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TECHNICAL SPECIFICATION

colour inside

Energy management system application program interface (EMS-API) – Part 600-1: Common Grid Model Exchange Specification (CGMES) – Structure and rules

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 61970-600-1, which is a technical specification, has been prepared by IEC technical committee 57: Power systems management and associated information exchange.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
57/1815/DTS	57/1871/RVDTS

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61970 series, published under the general title *Energy management system application program interface (EMS-API)*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

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 specification 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. This technical 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.

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.

ENERGY MANAGEMENT SYSTEM APPLICATION PROGRAM INTERFACE (EMS-API) –

Part 600-1: Common Grid Model Exchange Specification (CGMES) – Structure and rules

1 Scope

This technical specification on the CGMES defines the main rules and requirements related to the CGMES which are mandatory for achieving interoperability with the CGMES and for satisfying business processes. In this 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 IEC 61970-600-2:2017. 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.

Future editions of this technical specification will be released to describe following CGMES versions which will reflect additional requirements due to European network codes or guidelines.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

IEC 61970-452, *Energy management system application program interface (EMS-API) – Part 452: CIM model exchange specification*

IEC 61970-453, *Energy management system application program interface (EMS-API) – Part 453: Diagram layout profile*

IEC 61970-456, *Energy management system application program interface (EMS-API) – Part 456: Solved power system state profiles*

IEC 61970-552, *Energy management system application program interface (EMS-API) – Part 552: CIMXML Model exchange format*

IEC 61968-4, *Application integration at electric utilities – System interfaces for distribution management – Part 4: Interfaces for records and asset management*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms, definitions and abbreviated terms apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

NOTE For definitions which are not specified in the CGMES the definitions in the IEC 61970 standards shall be applied.

3.1 Terms and definitions

3.1.1
Common Grid Model Exchange Specification
CGMES
ENTSO-E specification 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

Note 1 to entry: This 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.

3.1.2
profile
uniquely named subset of classes, associations and attributes needed to accomplish a specific type of interface and based upon a canonical model

Note 1 to entry: This term 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.

3.1.3
CIM Extension
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

3.1.4
ENTSO-E Extension
CIM Extension, specifically managed by ENTSO-E

3.1.5
boundary set
set containing all boundary points necessary for a given grid model exchange

Note 1 to entry: 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.

3.1.6
boundary point
BP
connection point between two Model Authority Sets (MAS)

Note 1 to entry: 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.

3.2 Abbreviated terms

IEC The International Electrotechnical Commission, headquartered in Geneva

DSO	Distribution System Operator
TSO	Transmission System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity (ENTSO-E has 43 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 at 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 the 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 prepares 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 specification describes what is needed to create an assembly of multiple TSOs' Individual Grid Models (IGM) 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 node-breaker and 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 5.2). In the ENTSO-E data exchange process this unique identifier will be exchanged as rdf:ID.	Requirement
GENC2.	Software solutions shall not use “name” related attributes (name, short name, description, etc. inherited by many classes from the abstract class IdentifiedObject) to link the power system model. Only mRID (exchanged as rdf:ID) is used for this purpose.	Requirement
GENC3.	The rdf:ID defined within a data exchange process is the only globally unique and persistent identifier.	Requirement
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	Requirement
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.	Requirement
GENC6.	Applications which conform to the CGMES shall support IEC 61970-552 and rdf:ID expressed as a string.	Requirement
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.	Requirement
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	Requirement
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”.	Requirement
GENC10.	UTF-8 is the standard for file encoding. UTF-16 is not supported.	Requirement
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.	Requirement
GENC12.	Optional and required attributes and associations must be imported and exported if they are in the model file prior to import.	Requirement
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 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.	Requirement

ID	Specification	Type
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 shall 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.	Requirement
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 IEC 61970-452 and in the CGMES profiles shall be applied.	Requirement
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.	Requirement

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.	Requirement
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.	Requirement
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.	Requirement
MAS_4.	The mRID shall be persistent for the same given functional representation inside a given version of CIM.	Requirement
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.	Requirement
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.	Requirement
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.	Requirement
MAS_8.	Only one representation (the main class or its specialisation) should be present in a given instance file.	Requirement
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	Requirement
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.	Requirement
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 never have associations with objects in other TSO sets. This allows TSO modelling to be carried out independently of other TSOs	Requirement
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.	Requirement
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.	Requirement

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.	Requirement
HGEN2.	Each type of instance file (full and difference) shall have a file header.	Requirement
HGEN3.	The file header is declared at the top of the instance file i.e. at the beginning of the file.	Requirement

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. – 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.	Requirement

