Common Grid Model Exchange Specification (CGMES)

Version 2.5

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Foreword

The purpose of the Common Grid Model Exchange Specification (CGMES) is to define the interface between Transmission System Operators (TSO) software in order to exchange power system modelling information as required by the European Network of Transmission System Operators for Electricity (ENTSO-E) and TSO business processes.

The CGMES is used as a baseline exchange standard for the implementation of the Common Grid Model (CGM) methodologies in accordance with the requirements for the implementation of various European network codes and guidelines. The CGMES applies to applications dealing with power system data management, as well as applications supporting the following analyses:

- load flow and contingency analyses,
- short circuit calculations,
- market information and transparency,
- capacity calculation for capacity allocation and congestion management, and
- dynamic security assessment.

The conformity of the applications used for operational and system development exchanges with the CGMES is crucial for the needed interoperability of these applications. ENTSO-E therefore developed and approved the CGMES Conformity Assessment Framework as the guiding principles for assessing applications' CGMES conformity. Based on those principles. This publicly available specification relies on the CGMES Conformity Assessment Process operated by ENTSO-E in order to ensure that the CGMES is properly implemented by suppliers of the applications used by TSOs.

Introduction

1   Scope

This publicly available specification on the CGMES defines the main rules and requirements related to the CGMES and which are mandatory for achieving interoperability with the CGMES and for satisfying the business processes. In the document requirements are indicated as such in a tabular format. Some descriptions are merely used for clarification and are marked "Informational".

The profiles which belong to CGMES are defined in a separate document. The related technical information and documentation (i.e. RDFS, OCL, XMI and HTML) needed for the implementation of the CGMES, which is not copyrighted by either IEC or CENELEC, is available at the ENTSO-E web site.

The CGMES is defined using information on the Common Information Model (CIM) available in the public domain.

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

The CGMES is a superset of the former ENTSO-E CIM based data exchange standard (Profile 1) which was based on CIM14 (UML14v02) and has been used for certain network models exchanges since 2009. The CGMES reflects TSO requirements (as known by 2014) for accurate modelling of the ENTSO-E area for

power flow, short circuit, and dynamics applications whilst also allowing for the exchange of any diagram layouts including GIS data of a grid model.

Next editions of the publicly available specification will be released to describe following CGMES versions which will be reflecting the additional requirements due to European network codes or guidelines.

2   Normative references

The CGMES is based on the CIM 16 (UML16v29). Once the following IEC CIM standards are approved the CGMES would rely on them:

- IEC 61970-552 : CIM XML Model Exchange Format
- IEC 61970-301 : Common Information Model (CIM) Base
- IEC 61970-302 : Common Information Model (CIM) for Dynamics Specification
- IEC 61970-452 : CIM Static Transmission Network Model Profiles
- IEC 61970-453 : Diagram Layout Profile
- IEC 61970-456 : Solved Power System State Profiles
- IEC 61970-457 : Common Information Model (CIM) for Dynamics Profile
- IEC 61970-501 : Common Information Model Resource Description Framework (CIM RDF) schema
- IEC 61968-4 : Application integration at electric utilities – System interfaces for distribution management - Part 4: Interfaces for records and asset management.

3   Terms and definitions

For the purposes of this document, the following terms and definitions apply. For definitions which are not specified in the CGMES the definitions in the IEC CIM related standards shall be applied.

3.1
Common Grid Model Exchange Standard (CGMES)
This is an ENTSO-E standard used for the exchange of power system models between TSOs for the purpose of performing bilateral, regional or pan-European studies in the frame of TYNDP or TSOs' projects. It is based on IEC CIM Standards and further extended to meet Network Codes' and projects' requirements. The standard defines a set of data model exchange profiles.

3.2
Profile
This refers to the uniquely named subset of classes, associations and attributes needed to accomplish a specific type of interface and based upon a canonical model. The term profile may be used to define either the semantic model for an instance data payload or the syntactic schema for an instance data payload. A profile may be expressed in XSD, RDF, and/or OWL files. An instance data conforming to a profile can be tested in exchanges between applications. A profile is necessary in order to "use" the canonical model.

3.3
CIM Extension
A collection of classes, attributes and associations, which extend the standard IEC CIM model in order to cover use cases not currently supported by IEC standards, and which are not considered to be international use cases or are covered by a later version of the standard which is not yet supported.

3.4
ENTSO-E Extension
CIM Extension, specifically managed by ENTSO-E.

3.5
Boundary set
A boundary set contains all boundary points necessary for a given grid model exchange. A boundary set can have different coverage depending on the requirements of the common grid model exchange. A complete boundary set is necessary to assemble a pan-European power system model.

3.6
Boundary point (BP)
Boundary point is a connection point between two Model Authority Sets (MAS). A Boundary point could be a ConnectivityNode or a TopologicalNode placed on a tie-line or in a substation. A Boundary point must be contained in a Boundary Set and must not be contained in the MAS of a TSO. A Boundary point is referenced by Terminals in the MAS of a TSO. ConnectivityNode and TopologicalNode are terms specified in IEC CIM standards. If a Boundary point is placed on a tie-line, the term X-Node is often used instead of Boundary point. X-Node is therefore a specific type of Boundary point.

3.7
Abbreviations

IEC	The International Electrotechnical Commission, headquartered in Geneva
TSO	Transmission System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity. ENTSO-E has 41 TSO members.
MRID	CIM Master Resource Identifier
CIM	Common Information Model (electricity)
CGMES	Common Grid Model Exchange Standard
MAS	Model Authority Set
IOP	Interoperability Test
RDF	Resource Description Framework
EQ_BD	Boundary equipment profile or instance file
TP_BD	Boundary topology profile or instance file
EQ	Equipment profile or instance file
TP	Topology profile or instance file
SSH	Steady State Hypothesis profile or instance file
SV	State Variables profile or instance file
DL	Diagram Layout profile or instance file
GL	Geographical Location profile or instance file
DY	Dynamics profile or instance file
BP	Boundary point

4 Exchange process

There are various levels in which the exchange of power system data/models is necessary. A pan-European model exchange level covers the territory of all TSOs. Regional model exchanges can be realised between different TSOs in one or more synchronous areas. A model exchange on the national level includes interfaces between TSOs and DSOs, as well as between different DSOs.

The purpose of model exchanges is not only to exchange the data from one authority to another but also to satisfy the ultimate goal, namely to perform common studies using shared data. All parties involved in the process should be able to perform the same types of studies and be able to share project tasks between different parties which are using different power system analysis applications. Indeed, the interoperability between different applications used in the exchange process is therefore crucial in both reaching seamless data exchange and obtaining comparable study results when using this data.

The CGMES covers these ENTSO-E and TSO business processes by defining the following main types of exchanges valid for a particular study or process:

- Exchange of Boundary set: An exchange of a Boundary Set is necessary to prepare an exchange of an internal TSO model and to assemble a common grid model. The latest information on Boundary Sets covering pan-European area is available to TSOs and maintained in the ENTSO-E Network Modelling Database (NMD) where all TSOs negotiate and agree on the boundary information.
- Exchange of an Internal TSO model: A number of business processes require each TSO to provide models of its internal territory. To describe its internal territory in a single stand-alone exchange, a TSO is treated as a single model authority set and shall be able to exchange all profiles defined in the CGMES. The TSO prepared its internal model in such a way that it is easily and unambiguously combined with other TSO internal models to make up complete models for analytical purposes. This type of exchange can also be applied for the interface between a TSO and a DSO, where models covering transmission or distribution parts of the power system can be exchanged based on a mutual agreement between the TSOs and the DSOs. In this case, and if a TSO requests a DSO model, the DSO would provide its model in accordance with CGMES definitions which might be extended by the TSO requesting this type of exchange.
- Exchange of a Common grid model: A common grid model refers to the concept of having one model which can be used for multiple purposes. The standard describes what is needed to create an assembly of multiple TSOs Individual Common Grid Model (ICGM) of their responsible territory into a regional or pan-European model. Different business processes will require specific implementation of the profiles part of the CGMES and the exchange of respective instance files to meet interoperability inside the business process. The Common Grid Model meta-model description will ensure interoperability across the business process.

ENTSO-E and TSO business processes (e.g. system development planning, protection planning, operational planning, operation, fault study/simulation, market operation, etc.) are, of course, more complex than these operations, but what is important to note is that all processes are supported using only these basic kinds of interoperation.

Note that each power system model in CIM normally consists of multiple datasets (instance files) as defined in IEC CIM Standards and further specified by CGMES.

The CGMES supports a node-breaker and a bus-branch model exchanges. Moving forward the procedures of the model exchanges using the CGMES, it is expected that equipment and steady state hypothesis data (EQ and SSH instance files) will be the input source data for all processes. This type of model should be the

fully detailed model with all disconnectors/breakers, etc. Any configuration changes are made by changing switch statuses.

ID	Specification	Type
EXCH1.	The CGMES defines equipment and steady state hypothesis profiles as an input, meaning that all results, whether topology or state variables profiles data, must refer to the equipment and steady state hypothesis objects. Therefore, in the case that both equipment and steady state hypothesis instance files are available, there is no need to exchange topology or state variables instance files in order to obtain a load flow.	Requirement
EXCH2.	For node-breaker model exchanges the TopologicalNodes represent the output from a topology processing on the detailed input source operational data. These can be optionally exchanged to be used by tools which have an interest in the computed buses.	Information
EXCH3.	For node-breaker model exchanges mRID (rdfIDs in serialisation) of the TopologicalNodes are not persistent.	Information
EXCH4.	For node-breaker model exchanges a topology instance file is not exchanged using a difference file.	Requirement
EXCH5.	For bus-branch model exchanges the TopologicalNodes must be persistent.	Requirement
EXCH6.	If a contingency list is exchanged belonging to the model exchanged in bus-branch detail, it shall refer to ConductingEquipment (TopologicalNode, branches, etc.). This results in a constraint on interoperability between planning and operation processes.	Requirement
EXCH7.	If a contingency list is exchanged belonging to the model exchanged in node-breaker detail, it shall refer to ConductingEquipment (ConnectivityNode, which is not artificial, Busbar, etc.).	Requirement
EXCH8.	If a model has mixed representation (node-breaker and bus-branch) then the profile URI in the header related to the Equipment Operation is not included as only part of the network will include classes stereotyped with Operation.	Requirement

5 Specifications and functionalities

5.1 General constraints

The following rules are general in nature or involve multiple classes. Additional rules are defined in the notes to the individual classes in the profiles part of the CGMES.

ID	Specification	Type
GENC1.	All objects must have a persistent and globally unique identifier (it is the mRID - see Section 5.2). In the ENTSO-E data exchange process this unique identifier will be exchanged as rdf:ID.	Mandatory
GENC2.	Software solutions shall not use "name" related attributes (name, short name, description, etc. inherited by many classes from the abstract class	Mandatory

ID	Specification	Type
	IdentifiedObject) to link the power system model. Only mRID (exchanged as rdf:ID) is used for this purpose.	
GENC3.	The rdf:ID defined within a data exchange process is the only globally unique and persistent identifier	Mandatory
GENC4.	IEC 61970-552 defines the rdf:ID as UUID and its syntax (i.e. lower case and number of characters for the different groups part of the UUID). UUID algorithm ensures global uniqueness of the identifier. Example UUID: f81d4fae-7dec-11d0-a765-00a0c91e6bf6.	Mandatory
GENC5.	The CGMES defines the identifier as a case sensitive string which conforms to W3C (ISO 8859/1 8-bit single-byte coded graphic character set known as Latin Alphabet No. 1; http://www.w3.org/MarkUp/html3/specialchars.html) with a maximum character limit of 60 characters. A prefix could be added, if necessary, to ensure global uniqueness. The rdf:ID is the mRID plus an underscore "_" added in the beginning of the string.	Mandatory
GENC6.	Applications which conform to the CGMES shall support IEC 61970-552 and rdf:ID expressed as a string.	Mandatory
GENC7.	Each TSO is responsible for ensuring that the rdf:ID is globally unique. ENTSO-E role in ensuring global uniqueness of the rdf:ID is limited to coordination and harmonisation of the approaches used in different data exchanges and which shall conform to GENC4 and GENC5.	Mandatory
GENC8.	rdf:IDs must be kept persistent for all profiles except for State Variable and Diagram layout profiles: • For the State Variable profile the rdf:IDs for state variable classes (SvPowerFlow, SvVoltage, etc.) are not kept persistent. • For the Diagram layout profile the rdf:IDs of DiagramObjectPoint and DiagramObject classes may not be kept persistent	Mandatory
GENC9.	rdf:about expression is used for objects which are exchanged in an instance file for a given profile but defined in a different profile (i.e. exchanged in a different instance file). A stereotype "Description" is introduced to facilitate the implementation of this rule. All classes which shall be expressed by rdf:about are stereotyped with "Description".	Mandatory
GENC10.	UTF-8 is the standard for file encoding. UTF-16 is not supported.	Mandatory
GENC11.	Instance data to be exchanged must make use of the most detailed class possible within a profile, i.e. using sub-typed classes rather than general classes e.g. NuclearGeneratingUnit instead of GeneratingUnit.	Mandatory
GENC12.	Optional and required attributes and associations must be imported and exported if they are in the model file prior to import.	Mandatory
GENC13.	If an optional attribute does not exist in the imported file, it does not have to be exported in case exactly the same data set is exported, i.e. the tool is not obliged	Mandatory

ID	Specification	Type
	to automatically provide this attribute. This is not valid if the user is able to process the data, update the model and perform another export.	
GENC14.	In most of the profiles the selection of optional and required attributes is made on this basis so as to ensure a minimum set of required attributes without which the exchange does not fulfil its basic purpose. Business processes governing different exchanges can require mandatory exchange of certain optional attributes or associations. Optional and required attributes and associations must therefore be supported by applications which claim conformance with certain functionalities of the CGMES. This provides flexibility for the business processes to adapt to different business requirements and base the exchanges on CGMES compliant applications.	Mandatory
GENC15.	Breakers represent busbar couplers in a bus-branch model exchange. In this case, breakers are only included if they are to be retained. In case of a node-breaker model exchange the rules defined in the IEC 61970-452 and in the CGMES profiles shall be applied.	Mandatory
GENC16.	Roles and multiplicity: The direction of the associations in the profiles part of the CGMES is defined in the profiles. All associations are bidirectional, although an association instance is specified only at one end in the instance files. The documentation of the profiles, which is part of the CGMES, describes the association with the end user. It is allowed to include both ends of an association in the XML, although only the end designated by the profile is required. The following two examples present two options which can be seen in the CGMES profiles: • Example 1: The names "ConductingEquipment.Terminals" and "Terminal.ConductingEquipment" specify opposite ends of the association between the ConductingEquipment class and the Terminal class. In a one-to-many association, the association reference is included with the data of the "many side" class. Therefore, a ConductingEquipment can be associated with up to two Terminals, although a Terminal must be associated with one and only one ConductingEquipment. Consequently, the XML element corresponding to the ConductingEquipment class is not expected to contain any "ConductingEquipment.Terminals" elements. However, the XML element corresponding to the Terminal class is required to contain appropriate "Terminal.ConductingEquipment" elements. • Example 2: The names "TopologicalIsland.TopologicalNodes" and "TopologicalNode.TopologicalIsland" specify opposite ends of the association between the TopologicalIsland class and the TopologicalNode class. The XML element corresponding to the TopologicalNode class is not required to contain any "TopologicalNode.TopologicalIsland" elements. However, the XML element corresponding to the TopologicalIsland class is expected to contain appropriate "TopologicalIsland.TopologicalNodes" elements.	Mandatory

5.2 Model authority sets (MAS)

The CIM concept of Model Authority Sets is applied to enable the assembly or extraction of TSO models. Model Authority Sets allow an interconnection model to be divided into disjointed sets of objects, which in turn allows different parties to take responsibility for different parts of a common grid model.

ID	Specification	Type
MAS_1.	In any model exchange governed by the CGMES, each model object has an mRID.	Mandatory
MAS_2.	Across all models, the model object instance which represents a given real world asset (line, transformer, etc.) shall always have the same mRID.	Mandatory
MAS_3.	A CIM functional representation is given by CIM classes defined in CGMES UML. Within any one model, object mRIDs are unique, since the same element shall not be represented twice.	Mandatory
MAS_4.	The mRID shall be persistent for the same given functional representation inside a given version of CIM.	Mandatory
MAS_5.	In the case of upgrading from one version of CIM to another the mRID shall be kept persistent for the same functional representation in the new CIM given by a new CIM class. For instance, the change from CIM 15 to CIM 16 allows for a functional representation identified by the mRID for a ShuntCompensator which is changed to the newly introduced class NonLinearShuntCompensator with the same mRID.	Mandatory
MAS_6.	mRIDs are only generated for concrete classes in a given profile. In most cases there is no overlap of functionality between different concrete classes.	Mandatory
MAS_7.	A new mRID is generated in case there is a need to change the class (e.g. GeneratingUnit is changed to ThermalGeneratingUnit). If a physical unit given by mRID in the asset part of the CIM needs to be represented simultaneously as GeneratingUnit and ThermalGeneratingUnit (a given specialisation) it must have different mRIDs for GeneratingUnit and ThermalGeneratingUnit. If different business processes are required to support both types (GeneratingUnit and ThermalGeneratingUnit) the applications should maintain two mRIDs and in both cases support difference file exchange.	Mandatory
MAS_8.	Only one representation (the main class or its specialisation) should be present in a given instance file.	Mandatory
MAS_9.	Each object instance is assigned to one and only one Model Authority Set. There are two types of Model Authority Sets: • Boundary Sets • TSO sets	Mandatory
MAS_10.	Boundary Sets which contain Boundary points marking the boundary between individual models. Boundary Sets are managed by one authority (ENTSO-E) but have been defined by TSOs as a result of mutual agreement.	Mandatory
MAS_11.	TSO sets contain individual TSO instance files. Objects in the TSO sets have internal associations and have associations to Boundary sets. A TSO set shall	Mandatory

	never have associations with objects in other TSO sets. This allows TSO modelling to be carried out independently of other TSOs	
MAS_12.	Each TSO in ENTSO-E is a Model Authority and manages a Model Authority Set in its area of responsibility. The TSO as Model Authority is also responsible for assigning and maintaining object mRIDs in its area set.	Mandatory
MAS_13.	The territory that a TSO model represents may not be exactly the same as the territory managed by a TSO. In the CGMES, "TSO territory" always refers to the model responsibility territory.	Mandatory

5.3 File header

The following rules apply to all headers

ID	Specification	Type
HGEN1.	The definition of file header is specified in IEC 61970-552. The CGMES applies the same definition in any model exchange governed by the CGMES, each model object has an mRID.	Mandatory
HGEN2.	Each type of instance file (full and difference) shall have a file header.	Mandatory
HGEN3.	The file header is declared at the top of the instance file i.e. at the beginning of the file.	Mandatory

The following rules are applied to the model ID (rdf:about) in the file header:

ID	Specification	Type
HREF1.	New ID is generated for new instance files only when the context of instance data changes. An export done on the imported instance data without any changes should have the same model ID reference in the header.	Requirement
HREF2.	Dependent IDs refer to IDs of the dependent instance files at the time of the export.	Requirement
HREF3.	If all dependencies are resolved then there shall not be any unresolved references within the data.	Requirement
HREF4.	The dependency reference in the header shall be used as guidance and shall not restrict the possibility of importing profiles which are exported based on a previous version of a depending profile instance file. The standard does not prevent the tools from exchanging files where the file reference does not match. Unresolved or missing references shall be reported to the user. In general, users are free to combine files on an ad-hoc basis and tooling shall identify and optionally resolve all unresolved references.	Requirement
HREF5.	Model ID shall be the same if a re-export of a model contains the same objects and attributes.	Requirement

ID	Specification	Type
	• If the information exchanged with the instance file is the same then the re-export is considered identical. • Rearrangements of classes and attributes in the instance file are allowed.	

5.4 File body

ID	Specification	Type
FBOD1.	The IEC 61970-552 specification is used to format a file, although the instance file shall contain only the objects from one Model Authority Set.	Requirement
FBOD2.	An instance file could contain instance data of more than one profile from the CGMES only if all profile URIs are defined in the file header and as long as the instance data belongs to one MAS. All profile URIs are defined in the file header even if one profile is a superset of another, i.e. both URIs should be included.	Requirement
FBOD3.	Instance files may contain objects with associations to objects which will be packaged in a different instance file. This situation means that the instance file by itself is 'incomplete' – it may have dangling references and cannot be used except when combined with one or more other instance file as specified in the file header dependencies. When this occurs, validation for completeness can only be performed when all the parts are present.	Requirement
FBOD4.	The CGMES requires that at the receiving end of the exchange all references in the instance files pointing to instance files from other profiles which are part of the exchange should be satisfied. Therefore, the complete set of instance files necessary for the grid model must have fulfilled references (no dangling references are allowed).	Requirement
FBOD5.	When a difference model is created difference elements may be created due to very small numeric differences. This is unnecessary and the applications are designed in a way which prevents such meaningless difference files.	Requirement

5.5 Profiles and instance file types

There are nine different profiles in the CGMES. This section defines some specific rules for the profiles and their instance files so that the model exchange can be performed correctly.

5.5.1 CGMES profiles' properties

The profiles which are part of the CGMES are based on IEC CIM UML and maintained in an UML environment.

ID	Specification	Type
PROF1.	The UML namespace, namespaces of the profiles, ENTSO-E extensions, profiles versions as well as the identification of the versions of the UML and profiles are	Requirement

ID	Specification	Type
	defined in a Version class for each profile of the CGMES. These properties shall be used as a primary source for file header information.	
PROF2.	Profile specific notes have been added to various classes and attributes in the UML in order to further clarify different profiles and define specific rules. These notes are considered mandatory and shall be satisfied by the applications	Requirement
PROF3.	Only instances of concrete classes are used in actual exchanges (instance files). Those concrete classes may inherit attributes or associations from abstract classes.	Requirement
PROF4.	The CGMES uses UML stereotypes to categorise classes, attributes and associations used for different exchanges. This is mainly valid for the EQ (equipment) profile where the following categorisation is applied and defines the three different types of equipment instance files supported by CGMES: • EQ core: includes all classes/attributes/associations which are not stereotyped. These elements are part of both node-breaker and bus-branch types of model exchange. • EQ operation: includes all classes/attributes/associations stereotyped with "Operation". These elements are only necessary if a node-breaker model representation is exchanged. • EQ short circuit: includes all classes/attributes/associations stereotyped with "ShortCircuit". These elements are only necessary if a node-breaker or a bus-branch model representation is exchanged for the purpose of performing short circuit calculations	Requirement
PROF5.	The cardinality of given classes/attributes/associations stereotyped with "Operation" or "ShortCircuit" shall be respected if the exchange requires the inclusion of "Operation" or "ShortCircuit". The respective profile URI shall be declared in the file header. If the profile URI is not included in the header all classes/attributes/associations part of the undeclared profile are considered optional.	Requirement
PROF6.	Classes/attributes/associations which were introduced by ENTSO-E and therefore considered as CIM extensions are marked with a stereotype "Entsoe".	Requirement
PROF7.	Any classes/attributes/associations which are defined by the CGMES profiles can be used in grid model exchanges. The authority governing a given business process and related data exchange process shall specify all required attributes/classes/associations to be exchanged. An optional attribute can be required, while a required attribute as defined in the CGMES cannot be changed to optional without modification of the version of the profile. Applications and tools should be able to deal with this complexity and support all classes and attributes depending on the tools' functionalities, i.e. they should at least able to host the data and transfer with no change in case the tool is not able to use the data.	Requirement
PROF8.	All profiles which are part of the CGMES are documented as follows: • UML (XMI), which contains packages "CommonGridModelExchangeStandard" and "Extension". These packages	Information

ID	Specification	Type
	contain all definitions related to the profiles in the CGMES and are a source of other ways in which to document the CGMES. • RDFS, which contains RDF schema files for each profile of the CGMES. The files are generated by the application CimConteXtor. • HTML, which contains HTML documentation for each profile of the CGMES. The files are generated by the application CimConteXtor. • HTML_EA, which contains the HTML native Enterprise Architect export of the "CommonGridModelExchangeStandard" package. • Pdf, which contains detail description of the CGMES profiles.	
PROF9.	Annex E provides references to the CGMES documentation related to a specific version of the profiles.	Information
PROF10.	The dependencies between the profiles belonging to CGMES are defined in the following figure. The diagram defines the "ref" relations that show a dependency between two profiles. Profile schemas (RDFS) shall not be merged to create new joint merged profile definitions. Profile instance files shall list in the file header all profiles that describe the instance data so that an application can load all the profile schemas needed to validate the instance data. The "ref" relation may be added to the profile schemas such that an application working with instance data can use this information to load all needed profile schemas.	Mandatory

ID	Specification	Type
	The "ref" and "opt.ref" (optional reference) are used to indicate possible dependencies at instance data level. These dependencies are provided in the file header.	
PROF11.	The profile references in the file header specifies for which profiles' validation the instance file data is valid for.

