode) or power factor reference value (for PF control mode). Model shall accept these reference variables for initialization and be capable of changing these reference variables mid-simulation, i.e., dynamic signal references.
21. Allow protection models to be disabled where possible. Many studies result in inadvertent tripping of converter equipment, and the ability to disable protection functions temporarily provides study engineers with valuable system diagnostic information.
22. Allow the active power capacity of the model to be scaled. This is distinct from a dispatchable power order and is used for modelling different plant capacities or breaking a lumped equivalent plant into smaller composite models.

Model Efficiency Requirements

To improve study efficiency and model compatibility, the AESO requests that the model provided for each facility include the following features:

23. Be compiled using Intel Fortran compiler version 15 or higher. The model should not be dependent on a specific Fortran version to run. Models compiled in or requiring GNU FORTRAN or Compaq Visual FORTRAN to run, will not be accepted.
24. Use PSCAD version 4.6.3 or higher. The model should not rely on a specific PSCAD version to run.
25. Models must not have dependencies on additional external software. However, dependencies on free, commonly available redistributable libraries (e.g., ETRAN) may be accepted.
26. Initialize as quickly as possible (for example <5 seconds) to user supplied terminal conditions.
27. Support multiple instances of its own definition in the same simulation case.
28. Support the PSCAD “snapshot” feature where possible.
29. Support the PSCAD “multiple run” feature where possible.
30. Allow replication in different PSCAD cases or libraries through the “copy” or “copy transfer” features.
31. Must not use or rely upon global variables in the PSCAD environment.
32. Must not utilize multiple layers in the PSCAD environment, including ‘disabled’ layers.

A3.3.3 Synchronous and Induction Generators

Synchronous and induction generators include combustion turbine generators, steam turbine generators, hydro generators, and Type 1 and Type 2 wind turbines. The AESO may request EMT modelling from these generators on a case-by-base (see Section 4.5.6). The applicable EMT modelling requirements for these generators are:

- The simulation model must encompass the Multi-Mass Torsional Shaft Interface, specifically configured for either a Synchronous Machine or an Induction Machine, as deemed appropriate. The model should comprehensively incorporate inertia constants, shaft spring constants, torque distribution among the different masses, and damping coefficients. It is imperative to refrain from using an approximate representation of one stiff shaft in transient stability modelling.
- The model must encompass the representation of the machine saturation or magnetizing curve, along with the transformer magnetizing curves.
- For the generator excitation system, either a user-written PSCAD model or standard PSCAD block models are allowed. Standard PSCAD block models require a statement from the manufacturer or plant operator validating that these models accurately represent the excitation system's performance in transient simulations with a 50 micro-second time step or higher.
- The generator governor model should be represented using a user-written PSCAD model or a standard PSCAD block. Standard PSCAD block models require a statement from the manufacturer or plant operator confirming its accuracy in representing the generator's performance in transient simulations with a 50 micro-second time step or higher.
- The generator power system stabilizer (PSS) should be presented as a user-written PSCAD model or standard PSCAD block models with supporting validation from the manufacturer or plant operator.
- To ensure accuracy, all model parameters should reflect the actual installed settings in the field rather than manufacturer default parameters.
- The model should incorporate the generator grounding system as it significantly impacts the generator fault contribution.
- The model must include detailed representations of all installed protections under both balanced and unbalanced fault conditions. This includes overcurrent protection, various over-voltage and under-voltage protections (individual phase and RMS), frequency protection, loss of field protection, under/over-excitation protection, reverse power protection, out of step protection, and

any other special protection mechanisms. Additionally, the ability to enable and disable these protections should be integrated into the model.

- If applicable, the sub-synchronous oscillation (SSO) mitigation and/or protection must be represented, along with the capability to enable and disable SSO mitigation/protection.
- Incorporate dynamic reactive devices, including automatically controlled capacitor and reactor banks, where necessary.
- The model should encompass all pertinent electrical and mechanical configurations, including filters and specialized transformers. The model should account for any mechanical features such as gearboxes, pitch controllers, or other control and dynamic elements that impact electrical performance.. Any unrepresented or approximated control or dynamic features that influence simulation behavior should be documented.
- Accurate representation of behavior throughout the MW and MVAr output range, from minimum power to maximum installed capacity, is crucial.
- The model should be configured to match the expected site-specific equipment settings, with all user-tunable parameters or options adjusted to align with the site-specific equipment under evaluation and avoid reliance on default parameters.