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.	A difference model should not be created in case of very small numeric differences as these types of difference models are meaningless.	Requirement

5.5 Profiles and instance file types

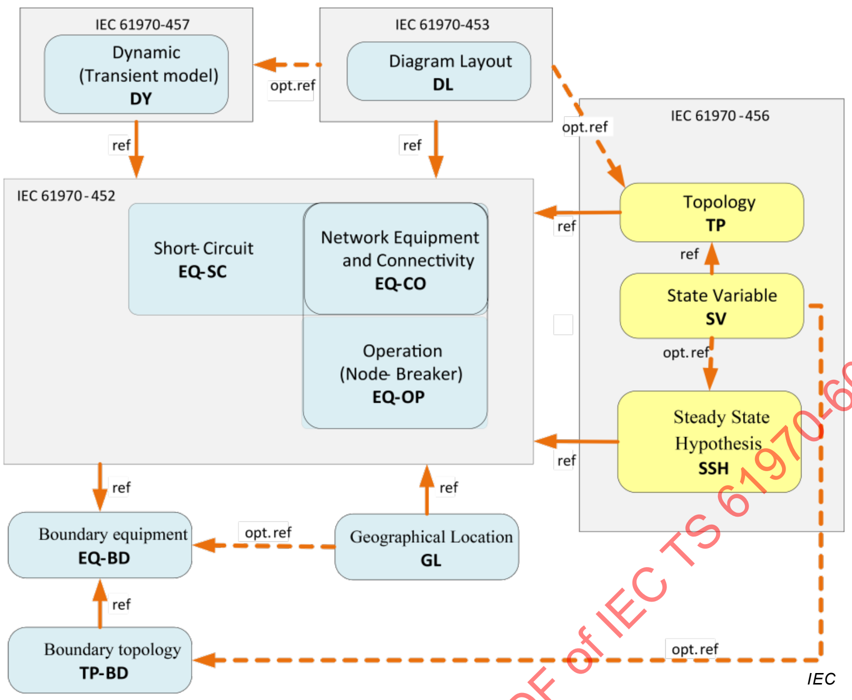
5.5.1 General

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

5.5.2 CGMES profiles' properties

The profiles which are part of the CGMES are based on IEC CIM UML and maintained in a 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 defined in a Version class for each profile of the CGMES. These properties shall be used as a primary source for file header information.	Requirement
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 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.	Information
PROF9.	Annex F provides references to the CGMES documentation related to a specific version of the profiles.	Information

ID	Specification	Type
PROF10.	The dependencies between the profiles belonging to CGMES are defined in the following figure  **Figure 1 – Dependencies between the profiles belonging to CGMES** Figure 1 defines the “ref” relations that show a dependency between two profiles. Profile schemas (RDFS) shall not be merged to create a 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. 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. The blue profiles are invariant, whereas the yellow ones are variant (meaning that the instance files may be different for every other scenario).	Requirement
PROF11.	The profile references in the file header specify 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.	Requirement

5.5.3 CGMES’ extensions

Due the complexity and specificity of the ENTSO-Es' 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 the 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

ID	Specification	Type
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>* ***<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>*	Requirement
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 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.	Requirement

5.5.4 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

5.5.5 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
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

5.5.6 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

5.5.7 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

5.5.8 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 EnergySchedulingTypes and BaseVoltages. 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
EQBD3.	Boundary equipment instance files can be updated using difference file exchange.	Requirement

5.5.9 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

5.5.10 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

5.5.11 Geographical location profile and instance file

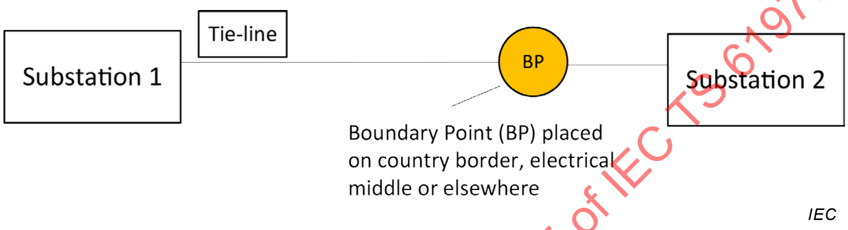
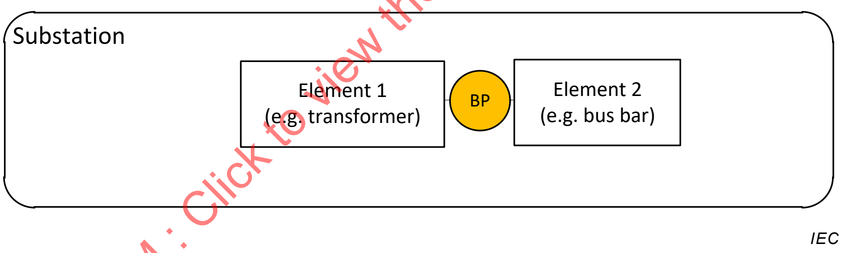
ID	Specification	Type
GL__1.	A geographical data instance file contains GIS data and is constructed based on IEC 61968-4, although it is limited to the classes which cover ENTSO-E needs.	Information
GL__2.	A geographical data instance file is exchanged in full, although it could be updated using difference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