The instance data file can contain data from multiple profiles (such as ShortCircuit or Operation) without being declared in the header profile references. However, the data belonging to non-declared profiles does not need to be imported and re-exported as the profiles are not defined in the file header. The user shall be informed if the data is not imported. | Mandatory |

5.5.2 CGMES' extensions

Due the complexity and specificity of the ENTSO-E's and TSOs's business processes, the CIM version used to create the profiles of the CGMES has been extended.

ID	Specification	Type
EEXT1.	ENTSO-E extensions defined in the frame of the CGMES and part of its profiles shall be equally supported in the same way as the IEC CIM.	Requirement
EEXT2.	All extension shall be an addition to an existing standard (CGMES of IEC CIM standards). ENTSO-E extensions which are part of the CGMES are extensions of the IEC CIM. When extending the CGMES it is permitted to create a restriction which does not prevent the validity of the CGMES. While an optional attribute or association can be made required as a part of the profiling work, a required attribute or association cannot be made optional as part of an extension.	Requirement
EEXT3.	Declaring the ENTSO-E Extension URI and the Corresponding Alias: The ENTSO-E extension URI and the corresponding alias shall be declared at the topmost element of your CIM/XML file along with CIM and other URI.

EXAMPLE (URI of the ENTSO-E CIM extension and the alias):

<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:cim="http://iec.ch/TC57/2013/CIM-schema-cim16#
    ….
    xmlns:entsoe="http://entsoe.eu/CIM/SchemaExtension/3/1#">
….
</rdf:RDF> | Requirement |
| EEXT4. | Using Extension URI Alias to Declare the Extended Data is illustrated in the following examples. In the first example the attribute IdentifiedObject.shortName is declared as an extended attribute and prefixed with the extension alias "entsoe". EXAMPLE (declaring an extended attribute):

<cim:ACLineSegment rdf:ID="_ f732688e-bace-4ece-bc2b-5d9792608092">
    <cim:IdentifiedObject.name>DFG-THY 1</cim:IdentifiedObject.name> | Requirement |

ID	Specification	Type

	<entsoe:IdentifiedObject.shortName>Brussels</entsoe:IdentifiedObject.shortName>
	    <cim:ACLineSegment.bch>4.61157E-05</cim:ACLineSegment.bch>
	    <cim:ACLineSegment.r>1.06601</cim:ACLineSegment.r>
	    <cim:ACLineSegment.x>34.28535</cim:ACLineSegment.x>
	    <cim:Conductor.length>45</cim:Conductor.length>
	    <cim:Equipment.aggregate>false</cim:Equipment.aggregate>
	    <cim:ConductingEquipment.BaseVoltage rdf:resource=
	    "#_ 4852044a-e072-441b-bc3c-dc7b00de7e5e" />
	  </cim:ACLineSegment>
	
	In the second example, if an instance of the extended class is declared as extension, then the extended class, i.e. ExtendedClass, and the extended attribute ExtendedClass.extendedAttribute must be prefixed with the extension alias "entsoe". EXAMPLE (declaring an extended instance or object):
	
	<entsoe:ExtendedClass rdf:ID="_ 21d3bbfb-0aec-4e44-8db0-ae2e064b22e2">
	    <cim:IdentifiedObject.name>EX11</cim:IdentifiedObject.name>
	<entsoe:ExtendedClass.extendedAttribute>20</entsoe:ExtendedClass.extendedAttribute >
	       ….
	  </entsoe:ExtendedClass >
	
	The third example illustrates the addition of an association, namely ENTSO-E extension. EXAMPLE (declaring an extended association):
	
	<cim:ACLineSegment rdf:ID="_9cdc68b4-3953-c88a-24de-820873445a59">
	    <cim:ACLineSegment.bch>0.000157</cim:ACLineSegment.bch>
	    <cim:ACLineSegment.gch>0</cim:ACLineSegment.gch>
	    <cim:ACLineSegment.r>1.04001</cim:ACLineSegment.r>
	    <cim:ACLineSegment.x>12</cim:ACLineSegment.x>
	    <entsoe:ConductingEquipment.ExtendedClass rdf:resource="#_9cf549dc-2453-d994-976a-c2ea44773145" />
	    <cim:Conductor.length>30</cim:Conductor.length>
	    <cim:IdentifiedObject.name>B1X3</cim:IdentifiedObject.name>
	  </cim:ACLineSegment>	

EEXT5.	The same principle related to extensions applies to any other extensions. Therefore, if an instance file produced by a given application/software contains some extensions specific to vendors' internal applications, the same method to declare such extended data shall be used.	Requirement
EEXT6.	An instant file which contains classes, associations and attributes not defined in the CGMES shall be processed by the receiving application which would ignore the extensions left undefined by the CGMES and make use of the rest of the data.	Requirement
EEXT7.	Extending an enumerator has to be done by adding a new enumerator which includes the additional values. Both the extended and the standard enumerator	Requirement

ID	Specification	Type
	have to comply with the profile, i.e. if the standard enumerator is mandatory, it shall be included in addition to the new (extended) enumerator.	

5.5.3   Equipment profile and instance file

ID	Specification	Type
EQ__1.	The equipment profile is separated by three functional parts: EQ core, EQ operation and EQ short circuit. The following types of equipment instance files and their relation with the EQ profiles can be exchanged: • Full EQ: contains all classes/attributes/associations defined in EQ core, EQ operation and EQ short circuit profiles. • EQ operation: contains all classes/attributes/associations defined in EQ core and EQ operation profiles. • EQ short circuit: contains all classes/attributes/associations defined in EQ core and EQ short circuit profiles. It covers a bus-branch model exchange which contains short circuit data.	Requirement
EQ__2.	An equipment instance file describes the equipment in the power system model covered by a MAS.	Requirement
EQ__3.	An equipment instance file would not normally change in case of frequent data exchange process. It can be updated with difference file exchange.	Requirement
EQ__4.	The SIPS allows for sharing of Protective Actions among different triggering conditions. SIPS should, when possible, have multiple trigger condition and/or protective action that would make it work in all different environments. Measurement classes and references to them are excluded from the profile.	Information
EQ__5.	If a generator is taken out by disconnecting switch it should be also be a protective action that take generator out of service, i.e. Equipment.inService = false.	Mandatory

5.5.4   Topology profile and instance file

ID	Specification	Type
TP__1.	A topology instance file contains all topology objects for a MAS. These topology objects reference the corresponding equipment describing how equipment is electrically connected.	Requirement
TP__2.	A topology instance file is the result of a network topology processing analysis. Because of this the topology instance file is considered as an output if the exchange is based on a node-breaker model exchange.	Information

ID	Specification	Type
TP__3.	Depending on the data exchange process a topology instance file may or may not change frequently. E.g. a topology instance file can be updated using difference file exchange in case of bus-branch model exchange.	Information

5.5.5 Steady state hypothesis profile and instance file

ID	Specification	Type
SSH_1.	A steady state hypothesis instance file contains all objects required to exchange input parameters to be able to perform load flow simulations.	Requirement
SSH_2.	A steady state hypothesis instance file is always exchanged in full. Due to the nature of the SSH profile, all objects in an steady state hypothesis instance file shall have persistent mRIDs and rdf:IDs.	Requirement

5.5.6 State variables profile and instance file

ID	Specification	Type
SV__1.	A state variable instance file contains all objects required to complete the specification of a steady-state solution.	Requirement
SV__2.	A state variables instance file is always exchanged in full.	Requirement
SV__3.	A state variables instance file of an assembled model contains state variables related objects for all model authority sets being part of the assembled model.	Requirement

5.5.7 Boundary equipment profile and instance file

ID	Specification	Type
EQBD1.	A boundary equipment instance file contains all objects defined in the boundary equipment profile and includes data for boundary information relating to a given exchange.	Requirement
EQBD2.	The boundary equipment profile defines which instance data represents types or voltages which are agreed for the CGMES based exchanges. Therefore, individual grid models shall refer to the boundary equipment instance file to use declared EnergySchedulingType-s and BaseVoltage-s. This does not limit different model authorities when it comes to defining additional types or voltages in their instance files, although there shall not be an overlap of data values between boundary equipment files and individual grid model instance files. For instance, ENTSO-E boundary equipment file defines base voltages for both 380 kV and 400 kV to which TSOs instance files should refer and not redefine these base voltages in their instance files.	Requirement

ID	Specification	Type
EQBD3.	Boundary equipment instance files can be updated using difference file exchange.	Requirement

5.5.8 Boundary topology profile and instance file

ID	Specification	Type
TPBD1.	A boundary topology instance file contains all objects defined in the boundary topology profile and includes data for boundary information relating to a given exchange.	Requirement
TPBD2.	A boundary topology instance file can be updated using difference file exchange.	Requirement

5.5.9 Diagram layout profile and instance file

A diagram instance file is based on the IEC 61970-453 Diagram layout profile standard and contains data necessary for the model diagram.

ID	Specification	Type
DL__1.	A full Diagram (non-difference instance file) represents a new drawing of the diagram. Data may change from one system drawing to another, e.g. two diagrams with the same mRID of the classes in the instance files do not need to be identical. The purpose of Diagram layout profile is to support the understanding of the equipment data. If a diagram generated by one system is updated by another the file does not need to be identical, with the exception of the edited changes. However, the updated and exported diagram instance file must include all the same relevant information and must have the same layout rendering in the new destination system (old source) as the original, with the exception of the changes. The expected behaviour is that a diagram may have a new layout with the same Diagram mRID as well as DiagramObject mRID. Persistence of Diagram and DiagramObject mRIDs is required if difference updates are supported.	Requirement
DL__2.	The objects in the equipment of the Diagram Layout instance are identified by the DiagramObject.IdentifiedObject.	Requirement
DL__3.	The diagram layout profile supports exchange of more than one diagram, e.g. detailed substation diagram, single line diagram, etc in one instance file of DL profile.	Requirement
DL__4.	A diagram layout instance file is always exchanged in full.	Requirement

5.5.10 Geographical location profile and instance file

ID	Specification	Type
GL__1.	A geographical data instance file contains GIS data and is constructed based on IEC 61968-4, although it is limited to the classes which cover ENTSO-E needs.	Information
GL__2.	A geographical data instance file is exchanged in full, although it could be updated using difference file exchange.	Requirement

5.5.11 Dynamics profile and instance file

ID	Specification	Type
DY__1.	A dynamics instance file represents the parameters necessary to model dynamic behaviour of the power system, e.g. transient and subtransient reactances of synchronous machines, parameters of the control block diagrams of excitation systems, turbine, governors, power system stabilisers, etc.	Information
DY__2.	A dynamics instance file would not normally change in case of frequent data exchange processes. It can be updated using difference file exchange.	Requirement

5.5.12 Manifest profile and instance file

ID	Specification	Type
MF__1.	A manifest instance file contains all objects required to complete the specification of a meta data of the models exchanged in a given business process. Therefore it describes the content the included in the exchange models.	Requirement
MF__2.	A manifest instance file is exchanged in full.	Requirement

5.5.13 Contingency profile and instance file

ID	Specification	Type
CO__1.	A contingency instance file contains all objects required to complete the specification of the contingency that has been studied and validated.	Requirement
CO__2.	A contingency instance file is exchanged in full.	Requirement

5.5.14 Availability Plan profile and instance file

ID	Specification	Type
AP__1.	An availability plan instance file contains all objects required to complete the specification of equipments' non availability for the study period.	Requirement
AP__2.	An availability plan instance file is exchanged in full and with a complete set for the period.	Requirement

5.5.15 Area Interchange Control profile and instance file

ID	Specification	Type
AIC__1.	An area interchange control instance file contains all objects required to complete the specification of congestion zones with their respective capacity.	Requirement
AIC__2.	An area interchange control instance file is exchanged in full.	Requirement

5.6 File exchange
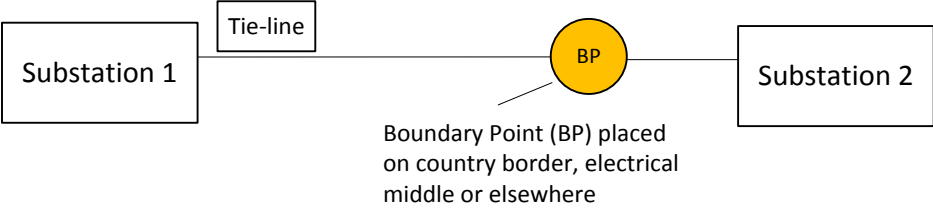
ID	Specification	Type
FILX1.	A given exchange consists of multiple files. The CGMES defines that all files in a given logical exchange must be zipped together[1]. The tools use zip files directly when importing and exporting in order to minimise users.	Information.
FILX2.	The CGMES defines is no naming convention applied to the .xml or .zip file names. Although different business processes may define such a file naming convention, the applications shall rely solely on the information provided in the file headers in order to process the instance files.	Information
FILX3.	One zip file can only contain the following types of files: • A single instance file of the following types: equipment (EQ), boundary equipment (EQ_BD), topology (TP), boundary topology (TP_BD), steady state hypothesis (SSH), state variables (SV), dynamics (DY), diagram layout (DL), geographical location (GL).	Information

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[1] Note that a given business process may require the instances to be exchanged in individual zip files
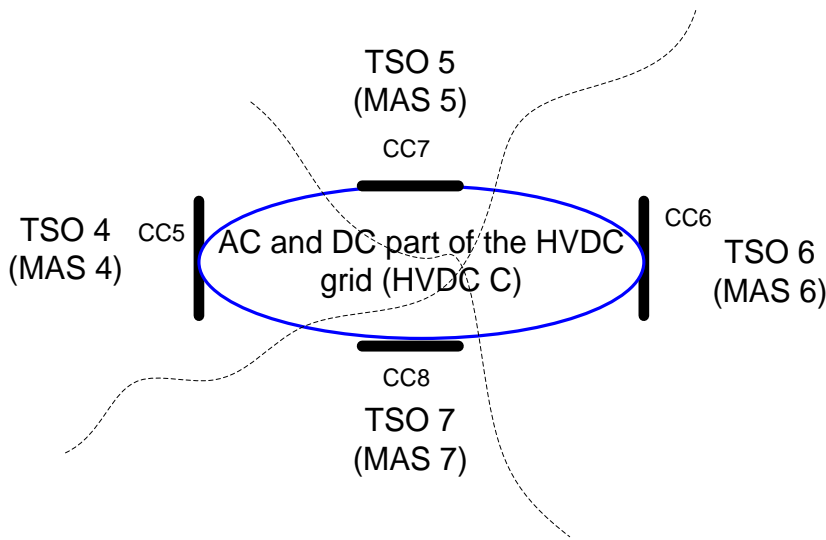
ID	Specification	Type
	• Combinations of equipment, topology, steady state hypothesis, state variables, dynamics, diagram and geographical instance files which are allowed by the CGMES and are related to one MAS only. • Difference files of one MAS only when exchanging a TSO model. • Equipment, topology, steady state hypothesis, state variables, dynamics, diagram and geographical files per MAS for an assembled model. • Difference files per MAS for an assembled model. • Boundary MAS instance files (full or difference or the assembled model is expressed with difference files) shall always be included in the zip file containing an assembled model	
FILX4.	The zip file shall not contain folders. It is only a container of *.xml files.	Requirement
FILX5.	The hierarchy and model dependency shall be respected when exchanging models. The number of files and the type of the files (full or difference) depends on the requirements set by the business process. The following examples show some possible situations: • If the equipment file is changed, all files (depending on the requirements of the exchange: equipment, topology, steady state hypothesis, state variables, dynamics, diagram and geographical files) must be sent as part of any exchange. • If only the steady state hypothesis file is changed, only the steady state hypothesis file must be sent as part of any exchange if there is no requirement to exchange the solved power system model. • If only the state variables file is changed, only the state variables file must be sent as part of any exchange. • If only the dynamics file is changed, only the dynamics file must be sent as part of any exchange. • If only the diagram file is changed, only the diagram file must be sent as a part of any exchange. • If only the geographical file is changed, only the geographical file must be sent as a part of any exchange.	Requirement
FILX6.	It is not allowed to exchange a topology file, a steady state hypothesis file, a state variables file, a dynamics file, a diagram file or a geographical file from one model and an equipment file from another model (or from an entity which has changed the equipment file) and attempt to assemble all files into one assembled model.	Requirement
FILX7.	In case difference files are exchanged, the same dependences as for full model exchange are followed. The difference file (e.g. equipment, topology or dynamics) should refer to the base model which is subject to an update. Dependencies are listed in the file header of each file which is exchanged	Requirement
FILX8.	CGMES supports Efficient XML Interchange (EXI), defined by W3C, as an alternative way of achieving smaller, faster, more efficient serialisation of XML data. Information about EXI is available here: • http://www.w3.org/XML/EXI/	Requirement

ID	Specification	Type
	• http://www.w3.org/XML/EXI/report.html This format is not a replacement for the CIM RDF XML that previous versions of the CGMES used. Instead it is a complimentary standard providing an alternative serialisation of the same data that is focussed on efficiency and speed and offers drop-in replacements that is already compatible with existing code. Business processes using CGMES will define the required schedule for implementation considering longer transition period form xml/zip to EXI exchange.	
FILX9.	Applications shall support cimx file extension, which is a zip file.	Mandatory

5.7 Boundary point – properties and location

ID	Specification	Type
BPPL1.	EquivalentInjection classes are used to represent the power flow exchanges through Boundary points. These classes are included in the individual model MAS (TSO MAS) and refer to the Boundary points in the Boundary set. A SvInjection class is not used for this purpose.	Requirement
BPPL2.	In case the use cases require the exchange of multiple SSH, TP, SV, etc. instance files which are dependent on an EQ instance file, this EQ shall always include an instance of EquivalentInjection per Boundary point. Therefore, in a multi TSO exchange a Boundary point will always have two EquivalentInjections per Boundary point contained in different TSO MAS. Rdf:IDs of those EquivalentInjections are kept persistent.	Requirement
BPPL3.	There are two options related to the location of the Boundary point (BP) in a network model representing the AC grid only: • Boundary point placed on a tie-line: The CGMES does not fix the position of the Boundary point on a tie-line. The Boundary point can be placed on a country border, at the electrical middle of the tie-line, or elsewhere based on mutual agreement between the two neighbouring MAS. Tie-line Substation 1 — BP — Substation 2 Boundary Point (BP) placed on country border, electrical middle or elsewhere	Requirement

ID	Specification	Type
	• Boundary point placed in a substation: The CGMES allows a Boundary point to be placed in a substation. The two neighbouring MAS shall agree between which two elements in a substation the Boundary point is placed. 	
BPPL4.	The CGMES supports HVDC modelling for a detailed representation of HVDC interconnections, TSO internal HVDC links and HVDC grid. The figures below illustrate different cases. Figure 1 - HVDC as interconnection or internal line	Information

ID	Specification	Type
	Figure 2 - HVDC grid	
BPPL5.	There are two main representations/exchanges of an HVDC link which are supported by the CGMES: • Simplified exchange (no exchange of the AC/DC part of the HVDC interconnections. A HVDC link is represented with two radial AC lines) • Detail exchange (AC/DC part of HVDC links is exchanged)	Information
BPPL6.	In the simplified exchange of an HVDC link the net interchange between the MAS is represented by EquivalentInjection classes referring to each common coupling node (CC).	Requirement
BPPL7.	The simplified exchange of an HVDC link could be applied to internal HVDC links (systems) as well as to HVDC interconnections.	Information
BPPL8.	In the detail exchange of an HVDC link the HVDC grid shall be exchanged as a MAS: • Separate instance files (EQ, TP, SSH, SV) are included in this MAS. • In case one TSO is responsible for the HVDC, the HVDC model is included in the TSO MAS (EQ, TP, SSH, SV).	Requirement
BPPL9.	In case of a detail exchange of an HVDC link, the HVDC MAS shall refer to the common coupling points (ConnectivityNode or to TopologicalNode) included in the Boundary set.	Requirement
BPPL10.	In case of more than one HVDC interconnection (including interconnections with different TSOs) the TSO can include them in a single HVDC MAS or in its own MAS.	Information

ID	Specification	Type
BPPL11.	In particular cases a Boundary point can be placed on a DCLineSegment and could possibly represent a different authority. The CGMES does not allow for the separation of the HVDC model at this specific Boundary point. It only makes sense to add a Boundary point with a location to identify certain responsibilities	Information

5.8 Model assembling process

ID	Specification	Type
MAPR1.	A complete (assembled) common grid model (solved or unsolved power system model) contains information from more than one model authority set. Part of the reason for the division into files per MAS is to create better flexibility when it comes to how complete assembled models for different purposes are formed from base parts. Model management systems can be designed based on this capability.	Information
MAPR2.	Among instance files which are to be combined to form an assembled model, there is no overlap – each object, association or attribute appears in one and only one of the instance files being combined.	Requirement

MAPR3.	The model assembling procedure in the CGMES is based on the Model Authority Sets concept. The procedure includes the following steps:
	
	• Model management system (calculation tool/software) imports all MAS (full set of files for MAS for each TSO and Boundary MAS). Depending on the implementation of the import process, the Boundary MAS must be imported first in case other MAS are subsequently imported. The following files/MAS should be available for import.
	   ○ At least two models from TSOs are available and represented in two different MAS. These models have necessary references to the Boundary set.
	   ○ TSO models which include classes (EquivalentInjection for SSH profile; SvPowerFlow and SvVoltage for SV) represent the flow between the MAS and the voltage of the Boundary points.
	   ○ Boundary MAS: Boundary instance files (equipment and topology) cover, but are not limited to, the area represented in the common grid model.
	• SvVoltage classes pointing to the Boundary set are set to the nominal voltage of the Boundary Node with zero angles in case the values for EquivalentInjection pointing to a Boundary Node are different.
	• EquivalentInjection.p and EquivalentInjection.q are set to zero, if a tie-line or a ConnectivityNode is connected. It is not necessary that these parameters be set to zero at the time of the import. Additional functions should be made available for users to cover all necessary use cases when dealing with TSO MAS and Boundary MAS.
	• A power flow can be performed to obtain a solution for the assembled power system model.
		Requirement

ID	Specification	Type
MAPR4.	An update of the assembled power system model is performed via an update of the concerned MAS (i.e. replacing of MAS files). A power flow solution is necessary to update the common state variables file valid for the updated assembled model.	Requirement
MAPR5.	State variable instance file for the common grid model include SvPowerFlow for injections of Boundary points. In order to solve an assembled model these injections are set to zero in case a Boundary point successfully connects the two MAS. Some injections (SvPowerFlow) may differ from zero to represent the exchange with other areas not included in the assembled model.	Requirement
MAPR6.	The exported assembled model shall have only one instance of SvVoltage per Boundary point.	Requirement
MAPR7.	The CGMES does not fix the content of an assembled grid model. Different business processes shall define the type (EQ, SSH, TP, SV, etc.) of data needed in the assembled model depending on the objectives.	Information
MAPR8.	The CGMES supports export of unsolved assembled model. The model can be a node-breaker or bus-branch model representation type, and shall always include SSH instance files if the purpose of the exchange is to perform (without data additions) a load flow calculation in a different application.	Information
MAPR9.	The exported assembled model contains multiple MAS. These exported multiple MAS include all changes which are introduced on the assembled model (changes made in the software which is used to assemble the model) per MAS. The following chart illustrates the assembly process:	Requirement

ID	Specification	Type
	TSO A: one MAS; set of files - zipped TSO B: one MAS; set of files - zipped ● ● ● TSO N: one MAS; set of files - zipped

Import

Boundary MAS (equipment and topology files) - zipped

Software for power flow/simulations

1. Import – all MAS (first Boundary then TSOs)
2. Set EquivalentInjection to zero (user's input needed)
3. Run power flow/simulations
4. User modifies assembled model including data in the individual MAS, if necessary and run power flow/simulations
5. Export of assembled model – per MAS including all modifications introduced using the tool

Export

Assembled power system model – one zip file; multiple MAS representing TSOs models and boundary MAS

TSO A: one MAS; EQ, TP, SSH, DY,GL   ● ● ●   TSO N: one MAS; EQ, TP, SSH, DY,GL

Boundary MAS: equipment and topology files

A Diagram file exported by the assembling MAS

A State variables file exported by the assembling MAS | |

ID	Specification	Type
MAPR10.	The model authority set of the state variable instance file of the assembled model is not defined in the file header.	Requirement
MAPR11.	The model authority set of the diagram layout instance file of the assembled model is not defined in the file header.	Requirement

5.9 RDF/XML model validity

In order to be considered a valid model, a given combined set of RDF/XML must adhere to the following criteria:

ID	Specification	Type
MVAL1.	The file must be well-formed as defined by the Extensible Markup Language (XML) 1.0 (Second Edition) (http://www.w3.org/TR/REC-xml).	Requirement
MVAL2.	The file must adhere to the rules set forth in the Simplified RDF Syntax for Power System Model Exchange as defined in IEC 61970-552.	Requirement
MVAL3.	The file must contain CIM entities which are valid according to the CIM RDF Schema file.	Requirement
MVAL4.	Use of IEC 61970-552 Ed2 for all profiles that are created in CGMES 2.5 • rdf:ID is replaced with rdf:about "urn:uuid:"+mRID; • rdf:about that refers to rdf:ID shall also be replaced with rdf:about "urn:uuid:"+mRID reference. The existing profiles from CGMES 2.4 could be serialised using IEC 61970-552 Ed1 for processes that needs backwards compatibility. However, for conformity it is allowed that a system only can serialise using IEC 61970-552 Ed2. A CGMES 2.4 importer can also support IEC 61970-552 Ed2. If a file is imported as IEC 61970-552 Ed1 with rdf:ID, and then exported according to IEC 61970-552 Ed2, the application needs to use rdf:about "urn:uuid:"+mRID if it is an UUID. If it not an UUID it should be left as is. The preferred serialization for CGMES 2.5 is IEC 61970-552 Ed2.	Requirement

5.10 Naming Convention

The naming convention of any profile is important in order to ensure that the information which is part of the data exchange can be understood and used. A power system model without appropriate naming information cannot be readily used for any human analyses and thus loses its meaning. Naming is complex issue as different applications can have inconsistent and sometimes conflicting naming conventions.