A3.3.4 System Restoration EMT Model Requirements

The models provided for the plants involved in blackstart and system restoration assessments shall fulfill the following additional requirements to adequately represent the performance of the plant and network in such studies.

The generator models shall include:

- Auxiliary transformers data.
- Major auxiliary loads including large fans and pumps. The information provided should include the size and number of motors, their inertia, operational reactance and time constants, and whether directly connected or interfaced via a variable speed drive.
- Descriptions or inclusion of any special abilities of the plant per the AESO’s blackstart requirements (e.g., soft-start capability, isochronous frequency control, etc.).
- A detailed description of any special control schemes active during system restoration.
- Surge arrester manufacturer, types, and V-I profiles.
- Protection data and settings, including over/under voltage and frequency, V/Hz, overcurrent, out of synchronism (out of step) or phase jump.
- Reactive power support devices including shunt devices, FACTS devices with detailed original equipment manufacturer (OEM) models, etc.

The transmission network model shall include:

- Geometrical representation of transmission lines, including conductor type and associated resistance, cable bundling configuration, transpositions tower types and spacing.
- Transmission transformers, including saturation profile, air core reactance, winding configurations, core structure, all reactance and time constants.
- Transformer differential protection relays data, with field settings.
- Locations of synchronizing breakers and synchro-check relay settings.
- Details of under- or over-voltage protection schemes of active cranking paths.
- Surge arrester manufacturer, types, and V-I profiles.
- Protection data and settings, including any over-voltage protection on transmission lines, overcurrent protection on transformers, etc.

A3.3.5 Sharing of Models and Information

Detailed EMT/PSCAD models often contain information which might be considered intellectual property of a specific equipment manufacture. This might put some restrictions on sharing of such models with other parties and lead to limitations on the model use. Sharing of models in black-boxed format, along with non-disclosure agreements (NDA) as required, is one approach to address the model confidentiality issue. When black boxing models, key parameters and flags in the model must still be accessible or adjustable by the user, as per the AESO's EMT modelling requirements. Other alternatives to handle model confidentiality may be considered e.g., the AESO may decide to perform the assessment in-house or select an external consultant to carry out the assessment by having an NDA in place among multiple parties.

Appendix 4 – EMT Model Verification, Validation and Quality Testing Requirements

Market participants must ensure the validation and verification of all EMT models for inverter-based resources, successfully passing through model quality tests as per Section 503.20 of the ISO rules, *Baseline and Model Validation Testing*. Along with the EMT model submission, the AESO expects that market participants will provide the EMT Model Validation Report, the EMT Model Verification Report, and the EMT Model Quality Testing Report. Figure A.1 illustrates the overall process to create a validated and appropriately parameterized PSCAD model for inverter-based facilities. Each step in Figure A4.1 is elaborated in the following subsections, except for the baseline and model revalidation step, which is articulated in the ID *#2017-013R Model Validation and Reactive Power Report Guidance*.