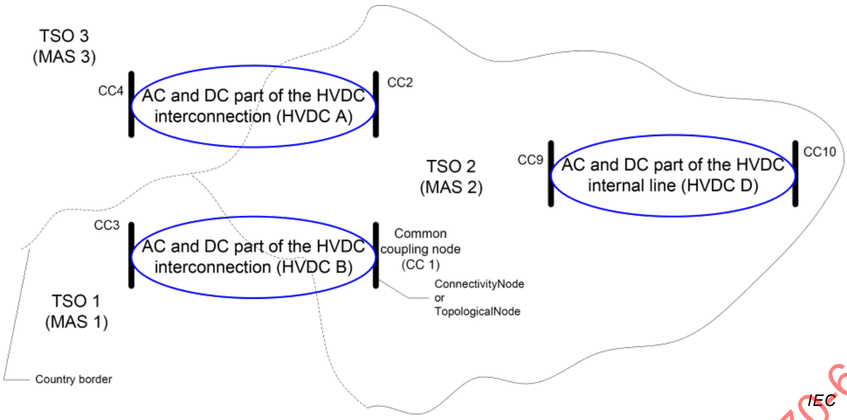
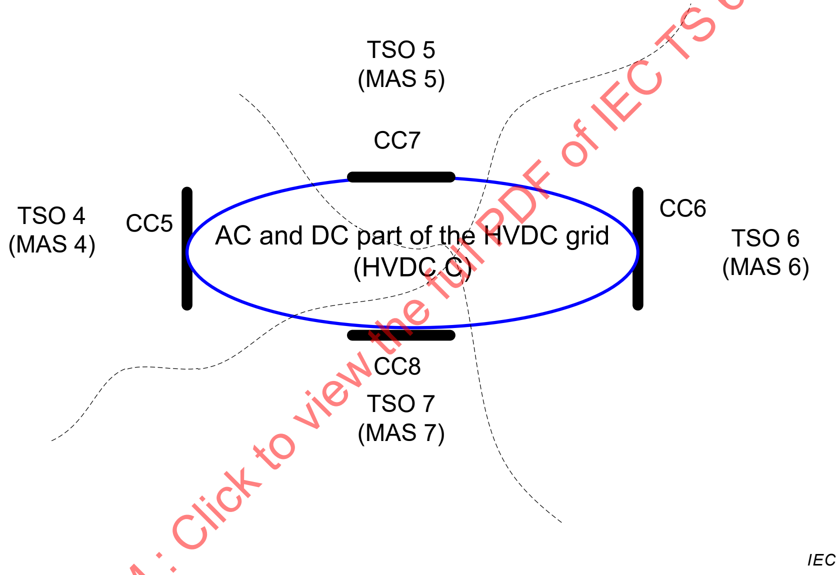
5.6 File exchange

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 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 may 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). – 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	Information
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 permitted 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