The CGMES, which uses multiple profiles, serves various business processes. These business processes have different needs in terms of naming information. There is no single set of rules which could be applied to deal with the specificities of different business processes axes such as:

- Bilateral, regional, ENTSO-E – pan-European data exchanges;
- Operational (day ahead and related processes), long term planning data exchanges;
- Node-breaker, bus-branch based data exchanges;
- Voluntary, project oriented, obligatory by an ENTSO-E process, obligatory by law data exchanges.

A restriction related to naming could serve one business process well but may represent a significant constraint for another business process. In addition, actors involved in the exchange are not necessarily the same.

CGMES applies the following naming principles:

- Names are mainly for humans. They shall not be used for any purposes object identification.
- Naming rules shall be driven by the use cases (mainly information presentation), not restricted by limitations of vendors systems and UML/profiling tools.
- Names are important in many cases. But restrictive requirements on naming may result in the interoperability issues. For example, the dynamically-created names may not be storable in the underlying data source, resulting in information loss.
- Physical modelling entities, such as Substation, Equipment, etc., require a name to be specified, while naming is optional for the components that make up a physical modelling entity, such as Terminal, RatioTapChanger, etc.
- Conceptual modelling entities may or may not require a name to be specified depending on whether these modelling entities shall be presented to end-users. DiagramObjects, for example, are meaningless for human audiences. TopologicalIsland, on the other hand, may require a name to be provided, since they could be shown in the power flow reports.
- Name of conceptual modelling entities shall be optional whenever possible. For example, if the conceptual modelling can be characterized by one or a combination of its attributes, then naming shall be optional. As an example, name for BaseVoltage may not be required, since it is characterized by attribute BaseVoltage.nominalVoltage, which could optionally serve as name. By the same token, if a conceptual modelling entity is uniquely associated with a physical modelling entity, then its name can be derived from the associated physical modelling entity if needed.

Therefore, the objective of the CGMES naming convention is to define a common framework related to naming rules which could be further restricted by different business processes.

The following rules related to the naming convention are defined:

ID	Specification	Type
NAMC1.	A template for further defining constraints related to the naming convention is provided in Annex A. The template shall be used by experts defining naming convention rules within a business process. The template shall be completed by a profile (EQ, TP, SV, etc.). As soon as a business process is defined and data exchange requirements agreed, the tables related to different profiles should be made available to all parties participating in the data exchange and vendors should be informed. This will allow: • TSO experts to be aware and respect requirements related to naming in the models.	Information

ID	Specification	Type

	• Vendors developing tools for power system analyses to ensure that:
	   o TSO experts are able to supply the names as required by the business process;
	   o An agreement for naming translation between requirements in the business process and the proprietary formats or TSO databases is in place;
	   o Export and import functionalities are compliant with the data exchange rules.
	• Vendors developing validation tools to adjust validation rules valid for the business process	

NAMC2.	The restrictions related to the naming convention are considered obligatory for any tool importing or exporting naming data if the tool claims compliance with the CGMES.	Requirement
NAMC3.	Further restrictions can be applied by different business processes. Business processes restrictions on naming must define required and optional attributes related to naming. These restrictions or rules should not contradict this naming convention and are considered mandatory for all parties participating in a given business process. • Tools used to validate instance data shall be able to validate against different sets of naming conventions which are applied to exchanges based on the CGMES. • Tools used for various power system analyses shall provide users with the opportunity to cope with different naming rules. These tools shall be developed to support the full scope of this naming convention.	Requirement
NAMC4.	Due to the current inheritance structure of the CIM used for the profile, the naming convention primarily addresses the attributes of the class IdentifiedObject. However, there are certain exceptions, including Boundary profiles whereby some ENTSO-E extensions are applied to ConnectivityNode and TopologicalNode.	Information
NAMC5.	The name related attributes have an informational character intended for human reading for explanations outside the classes. Software solutions must not count on this information to complete physical links of the power system model. All necessary links between different parts of the CIM XML are expressed by the reference schema which uses rdf:ID	Requirement
NAMC6.	Names shall conform to UTF-8	Requirement
NAMC7.	In cases where tools using instance data (compliant with the CGMES exchanges) need uniqueness rules, this shall be handled in the importing function based on requirements defined by the users.	Requirement
NAMC8.	It is obligatory that information exchanged in name related attributes is not modified by the tools within an exchange, i.e. • step 1: Tool A imports data from Tool B and modifies initial information to fit user requirement of tool limitation;	Requirement

ID	Specification	Type
	• step 2: Tool A is obliged to export the imported data in the same form and content as the data exported from Tool B. One of the main reasons behind this rule is the fact that exchanges in the ENTSO-E are meant to be bi-directional, i.e. there is a sending party and a receiving party which exchange models within studies and do not necessarily consume only the data.	
NAMC9.	It is mandatory that tools shall provide users with the ability to add and maintain naming related information for classes which represent physical equipment as well as classes which represent elements important for business processes (e.g. TopologicalNode). This information is then mapped onto relevant attributes and can be exported for the purpose of the exchange.	Requirement
NAMC10.	There is no need for a specific naming convention when it comes to the names of the instance files due to file header information which is defined by IEC CIM standards and the CGMES.	Information
NAMC11.	The following tables summarise the use of name related attributes in the different profiles. It provides the length of the strings which tools must support for all classes that inherit from IdentifiedObject or on ConnectivityNode and TopologicalNode.	Requirement

Table 1 — IdentifiedObject attributes

IdentifiedObject	String length, characters	Equipment profile	Topology profile	Study State Hypothesis profile	State variables profile	Diagram layout profile	Geographical location profile	Dynamics profile
.name	32 max	✓r	✓o	✓o	✓r	✓r	✗	✓o
.description	256 max	✓o	✓o	✗	✗	✗	✗	✓o
.energyIdentCodeEic	16 exactly	✓o	✓o	✗	✗	✗	✗	✗
.shortName	12 max	✓o	✓o	✗	✗	✗	✗	✗

Table 2 — IdentifiedObject attributes for ConnectivityNode in EQ_BD profile and for TopologicalNode in TP_BD profile

IdentifiedObject	String length, characters	Boundary equipment profile	Boundary topology profile
.name	32 max	✓r	✓r
.description	256 max	✓r	✓r
.energyIdentCodeEic	16 exactly	✓o	✓o
.shortName	12 max	✓r	✓r
.fromEndIsoCode	2 exactly	✓r	✓r

ID	Specification					Type
	.toEndIsoCode	2 exactly	✓r	✓r		
	.fromEndName	32 max	✓r	✓r		
	.toEndName	32 max	✓r	✓r		
	.fromEndNameTso	32 max	✓r	✓r		
	.toEndNameTso	32 max	✓r	✓r		
	Legend: ✓r – the attribute is present in the profile and required (required means that it is mandatory that this attribute be present in the instance data); ✓o - the attribute is present in the profile and optional; ✗ - the attribute is not present in the profile.					
NAMC12.	Additional specific rules related to the naming attributes are included as notes in the profile specifications. These notes are considered as mandatory rules. The same rules are summarised in Annex B.					Requirement
NAMC13.	OCL validation rule in the TP profile defines in which cases the attribute IdentifiedObject.name is required.					Requirement
NAMC14.	Name related attributes of the IdentifiedObject that are required can be exchanged as empty string i.e. <IdentifiedObject.name>< IdentifiedObject.name>.					Requirement

5.11 Modelling specifications

The following modelling specifications are defined to support the implementation of the CGMES.

ID	Specification	Type
MSPEC1.	RegulatingControl description specifies that in case multiple equipment, possibly of different types, control same terminal there must be only one RegulatingControl at that terminal. The most specific subtype of RegulatingControl shall be used in case such equipment participate in the control, e.g. TapChangerControl for tap changers. This setup is illustrated in the following figure. The applications shall ensure that the controlled terminal is the one of the controlled node.	Mandatory

ID	Specification	Type
	Node 1 Node 2 Terminal 2 TR1 Terminal SM1 Terminal 1TR1 Transformer - TR1 Synchronous Machine (SM) 1 **TapChangerControl** RegulatingControl.enable=true RegulatingControl.mode=voltage RegulatingControl.discrete=true RegulatingControl.enable=true RegulatingControl.mode=voltage RegulatingControl.discrete=false **RegulatingControl** Node 3 Transformer - TR2 Terminal 2 TR2 Terminal SM2 Terminal 1 TR2 Synchronous Machine (SM) 2	
MSPEC2.	CGMES requires the following implementation related to the tap change and phase shift transformers: • TapChanger.neutralU is the voltage at the terminal of the PowerTransformerEnd associated with the tap changer when all tap changers on the transformer are at their neutralStep position. Normally neutralU of the tap changer is the same as ratedU of the PowerTransformerEnd, but it can differ in special cases such as when the tapping mechanism is separate from the winding more common on lower voltage transformers. For CGMES neutralU equals ratedU. • RatioTapChanger.stepVoltageIncrement shall be in per cent of neutral voltage, per step position, not nominal. The right description of this attribute is: Tap step increment, in per cent of neutral voltage, per step position. • Nominal quantities are not related to the equipment but to the system nominal voltage in the grid. • Rated quantities such as ratedU are related to the nameplate data. • TapChanger.neutralStep is the step position where the voltage is neutralU when the other terminals of the transformer are at the ratedU. If there are other tap changers on the transformer those taps are kept constant at their neutralStep. • For PhaseTapChangerAsymmetrical, PhaseTapChangerSymmetrical and PhaseTapChangerLinear the neutralU is not relevant.	Mandatory

ID	Specification	Type
	• PhaseTapChangerNonLinear.voltageStepIncrement relates to the ratedU. The voltageStepIncrement is used for PhaseTapChangerAsymmetrical, PhaseTapChangerSymmetrical. • SvTapStep.position shall be required even if the TapChanger.controlEnabled is set to false. • As CGMES requires neutralU to be equal to ratedU, the following implementations are valid: ratedU + ratedU* stepVoltageIncrement*(SvTapStep.position-neutralStep) neutralU + neutralU*stepVoltageIncrement*(SvTapStep.position-neutralStep) neutralU + ratedU*stepVoltageIncrement*(SvTapStep.position-neutralStep) ratedU + neutralU*stepVoltageIncrement*(SvTapStep.position-neutralStep)	
MSPEC3.	Control of tap changers in a power flow type of application is made using the TapChangerControl class and the TapChanger.ltcFlag. If a TapChanger has a TapChangerControl (referenced TapChanger.TapChangerControl) means that the power flow application may control the tap changer. The TapChanger.ltcFlag provides information that the TapChanger has physical capability to move the tap under load. Also used in the IEC 60909 calculations to indicate if the tap can move on load. The meaning of the combinations for TapChanger.TapChangerControl and TapChanger.ltcFlag are described in the following table**Error! Reference source not found.**.	Mandatory

TapChanger. ltcFlag	TapChanger. TapChangerControl	Description
False	Not present	A real and fixed tap that is not controlled and cannot be moved on load (manual tap change). Power flow cannot be set to change the tap for voltage control during the calculation.
True	Not present	A real and fixed tap that is not controlled but can be moved under load, e.g. manually. Power flow cannot be set to change the tap for voltage control during the calculation. Optimal power flow might have access to these taps and change in order to optimize. Also State Estimator may estimate the tap position to find a better solution for the system state.
True	Present	A real tap with a possibility to change taps automatically for voltage control/active power (load flow) enabled. Depending on the RegulatingControl.enabled and TapChanger.controlEnabled in SSH, the power flow shall or shall not participate in the regulation. In cases where the RegulatingControl is associated with more than one tap changer or other devices the attribute TapChanger.controlEnabled can

ID	Specification			Type
			be set to false in order to set which of the taps are not enabled.	
	False	Present	An artificial tap changer can be used to simulate control behavior in power flow.	
	Please note that SvTapStep is required for all TapChangers.			
MSPEC4.	CGMES supports ACLineSegment-s between different terminal voltages. The following implementation is required: • All implementations shall use association to a BaseVoltage for the purpose of any per unit calculations and shall not rely on the voltages (neither nominal nor actual values obtained by previous or current solution) at the nodes, which the ACLineSegment connects to. • In case there are interconnected ACLineSegments with different BaseVoltage for different parts of the networks (when assembling different model authority sets) the application needs to handle this to ensure accurate physical units.			Mandatory
MSPEC5.	The following best practice implementation is recommended related to GeographicalRegion ans SubGeographicalRegion: • One GeographicalRegion should be exchanged per MAS. In case TSOs have a need to have the same GeographicalRegion (i.e. multiple TSOs in a country) the class GeographicalRegion shall be present in all TSO models and shall have different rdf:ID, but can have same name/description. • SubGeographicalRegion is normally a TSO or sub-area of a TSO. • There is no specific naming convention defined.			Mandatory
MSPEC6.	It is allowed to have values for GeneratingUnit.normalPF which sum is different than 1. The application that imports such model shall have a load flow calculation logic setup (for different MAS that use very different normalPF values, the values must be normalized) to use the information for the purpose of the distributed slack and preserve the original values of GeneratingUnit.normalPF in case of export. Example of GeneratingUnit.normalPF values (before normalization) for different MAS			Mandatory
MSPEC7.	The applications shall follow strictly the description of the PowerTransformerEnd which states "for a two Terminal PowerTransformer the high voltage PowerTransformerEnd has non zero			Mandatory

	MAS 1	MAS 2	MAS 3
GeneratingUnit.normalPF for Gen 1	0	200	50
GeneratingUnit.normalPF for Gen 2	0.3	500	60
GeneratingUnit.normalPF for Gen 3	0.4	150	45

ID	Specification	Type
	values on r, r0, x, and x0 while the low voltage PowerTransformerEnd has zero values for r, r0, x, and x0.". The high voltage side is given by the TransformerEnd.endNumber: "Number for this transformer end, corresponding to the end's order in the power transformer vector group or phase angle clock number. Highest voltage winding should be 1. Each end within a power transformer should have a unique subsequent end number. Note the transformer end number need not match the terminal sequence number." In case of a two winding transformer with same rated voltage (PowerTransformerEnd.ratedU) on both sides the application makes sure that only one side has TransformerEnd.endNumber equals to 1. Therefore the parameters are always provided for PowerTransformerEnd which has TransformerEnd.endNumber equal to 1.	
MSPEC8.	PhaseTapChangerTablePoint.angle in CGMES shall be implemented considering that "A positive value indicates a positive phase shift from the winding where the tap is located to the other winding (for a two-winding transformer).	Mandatory
MSPEC9.	The following rules are applied regarding the slack generator: • SynchronousMachine.referencePriority is used to define the slack generator - reference angle. SynchronousMachine.referencePriority is a required attribute in the SSH. • In SSH - SynchronousMachine.referencePriority - Priority of unit for use as powerflow voltage phase angle reference bus selection. 0 = don't care (default) 1 = highest priority. 2 is less than 1 and so on. Please note that GeneratingUnit.normalPF is used for representing distributed slack participation factor. • In SV - TopologicalIsland. AngleRefTopologicalNode - The angle reference node is the TopologicalNode to which a synchronous machine is connected and referenced from TopologicalIsland.AngleRefTopologicalNode. Therefore, this is the TopologicalNode to which a SynchronousMachine is connected and has SynchronousMachine.referencePriority equals 1 in SSH.	Mandatory
MSPEC10.	The attribute SynchronousMachine.qPercent shall be used as a participation factor not necessarily summing up to 100% for the participating devices in the control. The reason for this statement is that the attribute is exchanged in the EQ profile. The participation of the devices regulating particular node can be set in other profiles such as SSH. Therefore, the implementations shall consider this in the load flow calculation and normalize the participation based on what devices are participating in the regulation of a particular node.	Mandatory
MSPEC11.	The TopologicalIsland-s for a merged model which are defined in the state variables instance file for the merged model are created with the	Mandatory

ID	Specification	Type
	solving on the power flow of the merged model, i.e. there are no TopologicalIsland-s defined per MAS in a merged model. In case a solved model is exchanged for a single MAS the state variables profile must include at least one instance of TopologicalIsland.	
MSPEC12.	Interpretation of parameters of PowerTransformerEnd A two winding PowerTransformer has two PowerTransformerEnds. This gives the option to specify the impedance values for the equivalent pi-model completely at one end or split them between the two ends. The impedances shall be specified at the primary voltage side. The left side is the "primary" (high voltage) voltage side.	Mandatory
MSPEC13.	There are two different use cases related to the association Terminal.TopologicalNode: • reduction away of the Switching details to create bus-branch style model intended for traditional planning only. • keep the detailed model including the Switches and provide topology results also about the Switches. In cases of creation of a bus-branch model from a node-breaker model non-retained Switches are of no interest and their Terminal.TopologicalNode references shall not be included. If instead the model is intended to stay node-breaker it is of interest to know • if a Switch has been reduced away indicated by the two Switch Terminal.TopologicalNodes referring the same TopologicalNode. • if an open Switch connect two different TopologicalNodes that is useful when studying the consequences of closing the switch. In this case Terminal.TopologicalNode shall be included for all Switches. If the two sides of a Switch are connected to the same ConnectivityNode this should be considered an error. A Switch with the two sides connected to the same TopologicalNode is valid and normal situation, if not retained. A Switch connecting BusbarSections at different VoltageLevels is an error.	Mandatory
MSPEC14.	UnitMultiplier is not exchanged. It is defined that the multiplier is: • M for W, VA, VAh, Wh, VArh and Var • k for volt • 1 for all the rest of UnitSymbol values.	Mandatory

ID	Specification	Type
MSPEC15.	Load sign convention for SSH and SV is used for attributes where the sign convention is not specified. For reactive power (e.g. on RotatingMachine, StaticVarCompensator, etc.) positive means inductive. For EQ ratings the equipment is used as a reference rather than the node.	Mandatory
MSPEC16.	There shall not be any ground voltage level. The ConnectivityNode connected to the Ground instance belongs to the same containment instance as the grounding device. This means that the Ground instances are contained in the same voltage level where other switching devices are contained with a non-zero BaseVoltage.	Mandatory

6   CGMES governance

The overall governing process of the CGMES is a complex process and includes the following sub-processes:

- Standardisation process – a process to develop the CGMES, and which relies on the latest IEC CIM related standards.
- Interoperability process – the process to conduct IOPs targeting verification of the CGMES and IEC CIM standards. Feedback to standardisation bodies and organisations involved in the development of different profiles which form part of the CGMES.
- Business process – all business processes which use the CGMES, They define requirements and request additional improvements due to business needs.
- CGMES conformance process – this process ensures that tools used by parties involved in an exchange utilising the CGMES are implementing the CGMES correctly.
- Implementation process – the implementation process is triggered by a business process/need. It aims to apply a certain version of the CGMES to a business process.

The following chart illustrates the main stages related to the CGMES.
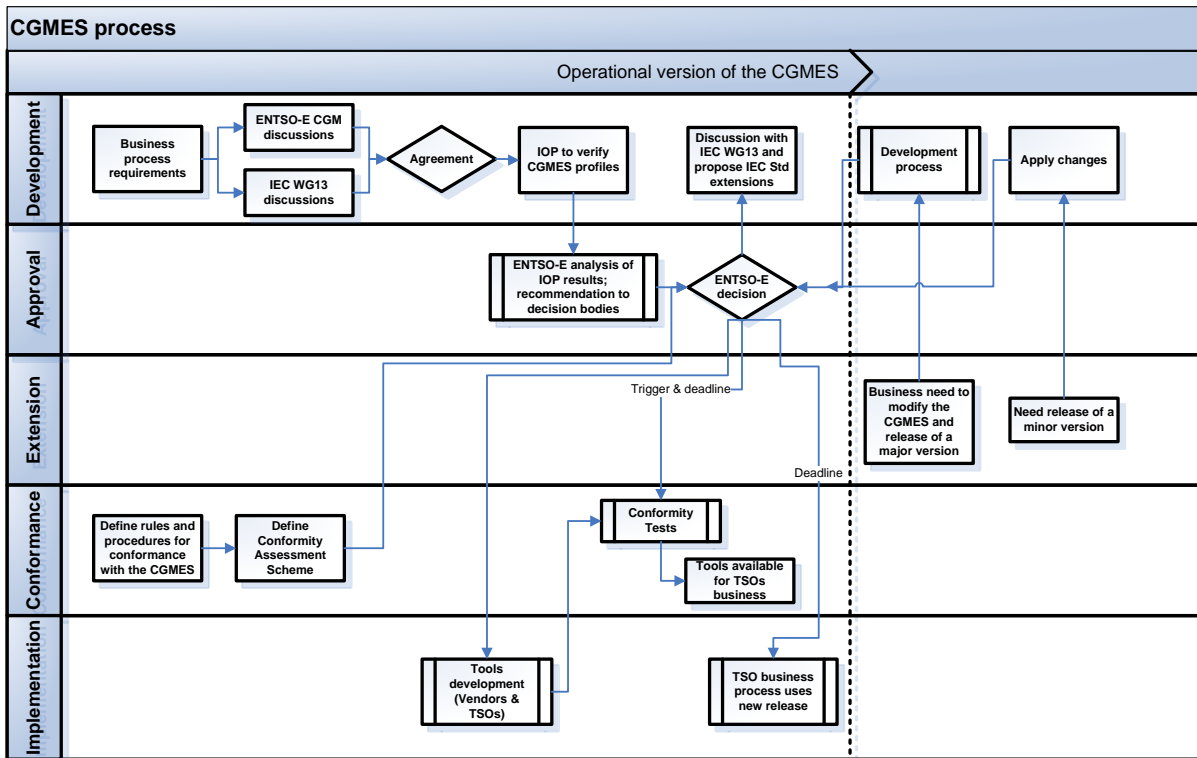
6.1 Versions of the CGMES and the profiles

Each version of the CGMES and the profiles part of the CGMES has its unique version identifier. The following rules related to versioning are defined:

ID	Specification	Type
VERS1.	The format of a version of the CGMES is xx.yy.zzz where xx, yy and zzz are non-negative integers, and must not contain leading zeroes, and: • xx - names the major version of the CGMES • yy – names the minor version of the CGMES • zzz –names the revision version of the CGMES	Requirement
VERS2.	Each profile part of the CGMES is assigned with a version defined by the profile URI which shall be declared in the file header of the instance files. The profile URI is specified in the UML of the CGMES.	Requirement
VERS3.	A profile URI changes every time a minor or a major version of a profile is released.	Requirement
VERS4.	The namespace URI of the ENTSO-E extensions changes every time a minor or a major version of the extension package is released.	Requirement
VERS5.	The namespace UML changes every time the CGMES changes the base version of the CIM, e.g. the base UML changes from CIM 16 to CIM 17.	Requirement
VERS6.	Each of the CGMES profiles is related to a profile defined by the IEC. The ENTSO-E UML lists the base URI of the IEC profiles for information only and to	Requirement

ID	Specification	Type
	link a specific profile of the CGMES to the closest IEC CIM profile. This information is provided in the base URI attribute of the version class to each profile of the CGMES	
VERS7.	A minor version is a compatible change to a profile. The minor version must be incremented if new, backwards compatible functionality is introduced to the CGMES. It must be incremented if any functionality is marked as deprecated. It may be incremented if substantial new functionality or improvements are introduced to the CGMES by adding additional profiles and/or ENTSO-E extension. It may include revision level changes. Revision version must be reset to 0 when minor version is incremented.	Requirement
VERS8.	The number of a major must be incremented if any backwards incompatible changes are introduced to the CGMES, e.g. something is deleted. It may include minor and revision level changes if the amount of changes is significant. The major version will also be incremented if one or more profile is no longer backwards compatible. Minor and revision version numbers must be reset to 0 when major version is incremented.	Requirement
VERS9.	Updates belonging to a minor version update should not break the interoperability for a major profile exchange. This means that a tool which supports a profile version, e.g. 2.4 (2 major version, and 4 minor version) shall be able to import a file which is generated based on profile version 2.5 where all the additional classes, attributes and associations are ignored.	Requirement
VERS10.	The revision version must be incremented if only backwards compatible error fixes are introduced. A fix is defined as an internal change that fixes incorrect behaviour. Updating documentation or a class, an attribute or a profile to reflect the intended behaviour are considered error fixes.	Requirement
VERS11.	A pre-release version may be denoted by appending a hyphen and a series of dot separated identifiers immediately following the revision version. Identifiers must comprise only ASCII alphanumeric and hyphen [0-9a-Za-z-]. Identifiers must not be empty. Numeric identifiers must not include leading zeroes. A pre-release version indicates that the version is unstable and might not satisfy the intended compatibility requirements as denoted by its associated normal version. Example: 2.5.0-alpha.	Requirement
VERS12.	Once a versioned package has been released, the contents of that version must not be modified. Any modifications must be released as a new version.	Requirement
VERS13.	The key words "must", "must not", "required", "shall", "shall not", "should", "should not", "recommended", "may", and "optional" in this section of the CGMES are to be interpreted as described in RFC 2119.	Requirement

6.2   Conformity assessment

Conformity assessment of tools is necessary to confirm that tools comply with a given profile part of the CGMES and can be used for model exchange in a given business process. Conformity assessment is business driven and ensures reliability of the model exchanges by confirming interoperability between applications. The conformity assessment processes that shall be followed is defined in the ENTSO-E CGMES Conformity Assessment Framework.