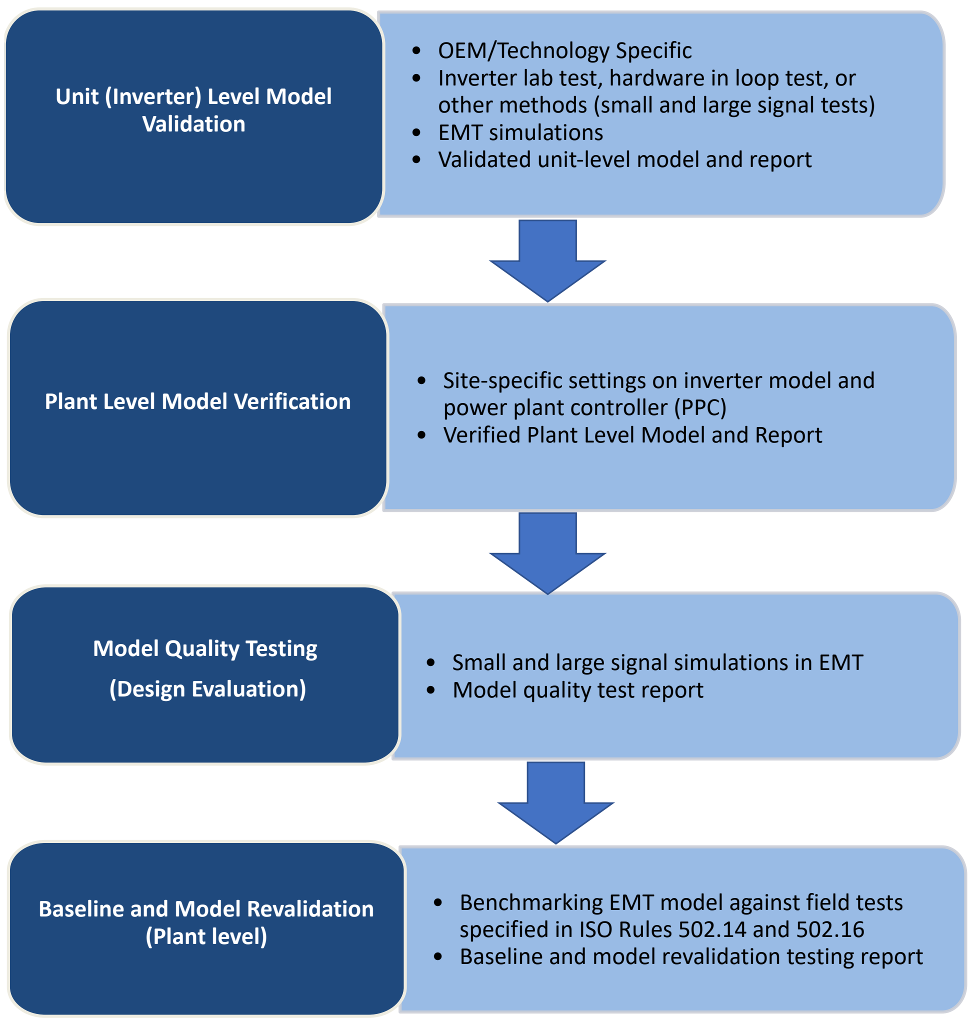

Figure A4.1. Overall Process to Create and Report PSCAD models for IBRs[14].

[14] The detailed requirements on "Baseline and Model Revalidation (Plant level)" are explained in ID 2017-013R.

A4.1 Unit (Inverter) Level EMT Model Validation

Model validation is the process of comparing measurements with simulation results to assess whether a model response sufficiently mimics the measured response.[15] Currently there is no standardized global requirements for IBR EMT model validation. One approach adopted by some jurisdictions is to ask for a validation report demonstrating the performance of the developed EMT model against the actual performance of the physical hardware during type-testing or other tests. The validated EMT model at unit or inverter level is a verified baseline model used as the main component of larger scale models like IBR plant. This provides traceability from the physical hardware to the developed models and increases the confidence of the overall plant model. This includes but is not limited to inverters, power plant controllers, and other dynamic facilities such as HVDC and FACTS. The EMT model used for validation tests does not necessarily need to be site-specific as the intent is to ensure that the developed EMT model accurately represents the physical hardware including all associated controls and protections. EMT model validation approaches that presently exist, include:

- On-site or commissioning tests
- Factory test results (e.g., laboratory tests, Power Hardware in the Loop (PHIL))
- Off-line simulation tests
- Continuous monitoring of disturbances

The AESO requires a validation report to be provided with each model submission validating the model performance with hardware measurements.

Requirements on which tests should be performed as part of the validation process are provided in the following section.