1 Note that a given business process may require the instances to be exchanged in individual zip files.

5.7 Boundary point – properties and location

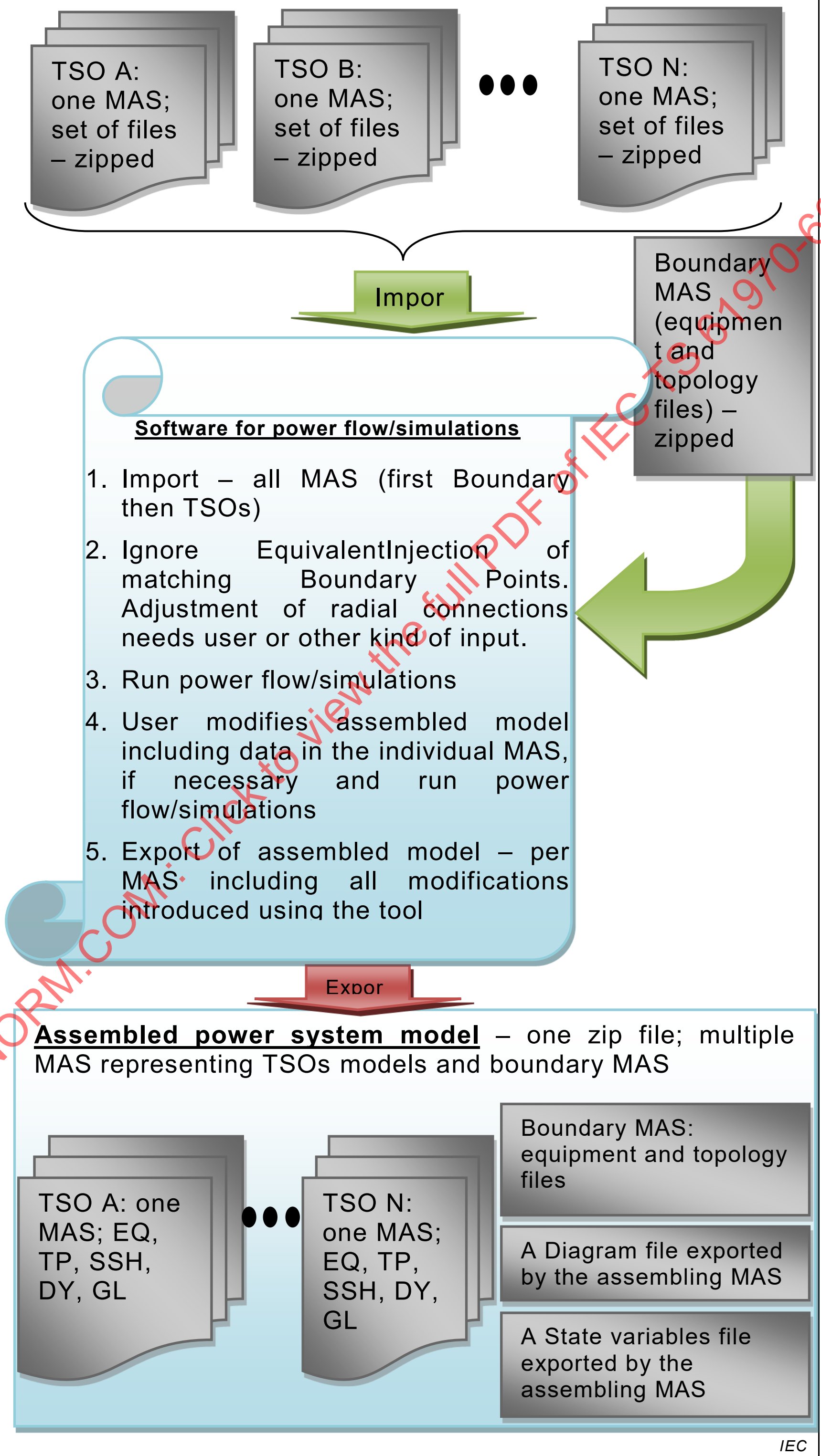
ID	Specification	Type
BPPL1.	EquivalentInjection classes are used to represent the power flow exchanges through Boundary points. These classes are included in the individual model MAS (TSO MAS) and refer to the Boundary points in the Boundary set. A SvInjection class is not used for this purpose.	Requirement
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 (see Figure 2): 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.  **Figure 2 – Boundary point placed on a tie-line** – Boundary point placed in a substation (see Figure 3): 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.  **Figure 3 – Boundary point placed in a substation**	Requirement

ID	Specification	Type
BPPL4.	The CGMES supports HVDC modelling for a detailed representation of HVDC interconnections, TSO internal HVDC links and HVDC grid. Figures 4 and 5 illustrate different cases.  **Figure 4 – HVDC as interconnection or internal line**  **Figure 5 – HVDC grid**	Information
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

ID	Specification	Type
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
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 may be performed to obtain a solution for the assembled power system model.	Requirement
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

ID	Specification	Type
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 chart in Figure 6 illustrates the assembly process:  Figure 6 – Assembly process	Requirement

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 shall 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 shall 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 shall contain CIM entities which are valid according to the CIM RDF Schema file.	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.

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.

Naming is a complex issue as different applications or processes can have naming conventions that are inconsistent or conflicting with naming conventions used by other applications or processes.

CGMES applies the following naming principles:

- Names are mainly for humans. They shall not be used for any purposes of 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.
- Names 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. – Vendors developing tools for power system analyses to ensure that: • TSO experts are able to supply the names as required by the business process; • An agreement for naming translation between requirements in the business process and the proprietary formats or TSO databases is in place; • Export and import functionalities are compliant with the data exchange rules. – Vendors developing validation tools to adjust validation rules valid for the business process	Information
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 process restrictions on naming shall 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; – 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.	Requirement
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

ID	Specification	Type
NAMC11.	Tables 1 and 2 summarise the use of name related attributes in the different profiles. They provide the length of the strings which tools must support for all classes that inherit from IdentifiedObject or on ConnectivityNode and TopologicalNode. (Tables 1 and 2 follow.)	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
.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.