Each new version of a tool shall be tested for conformity with a particular version of the CGMES used in ENTSO-E business processes prior to its usage in the business processes. ENTSO-E members are responsible for ensuring that tools which they use in the frame ENTSO-E business processes conform to the CGMES.

Test configurations (models) representing the main functionalities of the profiles of the CGMES shall be publicly available to all interested parties no later than 3 months after the approval of a major or minor release of the CGMES or its profiles. Depending on the complexity of the changes in the profiles the decision body approving the CGMES shall either confirm this deadline or specify another deadline.

Each new version of the CGMES shall include information on which conformity assessment procedures and test configurations should be updated.

Conformity assessment shall rely on a machine readable way of defining the validation rules and describing the constraints valid for a certain profile. Object Constraint Language (OCL) is used for this purpose.

6.3 Implementation process

The implementation of a version of the CGMES for use in a business process is launched as soon as the conformity assessment process has been finalised. The following rules are defined for the implementation process:

The implementation process is triggered by the body responsible for the model exchange. The body defines the deadline when the implementation process shall end and the business process switches to the new version of the CGMES.

The implementation process includes a period during which TSOs shall upgrade their tools and a period during which a trial tests running the business process with the new version of the CGMES. This is especially valid for operational exchanges where the exchange shall be reliable and completed more frequently than a planning model exchange process.

The CGMES contains various profiles. The implementation of each of them can have a different schedule depending on the business needs.

Due to the different requirements of the business processes, different versions of the CGMES profiles can be simultaneously operational. The ENTSO-E Secretariat shall maintain a publicly available list of version of the CGMES used in business processes. Vendors and TSOs shall adapt the implementation process and the support to the model exchange processes and be able to cope with a variety of the CGMES versions used in the exchanges.

Business processes shall be adapted in order to allow smooth interfaces between main types of exchange such as planning to planning, operation to operation, operation to planning, interface with distribution, etc. Business processes shall aim to use a limited number of different versions of the CGMES in order to decrease maintenance effort by TSOs and facilitate interoperability of data exchanges between business processes.

Annex A
(normative)

Template for further restrictions on naming

Class name	IdentifiedObject							
	.name		.description		.energyIdentCodeEic		.shortName	
	Status [✓r, ✓o, ×]	Required content/rules	Status [✓r, ✓o, ×]	Required content/rules	Status [✓r, ✓o, ×]	Required content/rules	Status [✓r, ✓o, ×]	Required content/rules

Legend: ✓r – the attribute is required; ✓o - the attribute is optional; × - users do not need to have the ability to add name to the attribute.

Annex B
(normative)

Summary of specific rules for naming convention

B.1 IdentifiedObject.name

Human readable name with a maximum string length of 32 characters. The length restriction is defined in the IEC 61970-452.

IdentifiedObject.name is a required attribute for the Boundary Equipment and Boundary Topology profiles.

The IdentifiedObject.name shall be consistent with the name of the object used in companies, in daily operation (e. g. in SCADA systems), in planning processes or in asset related systems.

The IdentifiedObject.name should allow for inter-communicating of TSO, using general names.

B.2 IdentifiedObject.description

Human readable description with maximum string length of 256 characters. The length restriction is defined in the IEC 61970-452.

IdentifiedObject.description is a required attribute for the Boundary Equipment and Boundary Topology profiles.

B.3 IdentifiedObject.energyIdentCodeEic

It is an ENTSO-E extension of the IEC CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of the EIC code (Energy identification Code). The length of the string is 16 characters as defined by the EIC code.

References:

- Local issuing offices for EIC: https://www.entsoe.eu/publications/electronic-data-interchange-edi-library/links-to-eic-websites/
- EIC description: https://www.entsoe.eu/index.php?id=73&libCat=eic

B.4 IdentifiedObject.shortName

It is an ENTSO-E extension of the IEC CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of a human readable short name with length of the string 12 characters maximum."

B.5 ConnectivityNode and TopologicalNode .fromEndIsoCode

It is an ENTSO-E extension of the IEC CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of the ISO code of the region to which the "from" side of the Boundary point belongs to or is connected to.

The ISO code is a two character country code as defined by ISO 3166 (http://www.iso.org/iso/country_codes). The length of the string is 2 characters maximum."

The attribute is required for the Boundary Model Authority Set where this attribute is used only for the TopologicalNode in the Boundary Topology profile and ConnectivityNode in the Boundary Equipment profile.

B.6 ConnectivityNode and TopologicalNode .toEndIsoCode

It is an ENTSO-E extension of the IEC CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of the ISO code of the region to which the "to" side of the Boundary point belongs to or is connected to.

The ISO code is a two character country code as defined by ISO 3166 (http://www.iso.org/iso/country_codes). The length of the string is 2 characters maximum."

The attribute is a required for the Boundary Model Authority Set where this attribute is used only for the TopologicalNode in the Boundary Topology profile and ConnectivityNode in the Boundary Equipment profile.

B.7 ConnectivityNode and TopologicalNode .fromEndName

It is an ENTSO-E extension of the IEC CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of a human readable name with length of the string 32 characters maximum. The attribute covers two cases:

- if the Boundary point is placed on a tie-line the attribute is used for exchange of the geographical name of the substation to which the "from" side of the tie-line is connected.
- if the Boundary point is placed in a substation the attribute is used for exchange of the name of the element (e.g. PowerTransformer, ACLineSegment, Switch, etc) to which the "from" side of the Boundary point is connected."

The attribute is required for the Boundary Model Authority Set where it is used only for the TopologicalNode in the Boundary Topology profile and ConnectivityNode in the Boundary Equipment profile.

B.8 ConnectivityNode and TopologicalNode .toEndName

It is an ENTSO-E extension of the CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of a human readable name with length of the string 32 characters maximum. The attribute covers two cases:

- if the Boundary point is placed on a tie-line the attribute is used for exchange of the geographical name of the substation to which the "to" side of the tie-line is connected.
- if the Boundary point is placed in a substation the attribute is used for exchange of the name of the element (e.g. PowerTransformer, ACLineSegment, Switch, etc) to which the "to" side of the Boundary point is connected."

The attribute is required for the Boundary Model Authority Set where it is used only for the TopologicalNode in the Boundary Topology profile and ConnectivityNode in the Boundary Equipment profile.

B.9 ConnectivityNode and TopologicalNode .fromEndNameTso

It is an ENTSO-E extension of the IEC CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of the name of the TSO to which the "from" side of the Boundary point belongs or is connected to. The length of the string is 32 characters maximum.

The attribute is required for the Boundary Model Authority Set where it is used only for the TopologicalNode in the Boundary Topology profile and ConnectivityNode in the Boundary Equipment profile."

B.10 ConnectivityNode and TopologicalNode .toEndNameTso

It is an ENTSO-E extension of the IEC CIM. The following description was given in the UML for this attribute: "The attribute is used for an exchange of the name of the TSO to which the "to" side of the Boundary point belongs or it is connected. The length of the string is 32 characters maximum.

The attribute is required for the Boundary Model Authority Set where it is used only for the TopologicalNode in the Boundary Topology profile and ConnectivityNode in the Boundary Equipment profile."

B.11 Future developments on CIM for dynamics

The following gaps and needs for future development are currently identified. Discussion regarding these topics is expected to:

- Extend user-defined models approach of the dynamics profile.
- The class StaticVarcompensator is present in the equipment model, but is not represented in the dynamic model. The class could probably be used to represent different FACTS components, although it should be possible to define type of SVC (TCR,TCR/TSC, STATCOM) as this is of importance when it comes to how dynamic response is modelled.
- There are no models representing branch quantities (like line relays and models which measure line flow). It is critical that this type of model should be tested at the IOP, since the input and behaviour is very different from unit models (topology dependency).
- Clarification regarding wind farms modelling is necessary. There is a need to verify that the models are compliant with the last IEC standard on wind modelling. There is also the need for adequate modelling of the wind power plants/parks.
- There are no relay models at all, whether for lines or for loads/units. Frequency dependent load relays are important.
- Models to represent dynamics behaviour of HVDC are necessary.

Annex C
(normative)

File header guidelines

C.1 Introduction

The annex is providing guidance on how to apply IEC 61970-552 which is defining file headers for complete instance files and difference instance files.

C.2 Exchange scenarios

The IEC 61970-552 gives as an example the following figure which is used in order to explain what information should be provided in different file headers.
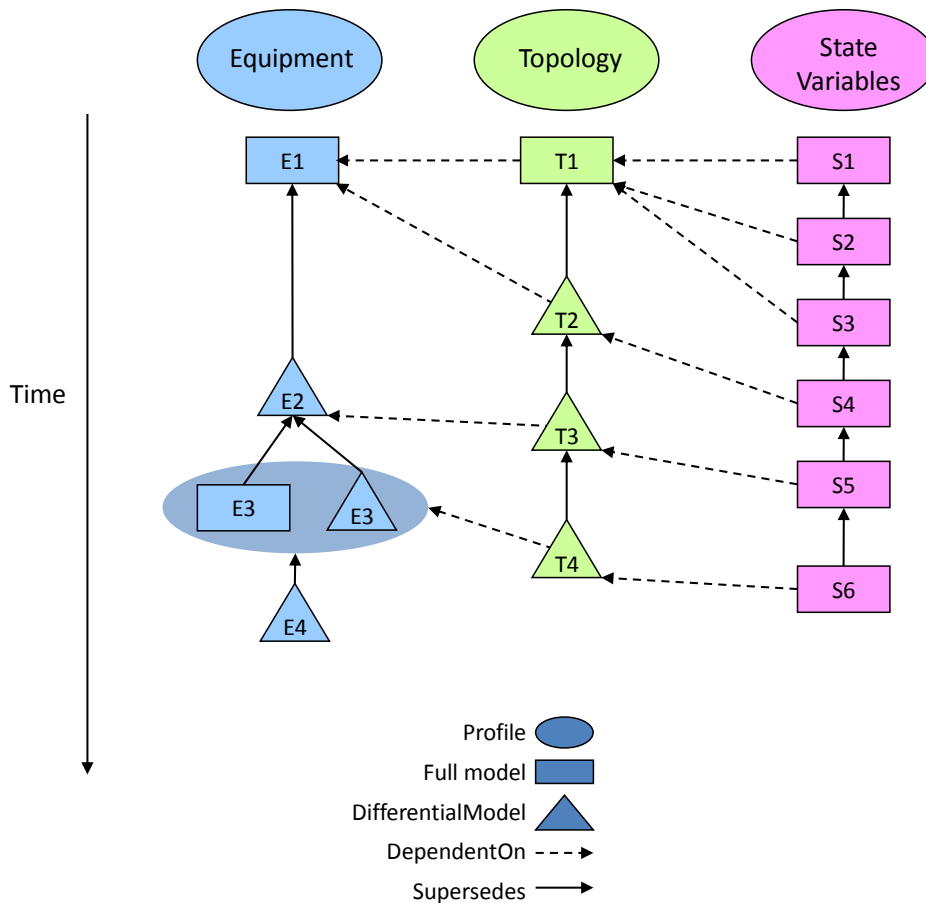
C.3 Examples

C.3.1 Example 1: File header of full model

This example is for full model E1 from the figure in section C.2.

Syntax	Comment/Explanation
<?xml version="1.0"?> <rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:cim="http://iec.ch/TC57/2013/CIM-schema-cim16#" xmlns:md="http://iec.ch/TC57/61970-552/ModelDescription/1#" xmlns:entsoe=http://entsoe.eu/CIM/SchemaExtension/3/1#>	
<md:FullModel rdf:about="urn:uuid:bcb6877a-e948-11e3-89cf-82687f4fc15c">	This is the ID of the model included in the instance file. Please refer to Chapter 4.3 in the CGMES. The ID to which other models (full or difference) refer in case of depend on or supersede. Please note that the "urn:uuid:" is used only for rdf:about or rdf:resource in the file header, i.e. it is not applied for other elements in the instance file.
<md:Model.scenarioTime>2030-01-15T17:00:00.000Z</md:Model.scenarioTime>	This is the date & time that this model represents, i.e. for which the model is valid. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.created>2014-05-15T17:48:31.474Z</md:Model.created>	The date & time when the model was created. It is the time of the serialization. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.description>CGMES Conformity Assessment: This is guidelines on the file header.</md:Model.description>	A description of the model and explanation of the purpose.
<md:Model.version>1</md:Model.version>	Version of the model. If the instance file is imported and exported with no change the version number is the kept same. The version changes only if the content of the file changes. It is the same logic as for the header id (see CGMES [R.4.3.4.1.]). The version is the human readable id. The version is integer number.
<md:Model.profile>http://entsoe.eu/CIM/EquipmentCore/3/1</md:Model.profile>	One to many URN/URI describing the profiles that governs this model. It uniquely identifies the profiles and its version. In this case EQ instance file contains one profile.
<md:Model.profile>http://entsoe.eu/CIM/EquipmentOperation/3/1</md:Model.profile> <md:Model.profile>http://entsoe.eu/CIM/EquipmentShortCircuit/3/1</md:Model.profile>	Additional profile URN/URI are included if classes and attributes that belong to Operation and Short Circuit are used and the instance file is intended for such use.
<md:Model.modelingAuthoritySet>http://elia.be/Planning/CGMES/2.4.14</md:Model.modelingAuthoritySet> </md:FullModel>	A URN/URI referring to the organisation role / model authority set reference. The organization role is the source of the model. It is the same for all profiles part of a model exchange. This concept might be modified in the future when applying the concept of "frames" which is under discussion.

C.3.2 Example 2: File header of full model that is depending on another model

This example is for full model T1 from the figure in section C.2.

Syntax	Comment/Explanation
<?xml version="1.0"?> <rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:cim="http://iec.ch/TC57/2013/CIM-schema-cim16#" xmlns:md="http://iec.ch/TC57/61970-552/ModelDescription/1#" xmlns:entsoe=http://entsoe.eu/CIM/SchemaExtension/3/1#>	
<md:FullModel rdf:about="urn:uuid:d63e4784-e94b-11e3-89cf-82687f4fc15c">	This is the ID of the model included in the instance file. Please refer to Chapter 4.3 in the CGMES. The ID to which other models (full or difference) refer in case of depend on or supersede. Please note that the "urn:uuid:" is used only for rdf:about or rdf:resource in the file header, i.e. it is not applied for other elements in the instance file.
<md:Model.scenarioTime> 2030-01-15T17:00:00.000Z</md:Model.scenarioTime>	This is the date & time that this model represents, i.e. for which the model is valid. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.created>2014-05-15T17:48:31.474Z</md:Model.created>	The date & time when the model was created. It is the time of the serialization. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.description>CGMES Conformity Assessment: This is guidelines on the file header.</md:Model.description>	A description of the model and explanation of the purpose.
<md:Model.version>1</md:Model.version>	Version of the model. If the instance file is imported and exported with no change the version number is the kept same. The version changes only if the content of the file changes. It is the same logic as for the header id (see CGMES [R.4.3.4.1.]). The version is the human readable id. The version is integer number.
<md:Model.profile>http://entsoe.eu/CIM/Topology/4/1</md:Model.profile>	One to many URN/URI describing the profiles that governs this model. It uniquely identifies the profiles and its version. In this case it is the profile URI of the TP profile.
<md:Model.DependentOn rdf:resource="urn:uuid:bcb6877a-e948-11e3-89cf-82687f4fc15c" />	A reference to the model documents that the model described by this document depends on, e.g. in this case the T1 model depends on E1 model. In general there can be 0 or many Model.DependentOn depending on the profile and the content of the instance file.
<md:Model.modelingAuthoritySet>http://elia.be/Planning/CGMES/2.4.14</md:Model.modelingAuthoritySet> </md:FullModel>	A URN/URI referring to the organisation role / model authority set reference. The organization role is the source of the model. It is the same for all profiles part of a model exchange. This concept might be modified in the future when applying the concept of "frames" which is under discussion.

C.3.3 Example 3: File header of full model that is depending on a model and supersedes another model

This example is for full model S2 from the figure in section C.2.

Syntax	Comment/Explanation
<?xml version="1.0"?> <rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:cim="http://iec.ch/TC57/2013/CIM-schema-cim16#" xmlns:md="http://iec.ch/TC57/61970-552/ModelDescription/1#" xmlns:entsoe=http://entsoe.eu/CIM/SchemaExtension/3/1#>	
<md:FullModel rdf:about="urn:uuid:aad4c9cc-e94d-11e3-89cf-82687f4fc15c">	This is the ID of the model included in the instance file. Please refer to Chapter 4.3 in the CGMES. The ID to which other models (full or difference) refer in case of depend on or supersede. Please note that the "urn:uuid:" is used only for rdf:about or rdf:resource in the file header, i.e. it is not applied for other elements in the instance file.
<md:Model.scenarioTime> 2030-01-15T17:00:00.000Z</md:Model.scenarioTime>	This is the date & time that this model represents, i.e. for which the model is valid. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.created>2014-05-15T17:48:31.474Z</md:Model.created>	The date & time when the model was created. It is the time of the serialization. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.description>CGMES Conformity Assessment: This is guidelines on the file header.</md:Model.description>	A description of the model and explanation of the purpose.
<md:Model.version>2</md:Model.version>	Version of the model. If the instance file is imported and exported with no change the version number is the kept same. The version changes only if the content of the file changes. It is the same logic as for the header id (see CGMES [R.4.3.4.1.]). The version is the human readable id. The version is integer number.
<md:Model.profile>http://entsoe.eu/CIM/StateVariables/4/1</md:Model.profile>	One to many URN/URI describing the profiles that governs this model. It uniquely identifies the profiles and its version. In this case it is the profile URI of the SV profile.
<md:Model.DependentOn rdf:resource="urn:uuid:d63e4784-e94b-11e3-89cf-82687f4fc15c" />	A reference to the model documents that the model described by this document depends on, e.g. in this case the S2 model depends on T1 model. In general there can be 0 or many Model.DependentOn depending on the profile and the content of the instance file.
<md:Model.Supersedes rdf:resource="urn:uuid:b1f4d506-e94f-11e3-89cf-82687f4fc15c"/>	When a model is updated the resulting model supersedes the models that were used as basis for the update. Hence this is a reference to the CIMXML documents which are superseded by this model. A model (or instance file) can supersede 1 or more models, e.g. a difference model or a full model supersede multiple models (difference or full). In this case more than one Model.Supersedes are included in

Syntax	Comment/Explanation
	the header. The referenced document(s) is (are) identified by the URN/MRID/UUID in the FullModel rdf:about attribute when full model(s) is (are) referenced and by the URN/MRID/UUID in the DifferenceModel rdf:about attribute when difference model(s) is (are) referenced. In this case the model S2 supersedes model S1 which has <md:FullModel rdf:about="urn:uuid:b1f4d506-e94f-11e3-89cf-82687f4fc15c">
<md:Model.modelingAuthoritySet>http://elia.be/Pl anning/CGMES/2.4.14</md:Model.modelingAutho ritySet> </md:FullModel>	A URN/URI referring to the organisation role / model authority set reference. The organization role is the source of the model. It is the same for all profiles part of a model exchange. This concept might be modified in the future when applying the concept of "frames" which is under discussion.

C.3.4 Example 4: File header of difference model that is depending on a full model and supersedes another full model

This example is for difference model T2 from the figure in section C.2.

Syntax	Comment/Explanation
<?xml version="1.0"?> <rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:cim="http://iec.ch/TC57/2013/CIM-schema-cim16#" xmlns:dm="http://iec.ch/TC57/61970-552/DifferenceModel/1#" xmlns:md="http://iec.ch/TC57/61970-552/ModelDescription/1#" xmlns:entsoe=http://entsoe.eu/CIM/SchemaEx tension/3/1#>	Please pay attention that for difference models xmlns:dm=http://iec.ch/TC57/61970-552/DifferenceModel/1# is included as well
<dm:DifferenceModel rdf:about="urn:uuid:7ca72efa-e952-11e3-89cf-82687f4fc15c">	This is the ID of the model included in the instance file. Please refer to Chapter 4.3 in the CGMES. The ID to which other models (full or difference) refer in case of depend on or supersede. Please note that the "urn:uuid:" is used only for rdf:about or rdf:resource in the file header, i.e. it is not applied for other elements in the instance file.
<md:Model.scenarioTime> 2030-01-15T17:00:00.000Z</md:Model.scenarioTime>	This is the date & time that this model represents, i.e. for which the model is valid. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.created>2014-05-15T17:48:31.474Z</md:Model.created>	The date & time when the model was created. It is the time of the serialization. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
<md:Model.description>CGMES Conformity Assessment: This is guidelines on the file header.</md:Model.description>	A description of the model and explanation of the purpose.
<md:Model.version>2</md:Model.version>	Version of the model. If the instance file is imported and exported with no change the version number is the kept same. The version changes only if the content of the file changes. It is the same logic as for the header id (see

Syntax	Comment/Explanation
	CGMES [R.4.3.4.1.]). The version is the human readable id. The version is integer number.
<md:Model.profile>http://entsoe.eu/CIM/Topology/4/1</md:Model.profile>	One to many URN/URI describing the profiles that governs this model. It uniquely identifies the profiles and its version. In this case it is the profile URI of the TP profile.
<md:Model.DependentOn rdf:resource="urn:uuid:bcb6877a-e948-11e3-89cf-82687f4fc15c" />	A reference to the model documents that the model described by this document depends on, e.g. in this case the T2 model depends on E1 model. In general there can be 0 or many Model.DependentOn depending on the profile and the content of the instance file.
<md:Model.Supersedes rdf:resource="urn:uuid:d63e4784-e94b-11e3-89cf-82687f4fc15c"/>	When a model is updated the resulting model supersedes the models that were used as basis for the update. Hence this is a reference to the CIMXML documents which are superseded by this model. A model (or instance file) can supersede 1 or more models, e.g. a difference model or a full model supersede multiple models (difference or full). In this case more than one Model.Supersedes are included in the header. The referenced document(s) is (are) identified by the URN/MRID/UUID in the FullModel rdf:about attribute when full model(s) is (are) referenced and by the URN/MRID/UUID in the DifferenceModel rdf:about attribute when difference model(s) is (are) referenced. In this case the model T2 supersedes model T1, i.e. this difference model is applied on the model which has the id mentioned in this Model.Supersedes.
<md:Model.modelingAuthoritySet>http://elia.be/Planning/CGMES/2.4.14</md:Model.modelingAuthoritySet>	A URN/URI referring to the organisation role / model authority set reference. The organization role is the source of the model. It is the same for all profiles part of a model exchange. This concept might be modified in the future when applying the concept of "frames" which is under discussion.
Here the place for the content of the difference file	This follows the syntax as defined in the 61970-452.
</dm:DifferenceModel>	

C.3.5 Example 5: File header of difference model that is depending on a difference model and supersedes another difference model

This example is for difference model T3 from the figure in section C.2.