A4.1.1 Model Validation Tests

To gauge model accuracy, a set of tests need to be performed to measure the physical hardware (e.g., inverter) and model response to both small and large magnitude disturbances of frequency and voltage, as well as response to sub synchronous oscillations. As a minimum, the following tests should be performed on both physical hardware and the developed case:

- Step change in voltage magnitude in both directions.
- Step change in frequency in both directions.
- Voltage and Frequency Ride-Through
- Faults
- System Strength
- Step change in voltage angle in both directions.
- Sub-synchronous test: Perform a frequency scan sweep to measure the sub-synchronous impedance as seen looking into the inverter over the range 5 to 55 Hz in 1 Hz increments. This test is generally conducted by adding a small voltage perturbation of variable frequency superimposed on the fundamental (60 Hz) voltage, and measuring the complex impedance as seen looking into the inverter. The results should be provided both as a plot and as a table and should display Resistance and Reactance plotted over 5 to 55 Hz. Values should be in per-unit

[15] IEEE 2800.2 “Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems”, Draft 0.4, last accessed: June 2023

on the inverter MVA base. This test should be conducted under the following conditions: strong system (short circuit ratio = 10), unity power factor, weak system lagging (short circuit ratio = 1.5, 0.95 lagging power factor), and Weak System Leading (short circuit ratio = 1.5, 0.95 leading power factor).

A4.2 Plant Level EMT Model Verification

Model verification is the process of checking documents and files, equipment and respective settings (e.g., controls & protection), and comparing them to model parameters or model structure.[16]

The overall plant dynamic model consists of:

- main power transformers
- equivalence AC collector system
- inverter moles developed by OEMs
- power plant controller models developed by OEMs
- any other reactive devices within the plant

To ensure the submitted PSCAD model matches the site-specific tunable parameters, the model verification report must be provided. A model verification must provide evidence that the facility components, including, inverters, PPC, reactive support devices, incorporate site-specific settings based on field evidence, screenshots, delivery reports, testing reports, nameplate photographs, signed commissioning reports, etc. At this point, the AESO does not have a template or pre-defined format for this report.

A4.3 Model Quality Tests (Design Evaluation)

A set of simulation tests need to be performed to verify the functionality and performance of the model. The objective is to evaluate the following functional and performance capabilities of the model upon completion of the following tests:

- The ability to follow power commands.
- The ability to limit output and output ramp rate.
- The ability to operate with required grid support functions, such as:
    - Plant Reactive Power/Voltage control–power factor control, reactive power control, voltage control.
    - Plant Active Power/Frequency control–Fast Frequency Response, Primary Frequency Response.
    - Dynamic reactive support such as reactive current injection (k-factor).
- Performance during disturbance within normal operating voltage range at point of connection (POC) meets regional requirements.
- The ability to ride-through high/low voltage and frequency events.
- The ability to ride-through expected high rate of change of frequency (ROCOF).
- The ability to ride-through severe phase angle changes.

The performance requirements specified for the transmission-connected facility are in accordance with the AESO's current technical rules and the recommendations set out in IEEE 2800-2022.[17] The

[16] IEEE 2800.2 “Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems”, Draft 0.4, last accessed: June 2023.
[17] "IEEE 2800-2022,” IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems."

performance of inverter-based DER model quality test shall comply with the specifications outlined in the Technical Interconnection Requirements established by the connecting DFO.

A4.3.1 Test Setup

A simulation test setup needs to be configured to examine the performance and functionality of the model. The setup includes the full representation of the model under study up to the point of interconnection where the facility is interconnected to the transmission system. This means that all the site-specific dynamic models needed to represent the facility will be included in the test. That includes generators, aggregated generator resources, step up transformers, collector system impedance, any additional static or dynamic reactive power equipment, all dynamic control systems (e.g., AVR, power plant controller, power system stabilizer, voltage and frequency protection, and etc.) as applicable. The transmission system is represented by an equivalent Thevenin circuit with adjustable voltage magnitude, frequency/angle and impedance which enables emulation of different operating conditions applicable to each simulation test outlined in the following sections. All tests for BESS should cover both charging and discharging conditions.

A4.3.2 Flat Start Test

The facility model shall initialize correctly and be capable of successful flat run. This test consists of a minimum 25 second simulation without any disturbance applied and shall be performed with facility operating at rated power and across a range of feasible reactive power output conditions and terminal voltages.

Acceptance criteria:

The test is considered successful if the model initializes correctly without revealing any continuous oscillation or divergence from initial system conditions. Voltage, frequency, and active and reactive power remain almost constant all through the simulation run.

A4.3.3 Small Disturbance Tests

A4.3.3.1 Small Voltage Disturbance Test

To examine the performance of automatic voltage regulator, the model shall be subject to a 3% voltage step change (both directions) at the POC.

Acceptance criteria:

The test is considered passed if the plant adjusts the reactive power output in an attempt to regulate the voltage at the set point. The plant output power should be sustained throughout the small voltage disturbance tests. The unit shall not trip and the response shall be stable. The overall dynamic response shall follow the performance target presented in Table A4.1.

TABLE A4.1: REQUIRED DYNAMIC PERFORMANCE RESPONSE PARAMETERS OF PLANT'S VOLTAGE CONTROLLER

Parameter	Units	Performance Target
Reaction time	Milliseconds	Less than 200
Maximum Step time response	Seconds	Between 1 to 30 seconds in consultation with the AESO. Any switched shunts or transformer tap changer operation needed to restore the dynamic reactive power capability shall respond within 60 seconds.

Damping ratio	Unitless	0.3

A4.3.3.2 Small Frequency Disturbance Test

The performance of Plant's governor or frequency controller shall be verified when it is subject to small system frequency changes. The model will be subject to a 0.3 Hz step change (both directions) of system frequency from nominal frequency. The real power output of the plant shall be initially set to 80% of maximum power leaving adequate headroom for the plant to respond to frequency changes. If the study plant is an energy storage facility (e.g., BESS), the test needs to be performed under both charging and discharging operating conditions.

Acceptance criteria:

The plant shall lower or raise its output power in response to the frequency change in accordance with its set droop and frequency dead band characteristics. The unit shall not trip and the response shall be stable. Any oscillations shall be positively damped with a damping ratio of 0.3 or higher. The overall dynamic response shall be equal or less than the values depicted in Table A4.2.

TABLE A4.2: REQUIRED DYNAMIC PERFORMANCE RESPONSE PARAMETERS OF PLANT'S GOVERNOR OR FREQUENCY CONTROLLER

Parameter	Units	Value
Reaction time	Seconds	0.5
Rise time	Seconds	4.0
Settling time	Seconds	10.0
Damping ratio	Unitless	0.3
Settling band	% of change	0.5% of plant continuous rating

A4.3.4 Ride-through Performance Test

The ride-through performance capability of the plant in response to grid voltage and frequency excursions needs to be evaluated. In this test, the grid voltage magnitude and frequency are varied as per the requirements set out in Section 503.5 *Voltage Ride-Through* ("Section 503.5"), Section 503.6 *Frequency and Speed Governing* ("Section 503.6"), The model dynamic response during and after ride-through is examined.

A4.3.4.1 Voltage Ride-Through

(a) Low voltage Ride-Through (LVRT)

In this test, the voltage at POC is varied over time according to the low voltage ride through values specified in Appendix 1 of Section 503.5.. If different voltage ride through requirements are specified in the AESO's functional specification, those shall be used for this test instead. The initial condition of the testing scenario should be designed to ensure that the facility operates at the MARP (and MACP for BESS) level, along with the required minimum lagging and leading power factor, as outlined in the requirement. The operating condition at POC before the voltage excursion occurs is as follow: Voltage=1.00 p.u., Frequency=1.00 p.u.

Acceptance criteria:

This test is considered acceptable if the plant successfully runs through the excursion and no protection trips the plant. The plant might operate in ride-through control modes temporarily during or right after the disturbance which might lead to plant real and reactive power output adjustments. However, it is expected the plant returns to at least 90% pre-disturbance condition once the disturbance is over.