Syntax	Comment/Explanation
<?xml version="1.0"?> <rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:cim="http://iec.ch/TC57/2013/CIM-schema-cim16#" xmlns:dm="http://iec.ch/TC57/61970-552/DifferenceModel/1#" xmlns:md="http://iec.ch/TC57/61970-552/ModelDescription/1#" xmlns:entsoe=http://entsoe.eu/CIM/SchemaExtension/3/1#>	Please pay attention that for difference models xmlns:dm=http://iec.ch/TC57/61970-552/DifferenceModel/1# is included as well
<dm:DifferenceModel rdf:about="urn:uuid:80323db8-ea73-11e3-9df6-82687f4fc15c">	This is the ID of the model included in the instance file. Please refer to Chapter 4.3 in the CGMES. The ID to which other models (full or difference) refer in case of depend on or supersede.

	Please note that the "urn:uuid:" is used only for rdf:about or rdf:resource in the file header, i.e. it is not applied for other elements in the instance file.
`<md:Model.scenarioTime>` 2030-01-15T17:00:00.000Z`</md:Model.scenarioTime>`	This is the date & time that this model represents, i.e. for which the model is valid. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
`<md:Model.created>`2014-05-15T17:48:31.474Z`</md:Model.created>`	The date & time when the model was created. It is the time of the serialization. The format is an extended format according to the ISO 8601-2005. The ENTSO-E exchanges should refer to UTC.
`<md:Model.description>`CGMES Conformity Assessment: This is guidelines on the file header.`</md:Model.description>`	A description of the model and explanation of the purpose.
`<md:Model.version>`3`</md:Model.version>`	Version of the model. If the instance file is imported and exported with no change the version number is the kept same. The version changes only if the content of the file changes. It is the same logic as for the header id (see CGMES [R.4.3.4.1.]). The version is the human readable id. The version is integer number.
`<md:Model.profile>`http://entsoe.eu/CIM/Topology/4/1`</md:Model.profile>`	One to many URN/URI describing the profiles that governs this model. It uniquely identifies the profiles and its version. In this case it is the profile URI of the TP profile.
`<md:Model.DependentOn rdf:resource="urn:uuid:21a419b4-ea74-11e3-9df6-82687f4fc15c" />`	A reference to the model documents that the model described by this document depends on, e.g. in this case the T3 model depends on difference model E2 which has `<dm:DifferenceModel rdf:about="urn:uuid:21a419b4-ea74-11e3-9df6-82687f4fc15c">`. In general there can be 0 or many Model.DependentOn depending on the profile and the content of the instance file.
`<md:Model.Supersedes rdf:resource="urn:uuid:7ca72efa-e952-11e3-89cf-82687f4fc15c"/>`	When a model is updated the resulting model supersedes the models that were used as basis for the update. Hence this is a reference to the CIMXML documents which are superseded by this model. A model (or instance file) can supersede 1 or more models, e.g. a difference model or a full model supersede multiple models (difference or full). In this case more than one Model.Supersedes are included in the header. The referenced document(s) is (are) identified by the URN/MRID/UUID in the FullModel rdf:about attribute when full model(s) is (are) referenced and by the URN/MRID/UUID in the DifferenceModel rdf:about attribute when difference model(s) is (are) referenced. In this case the model T3 supersedes the difference model T2, i.e. this difference model is applied on the model which has the id mentioned in this Model.Supersedes.
`<md:Model.modelingAuthoritySet>`http://elia.be/Planning/CGMES/2.4.14`</md:Model.modelingAuthoritySet>`	A URN/URI referring to the organisation role / model authority set reference. The organization role is the source of the model. It is the same for all profiles part of a model exchange. This concept might be modified in the future when applying the concept of "frames" which is under discussion.
Here the place for the content of the difference file	This follows the syntax as defined in the 61970-452.
`</dm:DifferenceModel>`	

Annex D
(normative)

PST transformer modelling

D.1 Introduction

This annex describes Phase-Shifting Transformer (PST) modelling according to the type and technology of the equipment; and more specifically, equivalent series reactance of phase shifters in the positive sequence as a function of the phase shift angle. In these specific models, the resistances and the magnetizing currents are always neglected.
This document also provides the mapping between the equations for each type and technology of PST to the CIM classes and attributes which are included in the CGMES.

D.2 Mapping to CIM classes and attributes

To illustrate how to use the PST modelling described in this document, the mapping to CGMES classes is presented in the following table:

PST type	CIM class
General Case	**cim:PhaseTapChangerTabular**
Symmetrical phase shifters	cim:PhaseTapChangerSymmetrical or cim:PhaseTapChangerLinear
Asymmetrical phase shifter	cim:PhaseTapChangerAsymmetrical
In-phase transformer and symmetrical phase shifter	cim:PhaseTapChangerSymmetrical and cim:RatioTapChanger
In-phase transformer and asymmetrical phase shifter	cim:PhaseTapChangerAsymmetrical and cim:RatioTapChanger

Recommendation: It is highly recommended to use tabular data to exchange PST parameters (cim:PhaseTapChangerTabular) instead of having to recalculate the parameters per tap according to each model type

Notes:

- Angle sign convention: Positive value indicates a positive phase shift from the winding where the tap is located to the other winding (for a two-winding transformer).
- RatioTapChanger.stepVoltageIncrement: Both positive and negative values are allowed.
- PhaseTapChangerNonLinear.voltageStepIncrement: Both positive and negative values are allowed.
- PhaseTapChangerAsymmetrical.windingConnectionAngle: Both positive and negative values are allowed.

PST attribute	CIM attribute
n	cim:PhaseTapChangerTablePoint.step

n_0	cim:TapChanger.neutralStep
δu	cim:PhaseTapChangerNonLinear.voltageStepIncrement
r	cim:TapChangerTablePoint.ratio
α	cim:PhaseTapChangerTablePoint.angle
$\delta\alpha$	cim:PhaseTapChangerLinear.stepPhaseShiftIncrement
$X(\alpha)$	cim:TapChangerTablePoint.x
$X(0)$	cim:PhaseTapChangerLinear.xMin or cim:PhaseTapChangerNonLinear.xMin
$X(\alpha_{max})$	cim:PhaseTapChangerLinear.xMax or cim:PhaseTapChangerNonLinear.xMax
θ	cim:PhaseTapChangerAsymmetrical.windingConnectionAngle

D.3 Reactance formulas summary table

Equipment type	Equivalent series reactance as a function of the phase shift angle
Symmetrical Phase shifters	$$X(\alpha) = X(0) + \left(X(\alpha_{max}) - X(0)\right)\left(\frac{\sin(\alpha/2)}{\sin(\alpha_{max}/2)}\right)^2$$
Asymmetrical Phase Shifter	$$X(\alpha) = X(0) + \left(X(\alpha_{max}) - X(0)\right)\left(\frac{\tan\alpha}{\tan\alpha_{max}}\frac{\sin\theta - \tan\alpha_{max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2$$
In-phase transformer and symmetrical phase shifter	$$X(r,\alpha) = X_r\left(r_{nom}\right)\left(\frac{r}{r_{nom}}\right)^2 + X_\alpha(0) + \left(X_\alpha(\alpha_{max}) - X_\alpha(0)\right)\left(\frac{\sin(\alpha/2)}{\sin(\alpha_{max}/2)}\right)^2$$
In-phase transformer and asymmetrical phase shifter	$$X(r,\alpha) = X_r\left(r_{nom}\right)\left(\frac{r}{r_{nom}}\right)^2 + X_\alpha(0)$$ $$+ \left(X_\alpha(\alpha_{max}^0) - X_\alpha(0)\right)\left(\frac{\tan\alpha}{\tan\alpha_{max}(r)}\frac{\sin\theta - \tan\alpha_{max}(r)\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2$$ $$\text{with } \alpha_{max}(r) = A\tan\left(\frac{\sin\theta}{\frac{r}{r_{nom}\tan\alpha_{max}^0}\left(\sin\theta - \tan\alpha_{max}^0\cos\theta\right) + \cos\theta}\right)$$ $$\text{and } \alpha_{max}^0 = \alpha_{max}(r_{nom})$$

Variable	Meaning

α_{max}	Maximal phase shift: the maximum angle value of the phase shifter angles table
r_{nom}	Nominal ratio of the in-phase transformer
α_{max}^{0}	Maximal phase shift when the in-phase transformer ratio is nominal

D.4 Symmetrical Phase shifters

D.4.1 One phase diagram and equations

$$V2 = V1e^{j\alpha} - jX(\alpha)I$$

$$V'1 = V1\left(1 + 2j\sin\frac{\alpha}{2}e^{j\frac{\alpha}{2}}\right) = e^{j\alpha}V1$$
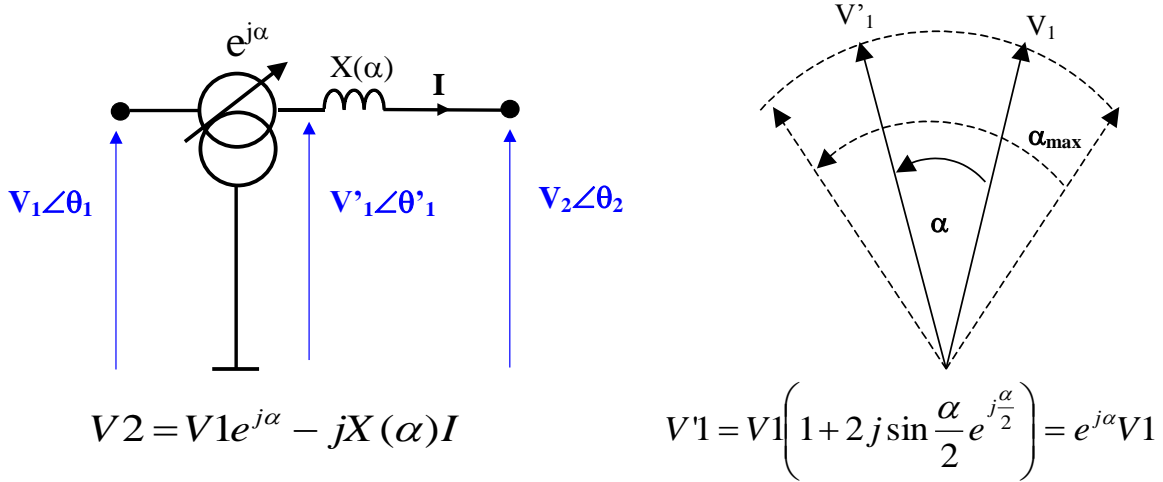
D.4.2 Expression of the angle and ratio per tap

Based on the figure above:

$$\alpha = (n - n_0)\cdot\delta\alpha \qquad \text{or} \qquad \alpha = 2A\tan\left(\frac{(n - n_0)\cdot\delta u}{2}\right)$$

$$r = 1$$

D.4.3 Expression of the equivalent series reactance given the angle

<u>Assuming</u> the reactance of the regulating winding varies as the square of the number of turns, the equivalent reactance can be written as follows for non delta-hexagonal technologies (see proof in section D.9.1):

$$X(\alpha) = X(0) + \left(X(\alpha_{max}) - X(0)\right)\left(\frac{\sin(\alpha/2)}{\sin(\alpha_{max}/2)}\right)^2$$

3 parameters:

- ➢ α_{max}: maximal phase shift
- ➢ $X(0)$: equivalent series reactance at zero phase shift $\alpha=0$
- ➢ $X(\alpha_{max})$: equivalent series reactance at maximal phase shift $\alpha=\alpha_{max}$

1 variable:

- ➢ α: current phase shift

The formula above is valid for single or double core symmetrical phase shifters except for the hexagonal technology.

For single core symmetrical phase shifters: X(0)=0

Impedance 225kV symmetrical double core phase shifter (in Ohm)
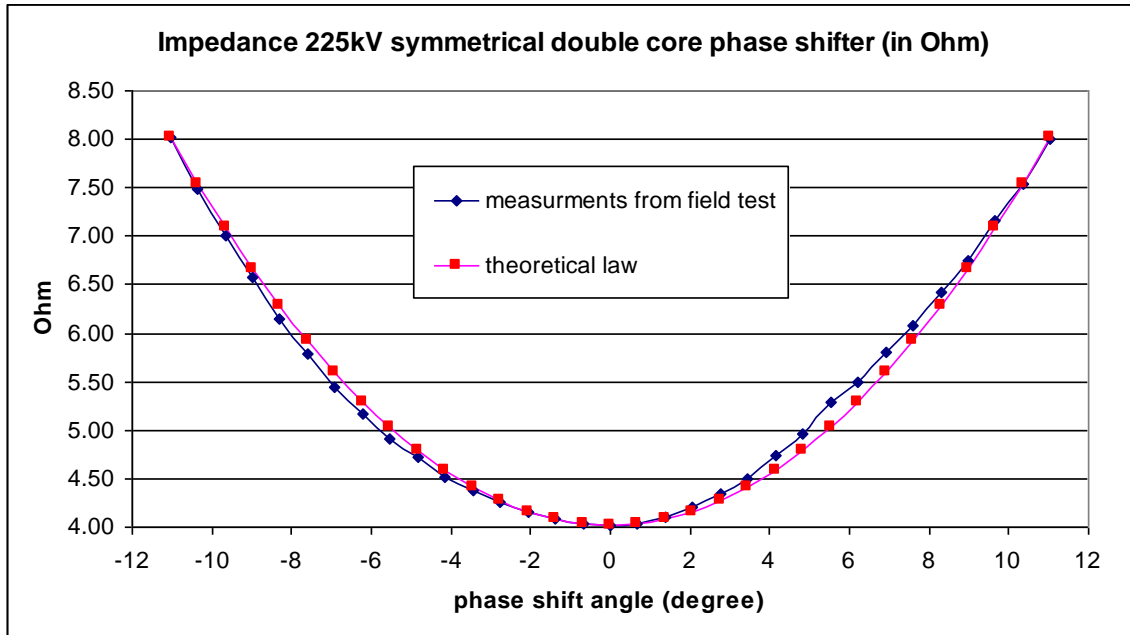
D.4.4 Three-phase diagrams
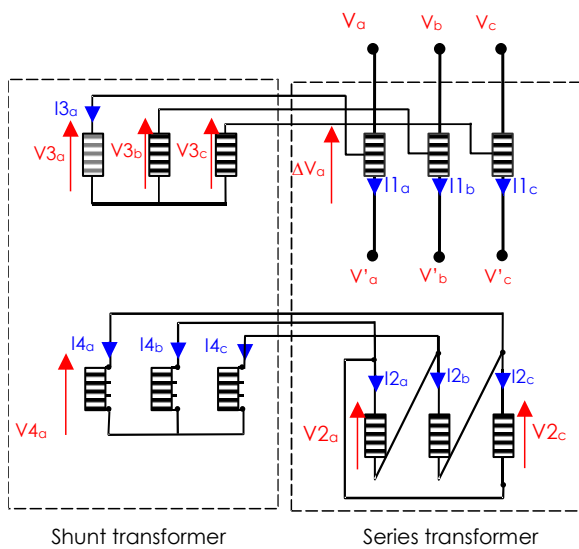
Dual core: Single core:
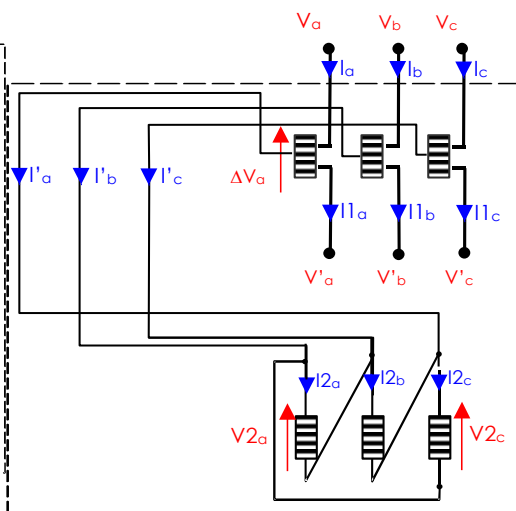
Single core, delta hexagonal:
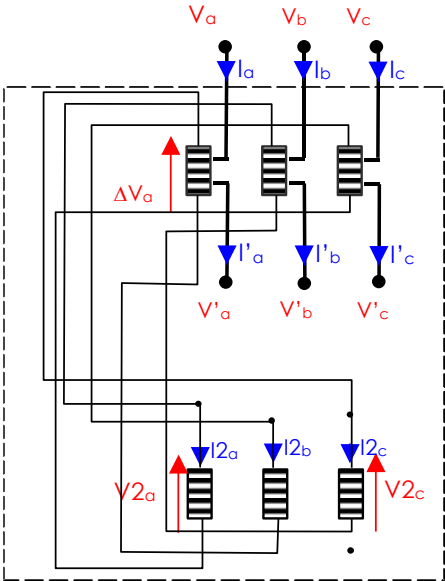
D.5 Quadrature booster

D.5.1 One phase diagram and equations
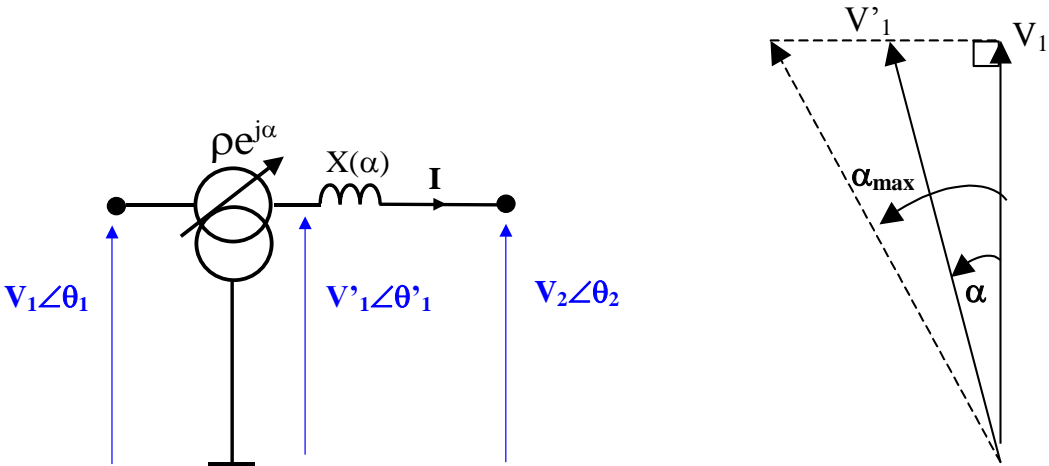
$$V'1 = V1(1 + j\tan\alpha) = \rho e^{j\alpha}V1 \qquad V2 = V1\rho e^{j\alpha} - jX(\alpha)I$$

ρ and α vary with $\rho.\cos\alpha$ = constant.

D.5.2 Expression of the angle and ratio per tap

Based on the figure above:

$$\alpha = A\tan\left((n - n_0) \cdot \delta u\right)$$

$$r = \frac{1}{\sqrt{\left((n - n_0) \cdot \delta u\right)^2 + 1}}$$

D.5.3 Expression of the equivalent series reactance given the angle

<u>Assuming</u> the reactance of the regulating winding varies as the square of the number of turns, the equivalent reactance of the quadrature booster can be written as follows (see proof in section D.9.2):

$$X(\alpha) = X(0) + \left(X(\alpha_{max}) - X(0)\right)\left(\frac{\tan(\alpha)}{\tan(\alpha_{max})}\right)^2$$

3 parameters:

- α_{max}: maximal phase shift
- $X(0)$: equivalent series reactance at zero phase shift
- $X(\alpha_{max})$: equivalent series reactance at maximal phase shift

1 variable:

- α: current phase shift

For quadrature boosters with a single core: $X(0)=0$

D.5.4 Three-phase diagrams

Dual core: Single core:

Shunt transformer   Series transformer
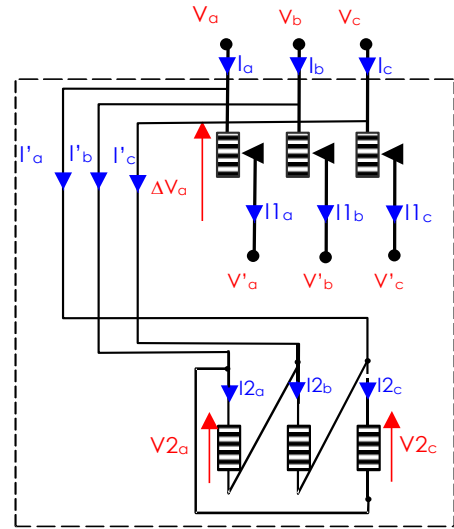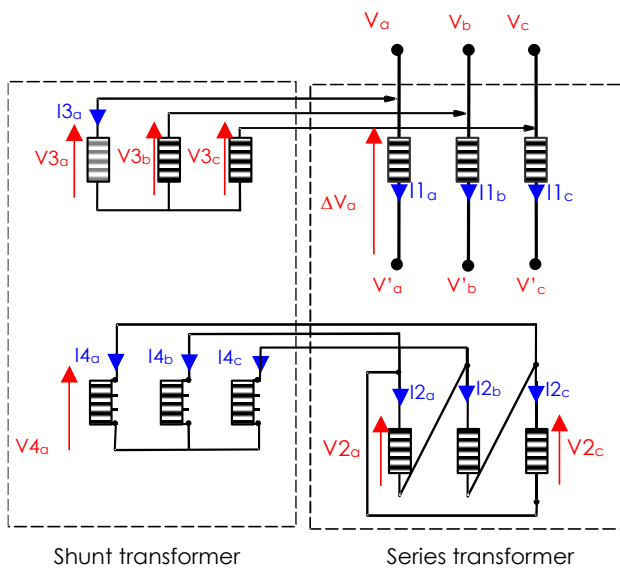
D.6 Asymmetrical Phase Shifter

D.6.1 One phase diagram and equations
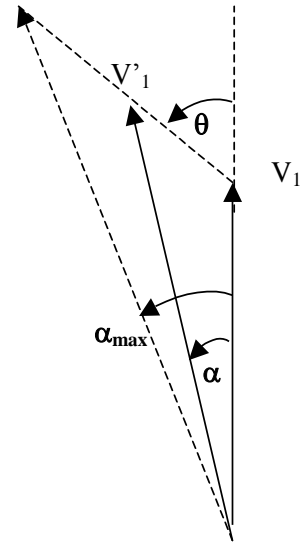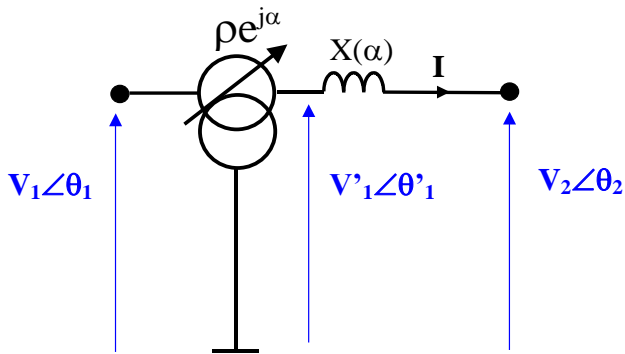
$$V'1 = V1\left(1 + e^{j\theta} \cdot \frac{\tan\alpha}{\sin\theta - \tan\alpha\cos\theta}\right) = \rho e^{j\alpha}V1$$

$$V2 = V1.\rho e^{j\alpha} - jX(\alpha)I$$

θ is fixed, only α and ρ vary.

D.6.2 Expression of the angle and ratio per tap

Based on the figure above:

$$\alpha = A\tan\left(\frac{(n-n_0)\cdot\delta u\cdot\sin\theta}{1+(n-n_0)\cdot\delta u\cdot\cos\theta}\right)$$

$$r = \frac{1}{\sqrt{((n-n_0)\cdot\delta u\cdot\sin\theta)^2 + (1+(n-n_0)\cdot\delta u\cdot\sin\theta)^2}}$$

D.6.3 Expression of the equivalent series reactance given the angle

Assuming the reactance of the regulating winding varies as the square of the number of turns, the equivalent reactance can be written as follows (see proof in section D.9.3):

$$X(\alpha) = X(0) + \left(X(\alpha_{max}) - X(0)\right)\left(\frac{\tan\alpha}{\tan\alpha_{max}}\frac{\sin\theta - \tan\alpha_{max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2$$

4 parameters:

- α_{max}: maximal phase shift
- $X(0)$: equivalent series reactance at zero phase shift
- $X(\alpha_{max})$: equivalent series reactance at maximal phase shift
- θ: boost voltage angle

1 variable:

- α: current phase shift

D.6.4 Three-phase diagram

Dual core:

Shunt transformer   Series transformer
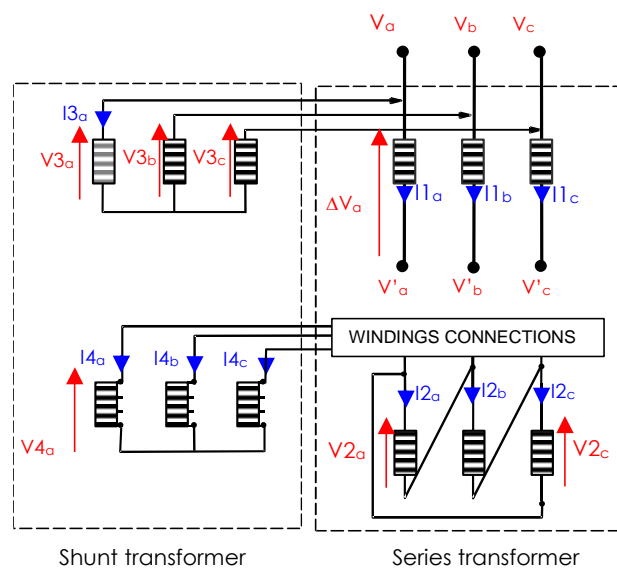
D.7 In-phase transformer and symmetrical phase shifter

D.7.1 One phase diagram and equations
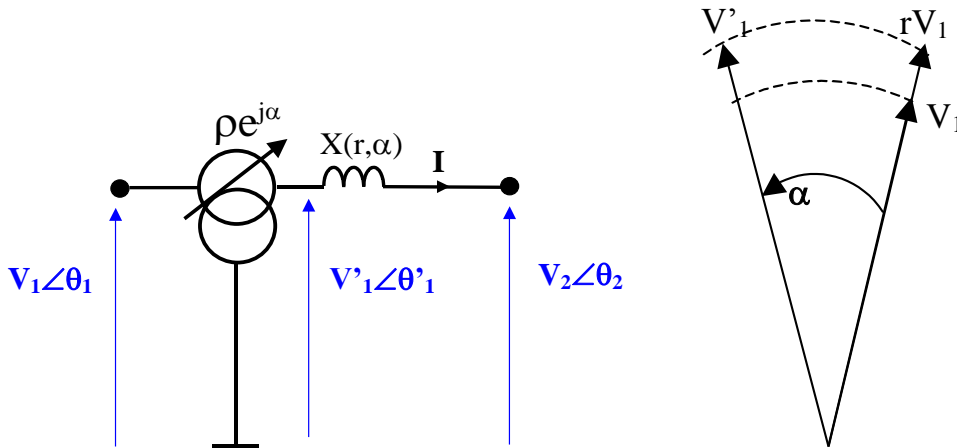
$$V2 = \rho V1 e^{j\alpha} - jX(\alpha)I.$$

$$V'1 = r.V1\left(1 + 2j\sin\frac{\alpha}{2}e^{j\frac{\alpha}{2}}\right) = \rho e^{j\alpha}V1$$

r and α vary, and $\rho = r$

D.7.2 Expression of the angle and ratio per tap

Same as D.4.2 with the addition of the in-phase transformer ratio r.

D.7.3 Expression of the equivalent series reactance given the angle and the in-phase transformer ratio

Assuming:

➢ the reactance of the regulating winding varies as the square of the number of turns,
➢ the equivalent reactance is the sum of the reactance of the in-phase transformer X_r and the reactance of the phase shifter part X_α,
➢ the phase shifting angle α does not depend on the in-phase ratio r

The equivalent reactance can be written as follows (**not proved**):

$$X(r,\alpha) = X_r(r_{nom})\left(\frac{r}{r_{nom}}\right)^2 + X_\alpha(0) + \left(X_\alpha(\alpha_{max}) - X_\alpha(0)\right)\left(\frac{\sin(\alpha/2)}{\sin(\alpha_{max}/2)}\right)^2$$

6 Parameters:

- ➢ r_{nom}: nominal ratio of the in-phase transformer
- ➢ $X_r(r_{nom})$: equivalent series reactance of the in-phase transformer at nominal in-phase ratio
- ➢ α_{max}: maximal phase shift
- ➢ $X_\alpha(0)$: equivalent series reactance of the phase shifter part at zero phase shift
- ➢ $X_\alpha(\alpha_{max})$: equivalent series reactance of the phase shifter part at maximal phase shift at nominal in-phase ratio (r_{nom})
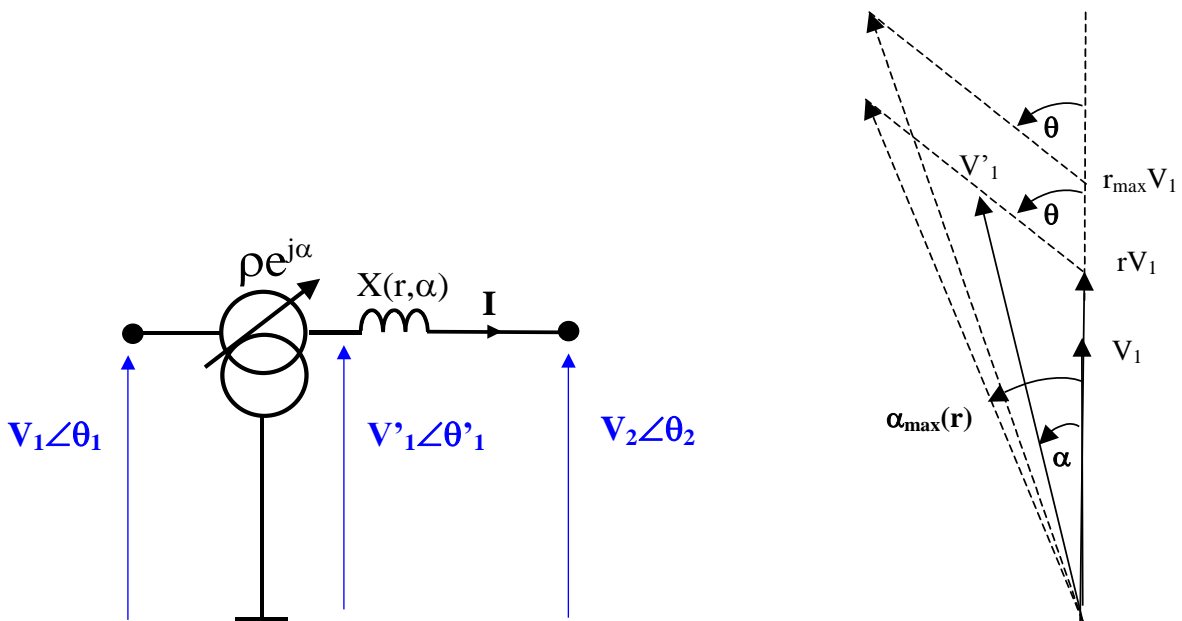
2 Variables:

- ➢ r: current ratio of the in-phase transformer
- ➢ α: current phase shift

D.7.4 Technology principles

No example found.

D.8 In-phase transformer and asymmetrical phase shifter

D.8.1 One phase diagram and equations

$$V'1 = rV1\left(1 + e^{j\theta}.\frac{\tan\alpha}{\sin\theta - \tan\alpha\cos\theta}\right) = \rho e^{j\alpha}V1 \qquad V2 = (V1 - jX(\alpha)I).\rho e^{j\alpha}$$

θ is fixed, only r and α are variables, ρ varies as a consequence.

D.8.2 Expression of the angle and ratio per tap

Not proved.

D.8.3 Expression of the equivalent series reactance given the angle and the in-phase transformer ratio

Assuming:

➢ the reactance of the regulating winding varies as the square of the number of turns,
➢ the equivalent reactance is the sum of the reactance of the in-phase transformer X_r and the reactance of the phase shifter part X_α,

The equivalent series reactance can be written as follows (**not proved**):

$$X(r,\alpha) = X_r\left(r_{nom}\right)\left(\frac{r}{r_{nom}}\right)^2 + X_\alpha(0) + \left(X_\alpha(\alpha_{max}^0) - X_\alpha(0)\right)\left(\frac{\tan\alpha}{\tan\alpha_{max}(r)}\frac{\sin\theta - \tan\alpha_{max}(r)\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2$$

with $$\alpha_{max}(r) = A\tan\left(\frac{\sin\theta}{\dfrac{r}{r_{nom}\tan\alpha_{max}^0}\left(\sin\theta - \tan\alpha_{max}^0\cos\theta\right) + \cos\theta}\right)$$ with $\alpha_{max}^0 = \alpha_{max}(r_{nom})$

6 Parameters:

➢ r_{nom}: nominal ratio of the in-phase transformer
➢ $X_r(r_{nom})$: equivalent series reactance of the in-phase transformer at nominal in-phase ratio r_{nom}
➢ θ: fix boost voltage angle
➢ $\alpha_{max}^0 = \alpha_{max}(r_{nom})$: maximal phase shift for nominal in-phase ratio (r_{nom})
➢ $X_\alpha(0)$: equivalent series reactance of the phase shifter part at zero phase shift
➢ $X_\alpha(\alpha_{max}^0)$: equivalent series reactance of the phase shifter part at maximal phase shift at nominal in-phase ratio (r_{nom})
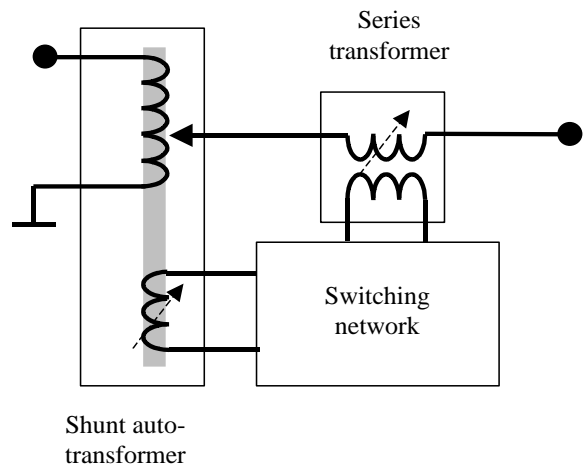
2 Variables:

➢ r: current ratio of the in-phase transformer
➢ α: current phase shift

For θ = π/2 (quadrature booster): $\boxed{\alpha_{max}(r) = A\tan\left(\dfrac{r_{nom}}{r}\tan\alpha_{max}^0\right)}$

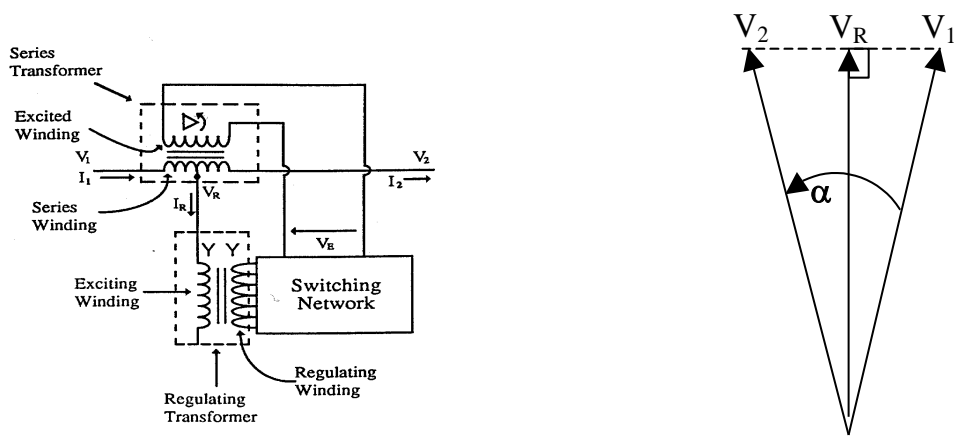### D.8.4 Technology principles

In-phase regulating auto-transformer
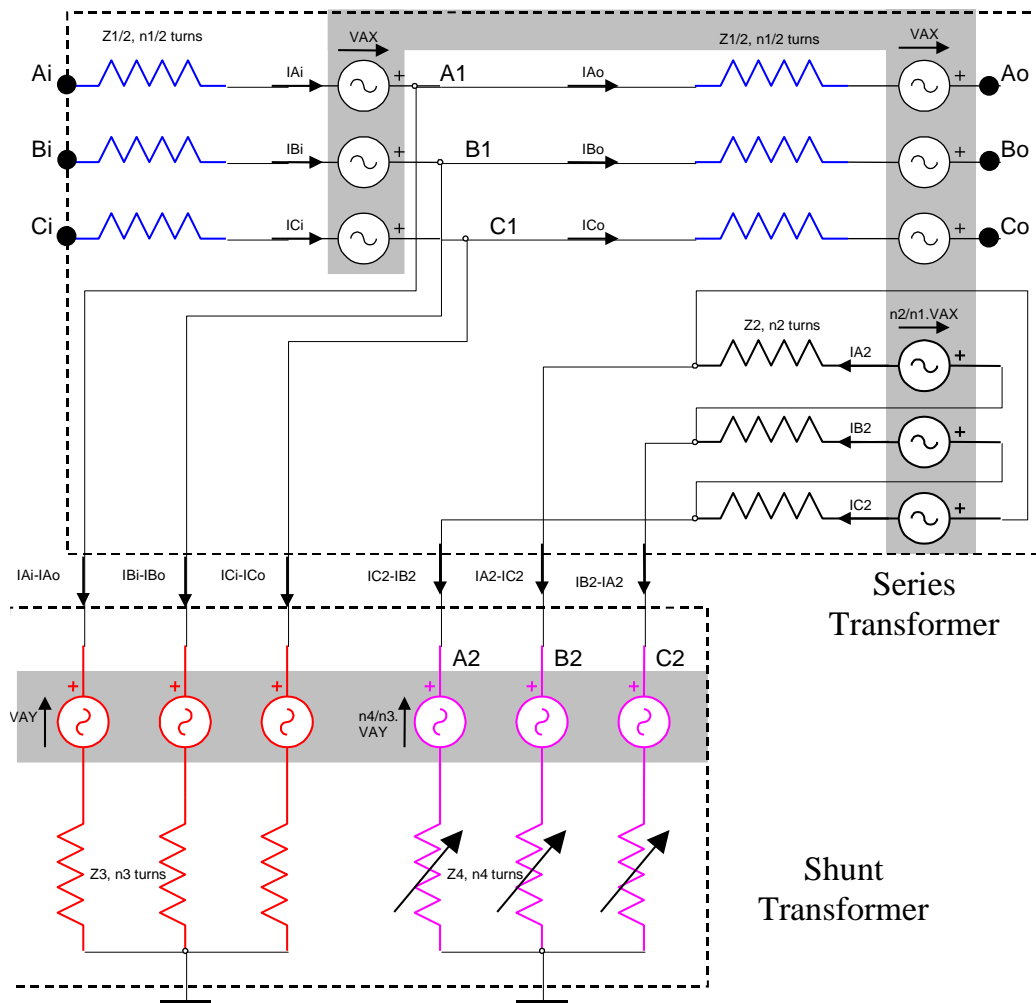

Shunt auto-
transformer

The phase shift regulation may be on the shunt or on the series transformer

D.9 Detailed calculations and examples

D.9.1 Symmetrical Phase Shifters with two cores

Detailed three phase diagram

Series Transformer

Shunt Transformer

Only n4 varies.

Example of numerical values:

$n1=120$

$n2=318$

$n3=680$

$n4_{max}=182$

$X1=1{,}23 \ \Omega$

$X2=8{,}64 \ \Omega$

$X3=101 \ \Omega$

Expression of the output current Io and the shunt current I3=Ii-Io:

When considering an ideal phase shifter, the conservation of the electric power is written:
$$Si = 3ViIi^* = 3VoIo^*$$

As the voltage angle is shifted by alpha: $Vo = e^{j\alpha}Vi$

The current angle must also be shifted by alpha as well: $\boxed{Io = e^{j\alpha}Ii}$

Then, the shunt current $\boxed{I3 = Ii - Io = (1 - e^{j\alpha})Ii}$

Expression of the shunt equivalent reactance

The shunt reactance Xshunt(α) is defined as the equivalent reactance which crossed by the series input current (*Ii*) would produce the reactive losses of the shunt transformer:

$$Qshunt = 3.Xshunt(\alpha).|Ii|^2$$

with:

$$Qshunt = 3.X3.|I3|^2 + 3.X4.|I4|^2$$

$$|I3|^2 = |Ii|^2|1 - e^{j\alpha}|^2 = 2(1 - \cos\alpha)|Ii|^2 = 4(\sin(\alpha/2))^2$$

$$|I4|^2 = \frac{n3^2}{n4^2}|I3|^2$$

$$Xshunt(\alpha) = 4(\sin(\alpha/2))^2\left(X3 + X4\left(\frac{n3}{n4}\right)^2\right)$$

Hypothesis: $X4 = X4_{max}\left(\frac{n4}{n4_{max}}\right)^2$

Then $Xshunt(\alpha) = 4(\sin(\alpha/2))^2\left(X3 + X4_{max}\frac{n3^2}{n4_{max}^2}\right)$

Expression of the equivalent series reactance

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The series reactance Xseries(α) is defined as the equivalent reactance which crossed by the series input current (Ii) would produce the reactive losses of the series transformer:

$$Qseries = 3.Xseries(\alpha).|Ii|^2$$

with:

$$Qseries = 3.\frac{X1}{2}.|Ii|^2 + 3.\frac{X1}{2}.|Io|^2 + 3.X2.|I2|^2$$

as seen previously: $Io = e^{j\alpha}Ii$

series transformer current relationship: $\frac{n1}{2}.Ii + \frac{n1}{2}.Io = +n2.I2$

then $\quad I2 = \frac{n1}{2n2}(1 + e^{j\alpha})Ii$ and $|I2|^2 = \left(\frac{n1}{2n2}\right)^2 |Ii|^2 |1 + e^{j\alpha}|^2 = \frac{1}{2}\frac{n1^2}{n2^2}(1 + \cos\alpha)|Ii|^2$

then

$$Xseries(\alpha) = X1 + \frac{1}{2}\left(\frac{n1}{n2}\right)^2 (1 + \cos\alpha)X2 = X1 + \left(\frac{n1}{n2}\right)^2 (1 - \sin(\alpha/2))X2$$

$$Xseries(\alpha) = \left(X1 + \left(\frac{n1}{n2}\right)^2 X2\right) - \left(\frac{n1}{n2}\right)^2 X2(\sin(\alpha/2))^2$$

Expression of the total equivalent reactance X

$$X(\alpha) = \left(X1 + \left(\frac{n1}{n2}\right)^2 X2\right) + 4(\sin(\alpha/2))^2\left(X3 + X4_{max}\frac{n3^2}{n4_{max}^2} - \left(\frac{n1}{2n2}\right)^2 X2\right)$$

or

$$X(\alpha) = X(0) + \left(X(\alpha_{max}) - X(0)\right)\left(\frac{\sin(\alpha/2)}{\sin(\alpha_{max}/2)}\right)^2$$

with:

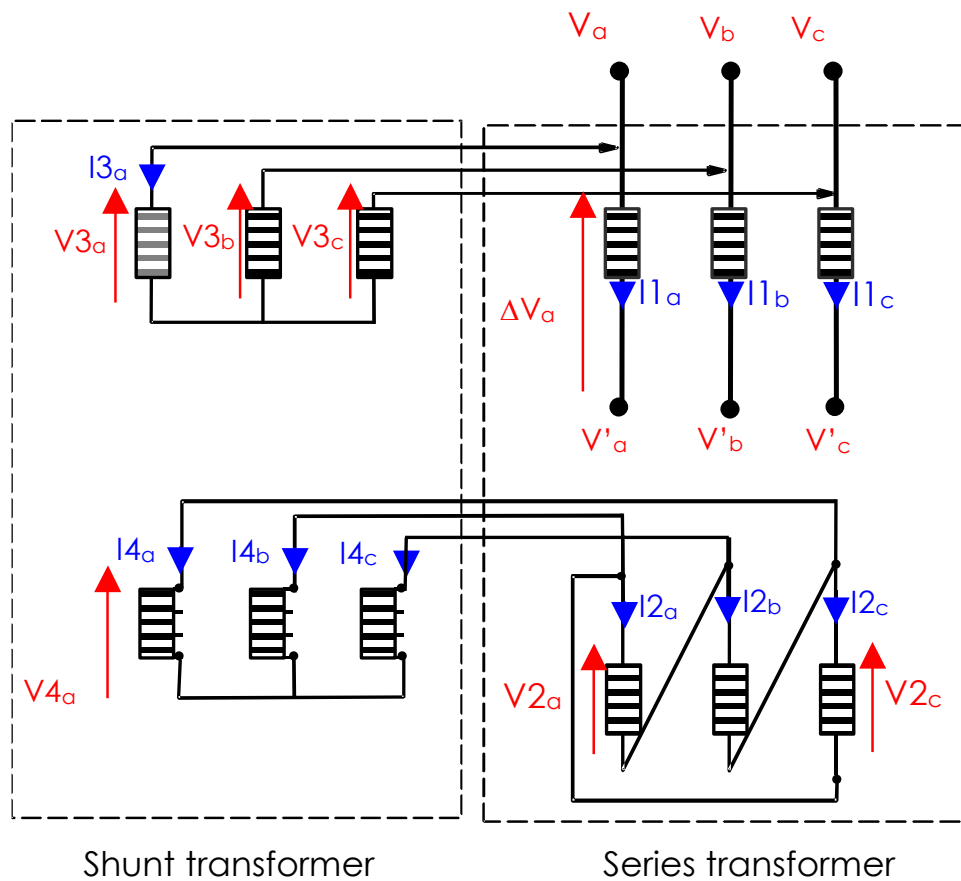$$X(0) = \left(X1 + \left(\frac{n1}{n2} \right)^2 X2 \right)$$

$$X(\alpha_{max}) - X(0) = 4(\sin(\alpha_{max}/2))^2 \left(X3 + X4_{max} \frac{n3^2}{n4_{max}^2} - \left(\frac{n1}{2n2} \right)^2 X2 \right)$$

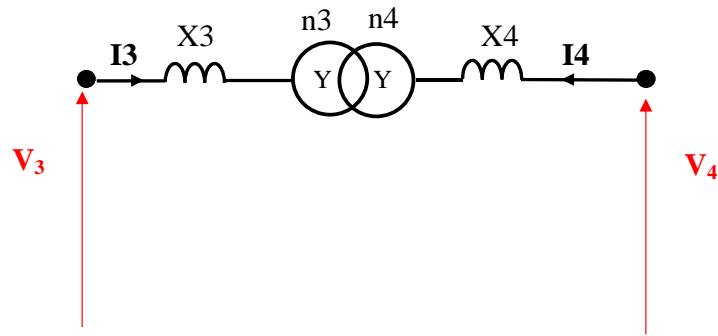**Remark:** only α varies.