For low voltage transient, the model should inject reactive current throughout the voltage recovery period. This reactive current injection should happen immediately or shortly after voltage begins to ramp up from zero. Current blocking mode (Momentary Cessation) might be allowed when voltage at POC goes below 0.10 p.u. However, the plant shall restart current exchange in less than or equal to five cycles as soon as the voltage goes beyond 0.10 p.u.

For 0.90 p.u. sustained voltage at POC voltage, the plant should provide voltage support to its maximum reactive power capability while real power recovers to the full power within 1.0 seconds of POC voltage recovery to 0.90 p.u.

(b) High Voltage Ride-Through (HVRT)

In this test, the voltage at POC is varied over time according to high voltage ride through values specified in Appendix 1of Section 503.5. If different voltage ride through requirements are specified in the AESO's functional specification, those shall be used for this test instead. The initial condition of the testing scenario should be designed to ensure that the facility operates at the MARP (and MACP for BESS) level, along with the required minimum lagging and leading power factor, as outlined in the requirement. The operating condition at POC before the voltage excursion occurs is as follow: Voltage=1.00 p.u., Frequency=1.00 p.u.

Acceptance criteria:

The test is accepted if the plant successfully runs through the excursion and no protection trips the plant. The plant might operate in ride-through control modes temporarily, during, or right after the disturbance, which might lead to plant real and reactive power output adjustments. However, it is expected the plant returns to pre-disturbance condition once the disturbance is over.

For high voltage transient, the model should absorb reactive power throughout the high voltage transient starting immediately or shortly after high voltage transient inception. For 1.10 p.u. sustained voltage at POC voltage, the plant should provide voltage support to its maximum reactive power capability. The real power should be sustained all through the high voltage transient. However, it might be acceptable to have a modest real power reduction (not more than 5% of plant Pmax) during the transient to accommodate more reactive power absorption.

A4.3.4.2 Frequency Ride-Through

(a) Low Frequency Ride-Through (LFRT)

In this test, the grid frequency at POC is varied over time according to the low frequency ride through values specified in Appendix 1 of Section 503.6. If different frequency ride through requirements are specified in the AESO's functional specification, those shall be used for this test instead. The initial condition of the testing scenario should be designed to ensure that the facility operates at the MARP (and MACP for BESS) level, along with the required minimum lagging and leading power factor, as outlined in the requirement. The operating condition at POC before the frequency excursion occurs is as follow: Voltage=1.00 p.u., Frequency=1.00 p.u.

Acceptance criteria:

This test is considered acceptable if the plant successfully runs through the frequency excursion in a stable manner and no protective function trips the plant. The plant might operate in ride-through control modes temporarily during or right after the disturbance which might lead to plant real and reactive power output adjustments. However, it is expected the plant returns to the pre-disturbance condition once the disturbance is over.

(b) High Frequency Ride-Through (HFRT)

In this test, the grid frequency at POC is varied over time according to the high frequency ride through values specified in Appendix 1 of Section 503.6. If different frequency ride through requirements are specified in the AESO's functional specification, those shall be used for this test instead. The initial condition of the testing scenario should be designed to ensure that the facility operates at the MARP (and MACP for BESS) level, along with the required minimum lagging and leading power factor, as outlined in the requirement. The operating condition at POC before the frequency excursion occurs is as follow: Voltage=1.00 p.u., Frequency=1.00 p.u.

Acceptance criteria:

This test is considered acceptable if the plant successfully runs through the frequency excursion in a stable manner and no protective function trips the plant. The plant might operate in ride-through control modes temporarily during or right after the disturbance which might lead to plant real and reactive power output adjustments. However, it is expected the plant returns to pre-disturbance condition once the disturbance is over.

(c) ROCOF

In this test, the grid frequency at POC is ramped up or down at a rate of 5.0 Hz/s. If different ROCOF value is specified in the AESO's functional specification, that shall be used for this test instead. The applied rate shall be the average rate of change of frequency over an averaging window of at 0.5 second.

Acceptance criteria:

The IBR facility should ride-through and should not trip. This test is only intended to provide greater understanding of the device capability to respond to frequency events.