D.9.2 Quadrature boosters

D.9.2.1   Quadrature booster with two cores

DETAILED THREE PHASE DIAGRAM

Shunt transformer   Series transformer

For each physical value X (X=V or I) $X = X_a = aX_b = a^2 X_c$ with $a = e^{j\frac{2\pi}{3}}$

shunt transformer with variable ratio n4/n3 with X3 reactance on the primary winding and X4 on the secondary winding:

$$V4 - jX4.I4 = \frac{n4}{n3}(V3 - jX3.I3) \qquad I3 = -\frac{n4}{n3}I4$$

$$V4 = \frac{n4}{n3}V3 + j\left(X_4 + X_3\left(\frac{n4}{n3}\right)^2\right)I4$$

Hypothesis: the X4 reactance varies like the square of the number of turns n4:

$$X_4 = X_4^{max}\left(\frac{n4}{n4_{max}}\right)^2$$

Series transformer of fixed ratio n1/n2 with X1 reactance on the primary winding and X2 on the secondary winding:

$$\Delta V = \frac{n1}{n2}V2 + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2\right)I1$$

$$I2 = -\frac{n1}{n2}I1$$

Link between series and shunt transformers:

  ➢ Primary windings:
    $V3 = V$

  ➢ Secondary windings:
    $$I4 = I4_a = I2_b - I2_c = (a^2 - a)I2_a = -j\sqrt{3}I2$$

    $$V2 = V2_a = V4_b - V4_c = (a^2 - a)V4 = -j\sqrt{3}V4$$

Calculation:
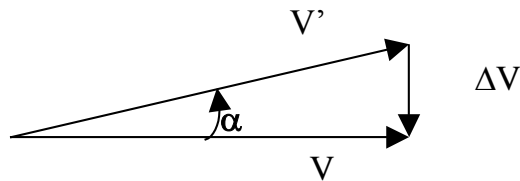
$$\Delta V = -j\frac{n4.n1}{n3.n2}\sqrt{3}V + j\left(X1+\left(\frac{n1}{n2}\right)^2 X2 + 3\left(\frac{n1}{n2}\right)^2 n4^2\left(\frac{X4^{max}}{n4_{max}^2}+\frac{X3}{n3^2}\right)\right)I1$$

$$I3 = -j\frac{n4.n1}{n3.n2}\sqrt{3}I1$$

At no load conditions (I=0):

$$\Delta V = -j\frac{n4.n1}{n3.n2}\sqrt{3}V$$

And geometrically:

$$\Delta V = -jV\tan\alpha$$

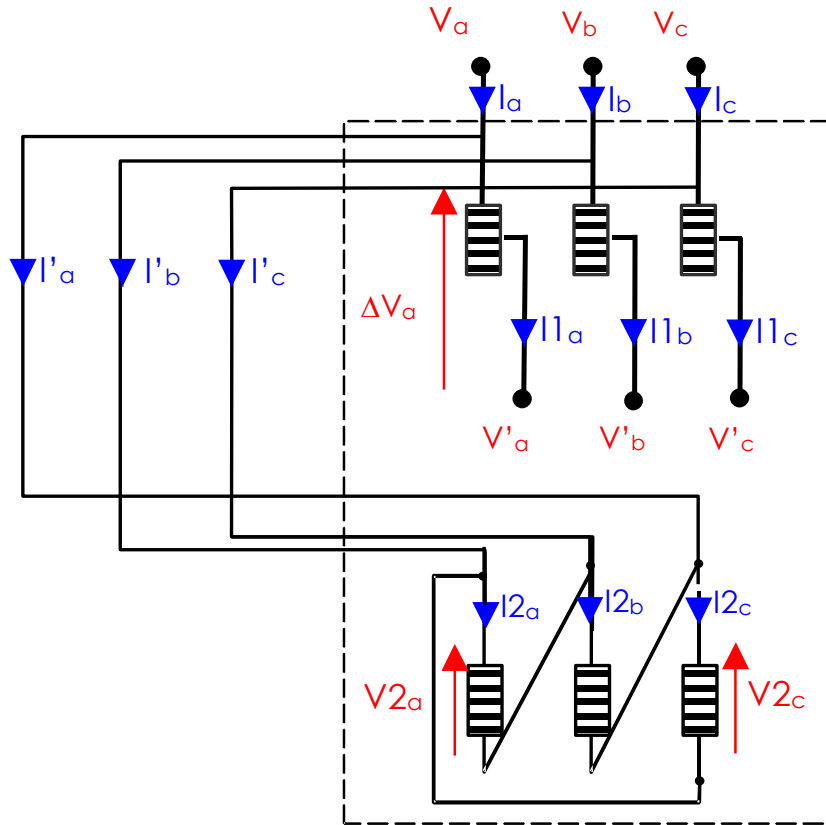hence $\dfrac{n4}{n4^{max}} = \dfrac{\tan\alpha}{\tan\alpha_{max}}$

And $\Delta V = -j\dfrac{n4.n1}{n3.n2}\sqrt{3}V + j\left(X1+\left(\dfrac{n1}{n2}\right)^2 X2 + 3n4_{max}^2\left(\dfrac{n1}{n2}\right)^2\left(\dfrac{X4^{max}}{n4_{max}^2}+\dfrac{X3}{n3^2}\right)\left(\dfrac{\tan\alpha}{\tan\alpha_{max}}\right)^2\right)I1$

comes:

$$\Delta V = -j\frac{n4.n1}{n3.n2}\sqrt{3}V + jXI \quad \text{with} \quad \boxed{X(\alpha) = X(0) + \left(X(\alpha_{max})-X(0)\right)\left(\frac{\tan(\alpha)}{\tan(\alpha_{max})}\right)^2}$$

D.9.2.2 Quadrature booster with a single core

Detailed three phase diagram

n1 varies.

$$I' = j\sqrt{3}I2$$

$$V2 = -j\sqrt{3}V$$

$$\Delta V = \frac{n1}{n2}V2 + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2 \right)I1$$

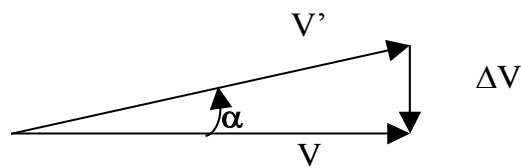$$\Delta V = -j\sqrt{3}\frac{n1}{n2}V + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2 \right)I1$$

Assuming $X1 = X1_{max}\left(\dfrac{n1}{n1_{max}}\right)^2$

$$\Delta V = -j\sqrt{3}\,\frac{n1}{n2}V + j\left(\frac{X1_{max}}{n1_{max}} + \frac{X2}{n2^2}\right)n1^2 I1$$

At no-load: $\Delta V = -j\sqrt{3}\,\dfrac{n1}{n2}V$
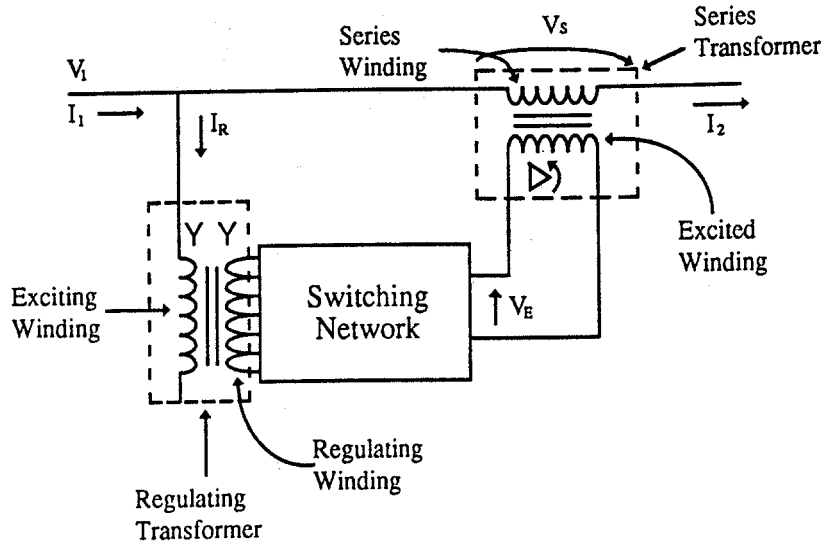
And geometrically:

$$\Delta V = -jV\tan\alpha$$

hence $\dfrac{n1}{n1^{max}} = \dfrac{\tan\alpha}{\tan\alpha_{max}}$

$$X(\alpha) = \left(X1_{max} + X2\frac{n1^2_{max}}{n2^2}\right)\left(\frac{\tan\alpha}{\tan\alpha_{max}}\right)^2$$
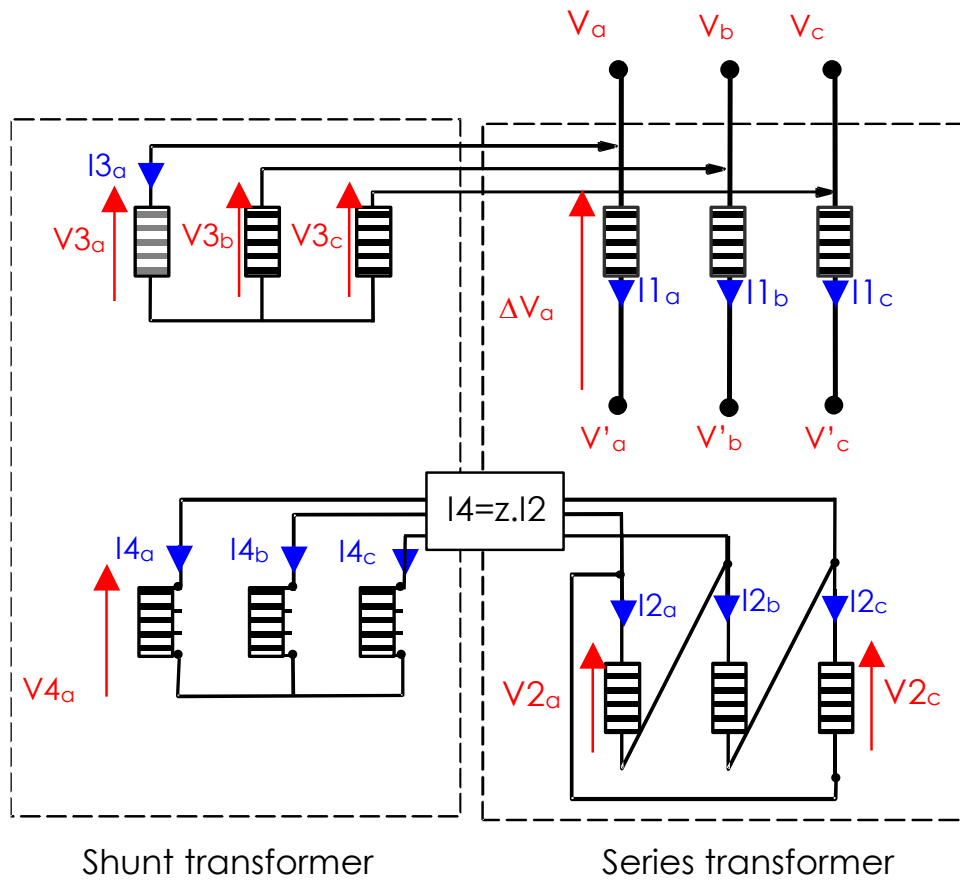
$$X(\alpha) = X(\alpha_{max})\left(\frac{\tan\alpha}{\tan\alpha_{max}}\right)^2$$

D.9.3 Asymmetrical phase shifter

D.9.3.1 Asymmetrical phase shifter with two cores

Detailed three phase diagram:

Shunt transformer   Series transformer

For each physical value X (X=V or I) $X = X_a = aX_b = a^2 X_c$ with $a = e^{j\frac{2\pi}{3}}$

shunt transformer equations:

$$V4 = \frac{n4}{n3}V3 + j\left(X_4 + X_3\left(\frac{n4}{n3}\right)^2\right)I4$$

$$I3 = -\frac{n4}{n3}I4$$

Hypothesis: the X_2 reactance varies like the square of the k_1 ratio:

$$X_4 = X_4^{max}\left(\frac{n4}{n4_{max}}\right)^2$$

Series transformer of fixed ratio k_2 with X_{series} reactance on the primary winding:

$$\Delta V = \frac{n1}{n2}V2 + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2 \right)I1$$

$$I2 = -\frac{n1}{n2}I1$$

Link between series and shunt transformers:

> Primary windings:
> $V3 = V$

> "z", a complex number, determines the coupling between the series and shunt transformer secondary windings:
> $$I4 = I4_a = z.I2$$
>
> $$V2 = z.V4$$
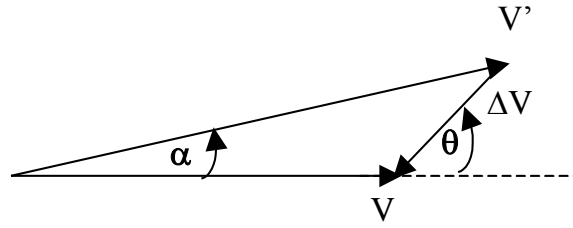>
> for a quadrature booster $z = -j\sqrt{3}$

Calculation:

$$\Delta V = \frac{n4.n1}{n3.n2}.z.V + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2 - z^2\left(\frac{n1}{n2}\right)^2 n4^2\left(\frac{X4^{max}}{n4^2_{max}} + \frac{X3}{n3^2}\right) \right)I1$$

$$I3 = \frac{n4.n1}{n3.n2}.z.I1$$

At no load conditions (I=0):

$$\Delta V = \frac{n4.n1}{n3.n2}.z.V$$

And geometrically: $\Delta V = -e^{j\theta}.V\dfrac{\tan\alpha}{\sin\theta - \tan\alpha\cos\theta}$

hence $\dfrac{n4}{n4^{\max}} = \dfrac{\tan\alpha}{\tan\alpha_{\max}} \dfrac{\sin\theta - \tan\alpha_{\max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}$
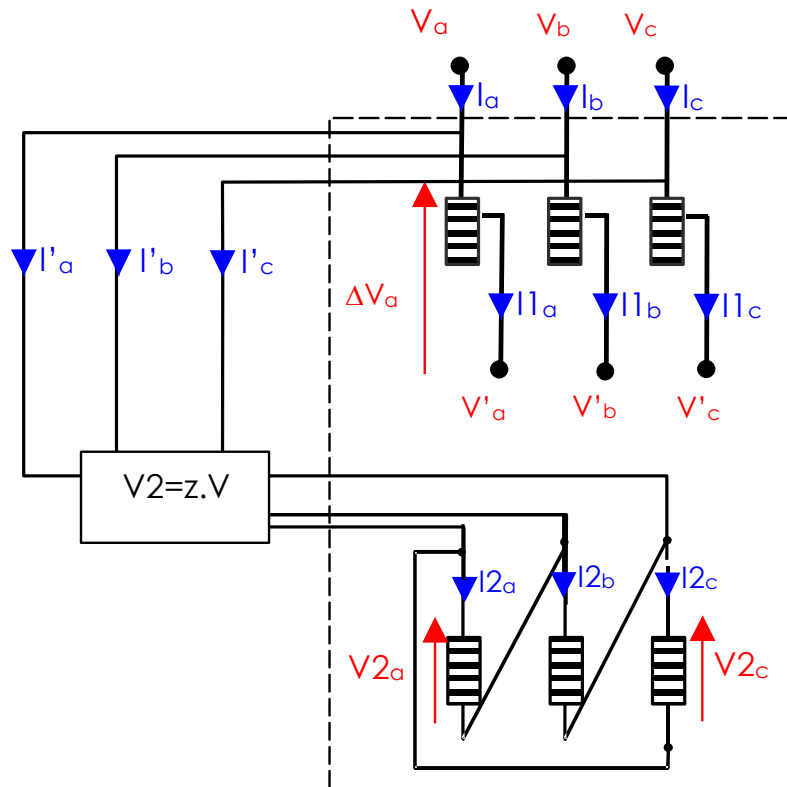
And

$$\Delta V = -j\frac{n4.n1}{n3.n2}\sqrt{3}V + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2 - z^2 n4_{\max}^2 \left(\frac{n1}{n2}\right)^2 \left(\frac{X4^{\max}}{n4_{\max}^2} + \frac{X3}{n3^2}\right)\left(\frac{\tan\alpha}{\tan\alpha_{\max}} \frac{\sin\theta - \tan\alpha_{\max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2\right)I1$$

comes:

$$\Delta V = z\frac{n4.n1}{n3.n2}V + jXI \qquad \text{with}$$

$$\boxed{X(\alpha) = X(0) + \left(X(\alpha_{\max}) - X(0)\right)\left(\frac{\tan\alpha}{\tan\alpha_{\max}} \frac{\sin\theta - \tan\alpha_{\max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2}$$

D.9.3.2 Asymmetrical phase shifter with a single core

Only n1 varies.

$$I' = -z.I2$$

$$V2 = z.V$$

$$\Delta V = \frac{n1}{n2}V2 + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2 \right)I1$$

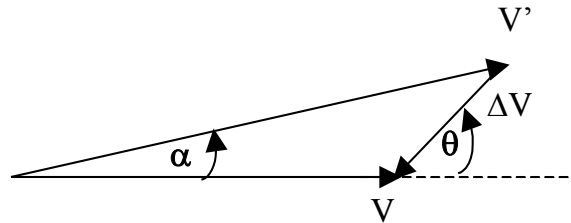$$\Delta V = z.\frac{n1}{n2}V + j\left(X1 + \left(\frac{n1}{n2}\right)^2 X2 \right)I1$$

Assuming $X1 = X1_{max}\left(\dfrac{n1}{n1_{max}}\right)^2$

$$\Delta V = z.\frac{n1}{n2}V + j\left(\frac{X1_{max}}{n1_{max}} + \frac{X2}{n2^2} \right)n1^2 I1$$

At no-load: $\Delta V = z.\dfrac{n1}{n2}V$

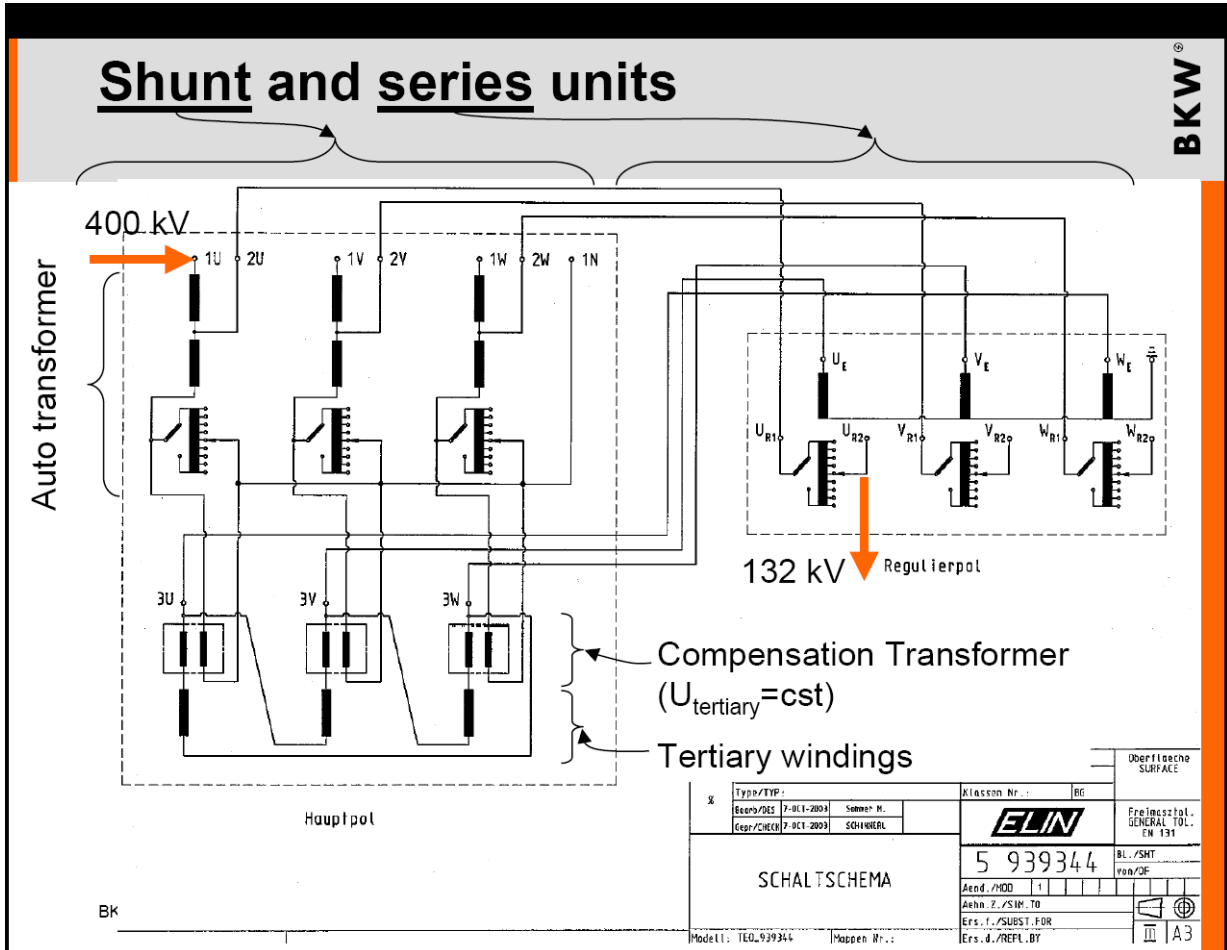And geometrically: $\Delta V = -e^{j\theta}.V\dfrac{\tan\alpha}{\sin\theta - \tan\alpha\cos\theta}$

hence $\dfrac{n1}{n1_{max}} = \dfrac{\tan\alpha}{\tan\alpha_{max}}\dfrac{\sin\theta - \tan\alpha_{max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}$

$$X(\alpha) = \left(X1_{max} + X2\dfrac{n1_{max}^2}{n2^2}\right)\left(\dfrac{\tan\alpha}{\tan\alpha_{max}}\dfrac{\sin\theta - \tan\alpha_{max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2$$
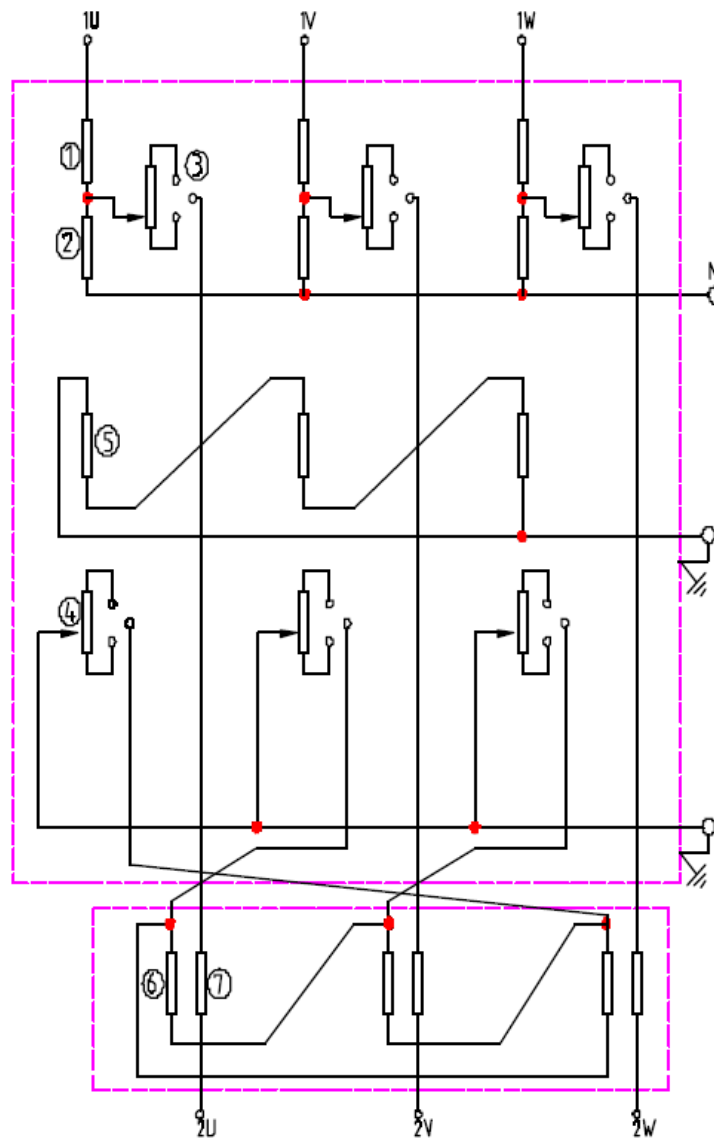
$$X(\alpha) = X(\alpha_{max})\left(\dfrac{\tan\alpha}{\tan\alpha_{max}}\dfrac{\sin\theta - \tan\alpha_{max}\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2$$

D.9.3.3   In-phase transformer and asymmetrical phase shifter

Examples of detailed three-phase diagrams: voltage regulating auto-transformer and Quadrature booster:

Voltage regulating auto-transformer and Quadrature booster:

1   EHV winding
2   HV winding
3   EV voltage regulating winding
4   Phase shift regulating winding
5   Tertiary winding
6   Primary winding of the series transformer
7   Secondary winding of the series transformer

Annex E
(normative)

CGMES profiles versions

The CGMES version 2.5 uses the following profiles and extensions:

- XMI: ENTSOE_CGMES_v2.4.15_7Aug2014_XMI.zip
- HTML: ENTSOE_CGMES_v2.4.15_7Aug2014_HTML.zip
- RDFS: ENTSOE_CGMES_v2.4.15_7Aug2014_RDFS.zip
- HTML_EA: ENTSOE_CGMES_v2.4.15_7Aug2014_HTML_EA.zip
- PDF: ENTSOE_CGMES_v2.4.15_7Aug2014_PDF.pdf
- OCL: ENTSOE_CGMES_v2.4.15_7Aug2014_OCL.zip
- EQ_BD profile version: 3.1
- TP_BD profile version: 3.1
- EQ profile version: 3.1
- TP profile version: 4.1
- SSH profile version: 1.1
- SV profile version: 4.1
- DL profile version: 3.1
- GL profile version: 2.1

Annex F
(normative)

Use of Modelica in the Dynamics profile

F.1 Introduction

The purpose of the annex is to illustrate the use of Modelica to describe models (control diagrams) for dynamics simulations.

Dynamics models exchange supplies data for one of the most complex analyses of a power system. The requirements of the data exchanges are directly related to the level of detail of the power system modelling applied in a given area. The DY (dynamics) profile supports the exchange of dynamic behaviour models used by software applications which perform analysis of the steady state stability (small-signal stability) or transient stability of a power system as defined by IEEE / CIGRE Standard Terms and Definitions for Power System Stability Analysis.

There are three ways in which the current version of the dynamics profile is designed to support as follows:

- Standard models exchange – a simplified approach to exchange, where models are contained in packages in predefined libraries of classes which represent dynamic behaviours of elements of the power system interconnected in a standard manner. Block diagrams and other information are also defined. The current profile supports a set of standard models.
- User-defined models exchange - a more flexible approach which permits users to exchange the definitions of a model by defining elementary control blocks and interconnections between these blocks in an explicit manner in the instance data. It is a way in which to exchange full information on user defined models. The profile does not fully support this type of exchange, namely does not support the mechanism to model the individual elements from the control blocks and describe how these are linked each other.
- Proprietary models exchange - an exchange which provides users with the ability to exchange the parameters of a model representing a vendor-proprietary device where an explicit public description of the model is not desired. It is a way in which to exchange proprietary models, and the models' "black box" (dll, etc.). All parties participating in the exchange should have the model (dll, etc.). Only parameters of models are exchanged. The profile supports this approach. It allows for the exchange of model name and description as well as an unlimited number of parameters per model.

Dynamics models are typically described using both graphics and text. Therefore there is a high level of complexity and room for interpretation. Besides many other functionalities, Modelica facilitates the process of describing the behaviour of the elements in the power system in a form of natural mathematical equations. This approach limits the interpretation of the control logic and dynamic behaviour which is a challenge in case the classically used methods to describe this are not well documented, because the generated model can be directly run on standard, open tools to give reference results and enable to better understand expected behaviours. Besides, Modelica leads to well-defined interfaces, which are very useful for models reusability and standardisation.

As required by the CGMES, vendors shall support proprietary model exchange which shall be used for an exchange of user defined models if all parties involved in the exchange have modelled the user defined models in their tools.

Therefore the CGMES mechanism to exchange information on the proprietary models is to demonstrate how the proprietary models can in fact be modelled based on Modelica code for different elements of the power system.

F.2 Supported types user defined models by CGMES

In its current version the DY profile of the CGMES supports the following user defined models which are used to link with the Modelica code. In case additional dynamics models (e.g. to be able to represent the dynamics behaviour of HVDC, etc.) need to be linked with the static (load flow) part of the model respective CIM classes can be created and associated with the equipment.

- WindPlantUserDefined
- WindType1orType2UserDefined
- WindType3or4UserDefined
- SynchronousMachineUserDefined
- AsynchronousMachineUserDefined
- TurbineGovernorUserDefined
- TurbineLoadControllerUserDefined
- MechanicalLoadUserDefined
- ExcitationSystemUserDefined
- OverexcitationLimiterUserDefined
- UnderexcitationLimiterUserDefined
- PowerSystemStabilizerUserDefined
- DiscontiniousExcitationControlUserDefined
- PFVArControllerType1UserDefined
- VoltageAdjusterUserDefined
- PFVArControllerType1UserDefined
- VoltageCompensatorUserDefined
- LoadUserDefined

All classes listed above are linking models connected as shown in the interconnection diagram below. It is important to note that this is also valid for cross compound systems. In addition, and just as an example, the class SynchronousMachineUserDefined can be used to link a Modelica code that represents the behaviour of a given synchronous machine including the associated controls such as excitation system, turbine, governor, etc.
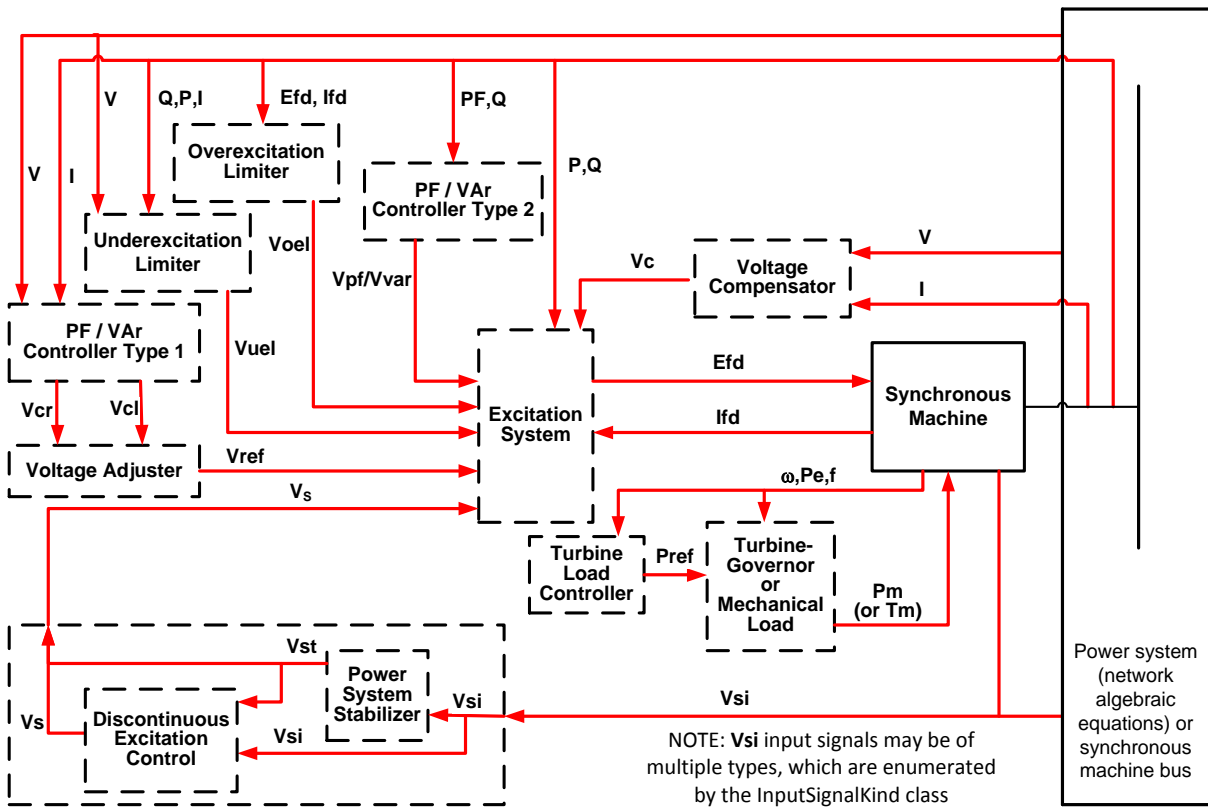
Synchronous Machine Interconnection

F.3 Modelling of user defined model in the CGMES

In order to illustrate the mechanism how Modelica code is connected to the CGMES an example of modelling of a simple excitation system is presented.

In the CGMES the user defined model (in the example of excitation system this is ExcitationSystemUserDefined) class which is to be used to link with the Modelica code is already properly linked to the respective synchronous machine in the load flow part of the model. This is illustrated in the UML diagram below.
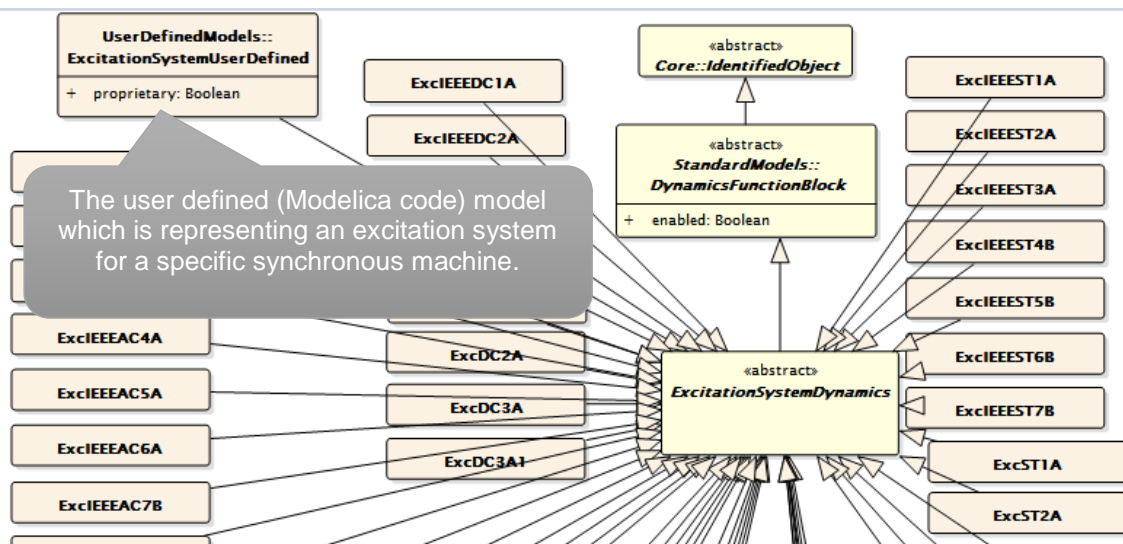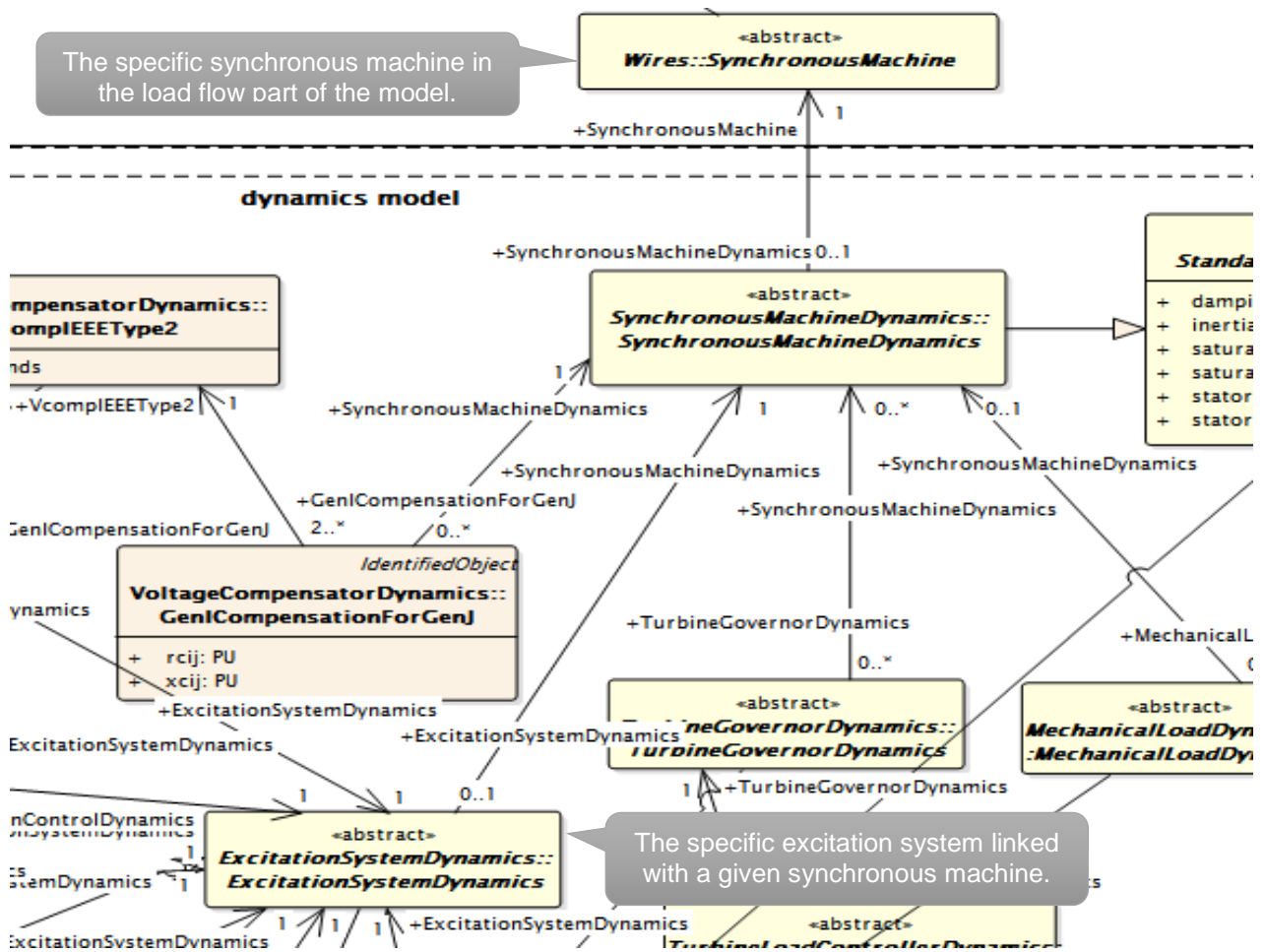
The figure below illustrates the approach applied to a turbine-governor model. The same concept is used to explain the modelling of the CGMES ExcSEXS excitation system - the link with Modelica code.
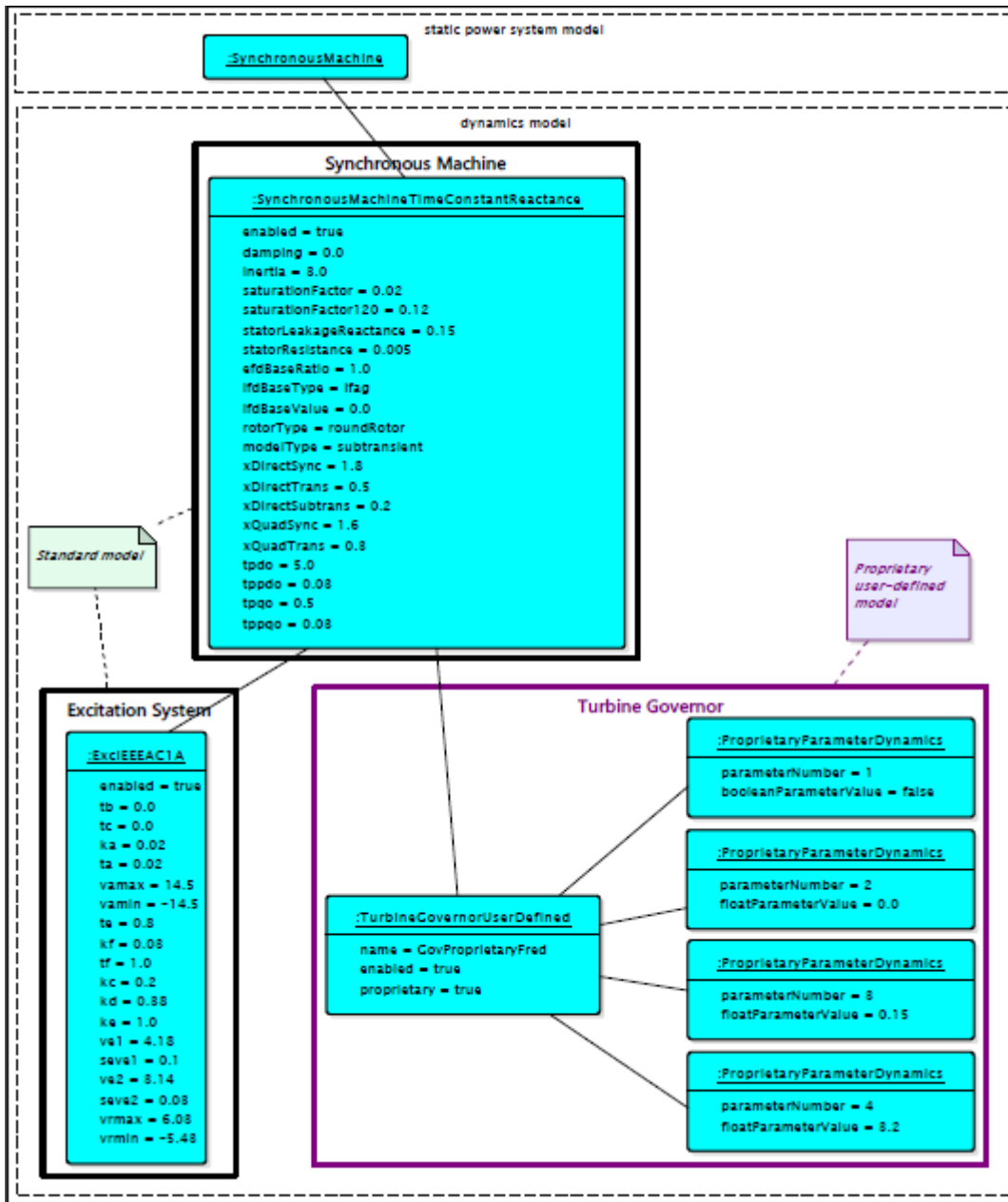
The ExcSEXS model in CGMES has the following structure.
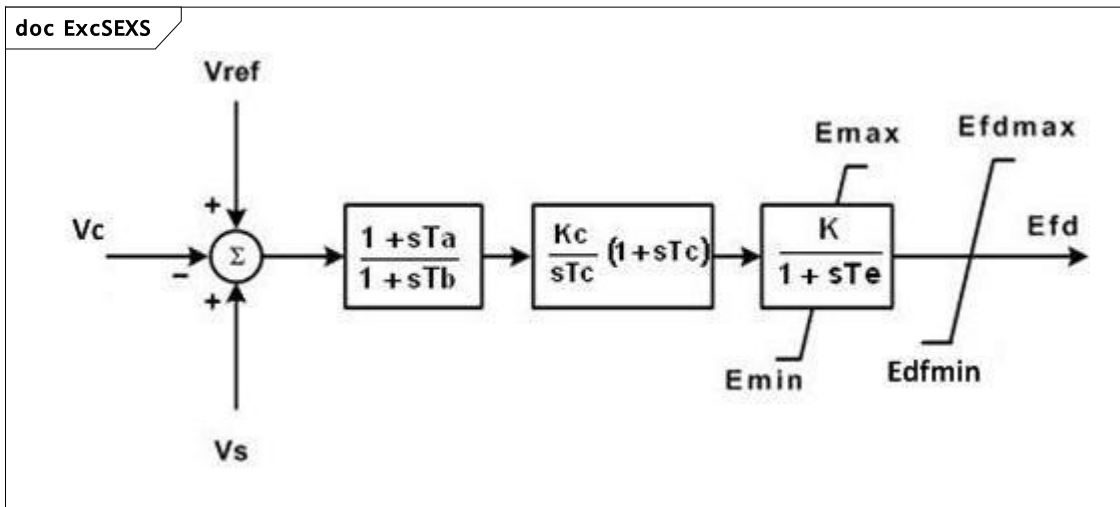
The instance data for the standard model ExcSEXS is the following. Please pay attention that the values for the parameters are indicative. In a real exchange these values will be different for different synchronous machines to which this type of model is associated with.

```xml
<cim:ExcSEXS rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6">

  <cim:DynamicsFunctionBlock.enabled>true</cim:DynamicsFunctionBlock.enabled>

  <cim:ExcSEXS.efdmax>4</cim:ExcSEXS.efdmax>

  <cim:ExcSEXS.efdmin>0</cim:ExcSEXS.efdmin>

  <cim:ExcSEXS.emax>4</cim:ExcSEXS.emax>

  <cim:ExcSEXS.emin>0</cim:ExcSEXS.emin>

  <cim:ExcSEXS.k>200</cim:ExcSEXS.k>

  <cim:ExcSEXS.kc>1</cim:ExcSEXS.kc>

  <cim:ExcSEXS.tatb>0.3</cim:ExcSEXS.tatb>

  <cim:ExcSEXS.tb>10</cim:ExcSEXS.tb>

  <cim:ExcSEXS.tc>0</cim:ExcSEXS.tc>

  <cim:ExcSEXS.te>0.05</cim:ExcSEXS.te>

  <cim:ExcitationSystemDynamics.SynchronousMachineDynamics    rdf:resource="#_30000630-1907-49bb-811b-3e3ce79cdfdb" /> <!-- This is a pointer to the type of the standard dynamics model for the synchronous machine which will then point to the synchronous machine in the load flow part of the model. -->

  <cim:IdentifiedObject.name>Exc_SEXS… free text up to 32 chars</cim:IdentifiedObject.name>

  <cim:IdentifiedObject.description>This    is    standard    model    …    free    text    up    to    256    chars</cim:IdentifiedObject.description>
```

</cim:ExcSEXS>

F.4 Modelica way to link with the code of the model

In Modelica the excitation model type SEXS is described by the equations related to the model. These equations are defined in a function[2] which has the input parameters that are the parameters of the model needed for the equations. For instance the excitation system type SEXS will be called with the following string:

Electrical.Controls.SEXS sEXS(T_AT_B=0.3,T_B=10,K=200,T_E=0.05,E_MIN=0, E_MAX=4,EFD_MAX=4, EDF_MIN=0,KC=1,T_C=0)

This string has the following main elements:

- The path (namespace) to the model i.e. Electrical.Controls.SEXS
- The name of the model (the instantiated object) in the Modelica library, i.e. sEXS
- The parameters used by the Modelica code of the model, i.e. (T_AT_B=0.3,T_B=10,K=200,T_E=0.05,E_MIN=0,E_MAX=4,EFD_MAX=4, EDF_MIN=0,KC=1,T_C=0, Ec0=1)

F.5 CGMES proprietary model exchange applied to link with Modelica code

In order to use the proprietary model exchange mechanism for an excitation system an instance of the class ExcitationSystemUserDefined is used with attribute ExcitationSystemUserDefined.proprietary set to true. In addition for each of the attributes of the model an instance of the class ProprietaryParameterDynamics is exchanged. Depending on the type of the parameter (float, boolean or integer) one of the attributes floatParameterValue or booleanParameterValue or integerParameterValue is used. The order of the parameter in the list of parameters is provided by the attribute parameterNumber.

The way of linking with the Modelica code is useful in cases when the names of the attributes used in the code are considered confidential. This will be the case if the approach is used for providing input parameters for a model expressed in any other type of code which is understood by the application importing CGMES instance data.

If this approach is applied the following CGMES instance data is used in order to transfer the information needed for the Modelica code representing the model type ExcSEXS in CGMES.

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[2] Please note that equations of the models along with all of the parameters and variables are not functions in Modelica but they are called models, or, in the traditional sense of object oriented programming, classes. So what is actually seen in the "calling" is instantiation of the exciter object from its class and specification of its parameters.

```xml
<cim:ExcitationSystemUserDefined rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6">
  <cim:DynamicsFunctionBlock.enabled>true</cim:DynamicsFunctionBlock.enabled>
  <cim:ExcitationSystemUserDefined.proprietary>true</cim:ExcitationSystemUserDefined.proprietary>
  <cim:ExcitationSystemDynamics.SynchronousMachineDynamics rdf:resource="#_30000630-1907-49bb-811b-3e3ce79cdfdb" />
  <cim:IdentifiedObject.name>sEXS</cim:IdentifiedObject.name>
  <cim:IdentifiedObject.description>Use Modelica code which defined this model....</cim:IdentifiedObject.description>
</cim:ExcitationSystemUserDefined>
<cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_1">

<cim:ProprietaryParameterDynamics.floatParameterValue>0.3</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>1</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_2">

<cim:ProprietaryParameterDynamics.floatParameterValue>10</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>2</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_3">

<cim:ProprietaryParameterDynamics.floatParameterValue>200</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>3</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_4">

<cim:ProprietaryParameterDynamics.floatParameterValue>0.05</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>4</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_5">

<cim:ProprietaryParameterDynamics.floatParameterValue>0</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>5</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
```

```
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_6">

<cim:ProprietaryParameterDynamics.floatParameterValue>4</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>6</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined     rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_7">

<cim:ProprietaryParameterDynamics.floatParameterValue>4</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>7</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined     rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_8">

<cim:ProprietaryParameterDynamics.floatParameterValue>0</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>8</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined     rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_9">

<cim:ProprietaryParameterDynamics.floatParameterValue>1</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>9</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined     rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_10">

<cim:ProprietaryParameterDynamics.floatParameterValue>0</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>10</cim:ProprietaryParameterDynamics.parameterNumber>
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined     rdf:resource="#_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
  <cim:ProprietaryParameterDynamics rdf:ID="_bc109c7c-c361-4c3f-afb4-317b0bc0c4f6_11">

<cim:ProprietaryParameterDynamics.floatParameterValue>1</cim:ProprietaryParameterDynamics.floatParameterValue>

<cim:ProprietaryParameterDynamics.parameterNumber>11</cim:ProprietaryParameterDynamics.parameterNumber>
```

```xml
  <cim:ProprietaryParameterDynamics.ExcitationSystemUserDefined     rdf:resource="#_bc109c7c-c361-4c3f-
afb4-317b0bc0c4f6" />
</cim:ProprietaryParameterDynamics>
```

Bibliography

[1]   Bibliography

[2]

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