A4.3.5 System Strength Test

Tests need to be carried out to verify plant's reliable performance under varying system strength at POC. This test will demonstrate plant performance under weak grid conditions given system strength at POC is subject to variation triggered by outages, network reconfiguration, etc. The model shall be tested for a set of short circuit ratios (SCRs) at POC starting from a strong system condition toward weaker conditions. The SCR adjustment is achieved by varying the Thevenin circuit impedance. The simulation starts at a pre-defined SCR followed by applying a solid three phase to ground fault at POC which will be cleared after 6 cycles and SCR will be changed to a lower value. This sequence continues until the model performance is adversely impacted.

Acceptance criteria:

Models should provide a stable or well-damped oscillatory response for all SCRs higher than the minimum SCR specified by the AESO or SCR=3 (whichever is lower) . The plant reactive power output shall reflect a proper action by plant AVR. This means the plant AVR should respond to restore voltage schedule at POC by adjusting of plant reactive power output.

A4.3.6 Fault Simulation Test

The model performance shall be tested when the facility is subject to faults at POC. Two types of faults applied at the POC bus will be performed:

- 3-phase to ground fault with 6-cycle clearing time
- 1-phase to ground fault simulation with 6-cycle clearing time.

Acceptance criteria:

Models shall provide a stable or well damped oscillatory response following and during fault recovery time.

A4.3.7 Phase Angle Jump Test

The performance of the model shall be examined when the plant is subject to sudden increase or decrease in grid voltage. This condition sometimes transpires in the grid during disturbances that might cause the model to lose control or exacerbate the applied disturbance. The test consists of exposing the model to an instantaneous voltage phase angle jump (both directions) at POC, to determine the biggest phase angle change the model can withstand while remaining online and recovering to normal operation.

Acceptance criteria:

The IBR facility should ride-through positive-sequence phase angle changes of less than or equal to 25 electrical degrees. This test is only intended to provide greater understanding of the device performance during disturbance.

A4.3.8 Reference Setpoint Step Test

Non-fault disturbance tests are required to verify the response of the plant to reference set points (i.e., active power, voltage, power factor, reactive power, and etc.). This test entails applying of 5% step changes on reference set points (e.g., active power reference in power plant controller) and examine what performance the model exhibits.

Acceptance criteria:

The plant shall follow the reference set point and settles within a reasonable time taking into account system strength (i.e., SCR), reactive power flow, ramp rate limit settings, and droop functionality if applicable. The overall dynamic response shall be equal to or less than the values depicted in Table A4.7

TABLE A4.7: REFERENCE SETPOINT STEP PERFORMANCE TARGET

Parameter	Units	Performance Target
Reaction time	Seconds	0.5
Rise time	Seconds	4.0
Settling time	Seconds	10.0
Damping ratio	Unitless	0.3
Settling band	% of change	0.5% of plant continuous rating

A4.4 Baseline and EMT Model Revalidation

The purpose for baseline and model revalidation report is to ensure that the EMT model is validated when a baseline or model validation test is performed per Section 503.20 of the ISO rules, *Baseline and Model Validation Testing*. The PSCAD model of the entire facility needs to be validated against the small signal tests performed in the field to demonstrate the EMT model mimics the response observed from the tests. Refer to the Sections 503.20to determine when baseline testing or model revalidation testing should be performed for an existing facility.

A4.4.1 Benchmarking Positive Sequence Dynamic Models

The validated EMT model can better represent the dynamics of the field equipment with detail control logics being modeled. Compared with the other conventional positive sequence RMS models, the EMT model is generally considered as the highest fidelity models applied for the system stability studies.

During the model submission at commissioning period, the positive sequence dynamic models should be benchmarked against verified EMT models to improve their quality and to ensure that the model performance is consistent across the simulation platforms.

In general, the following simulations must be run in PSS/E and benchmarked against PSCAD results to demonstrate basic reasonable model performance:

- Flat Start Test (no disturbance test)
- Small Voltage Disturbance Test
- Small Frequency Disturbance Test
- Voltage Ride-Through Test (HVRT & LVRT)
- Reference Setpoint Step Change Test
- System Strength Test (SCRs)
- Fault and Fault Clearing Test