ID	Specification	Type
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 defined 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>	

6 CGMES governance

6.1 General

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 chart in Figure 7 illustrates the main stages related to the CGMES.

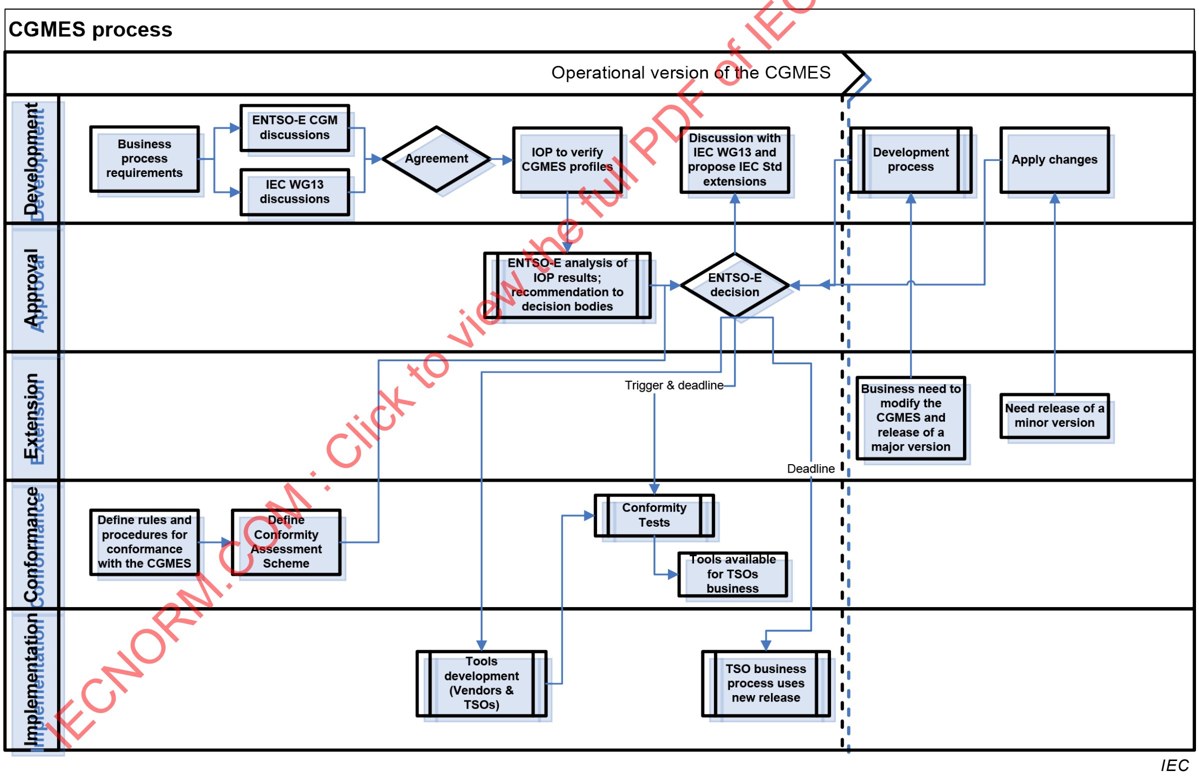


Figure 7 – Main development stages of the CGMES

6.2 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 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	Requirement
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 shall 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 shall 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 shall 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 shall comprise only ASCII alphanumeric and hyphen [0-9a-Za-z-]. Identifiers shall not be empty. Numeric identifiers shall 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 shall 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

6.3 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.

6.4 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 conventions

B.1 IdentifiedObject.name

Human readable name with a maximum string length of 32 characters. The length restriction is defined in 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 TSOs, using general names.

B.2 IdentifiedObject.description

Human readable description with maximum string length of 256 characters. The length restriction is defined in 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/data/energy-identification-codes-eic/eic-lio-websites/Pages/default.aspx
- EIC description: https://www.entsoe.eu/data/energy-identification-codes-eic/eic-documentation/Pages/default.aspx

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 General

This annex provides guidance on how to apply IEC 61970-552 which defines file headers for complete instance files and difference instance files.

C.2 Exchange scenarios

IEC 61970-552 gives as an example the following figure (Figure D.1) which is used in order to explain what information should be provided in different file headers.

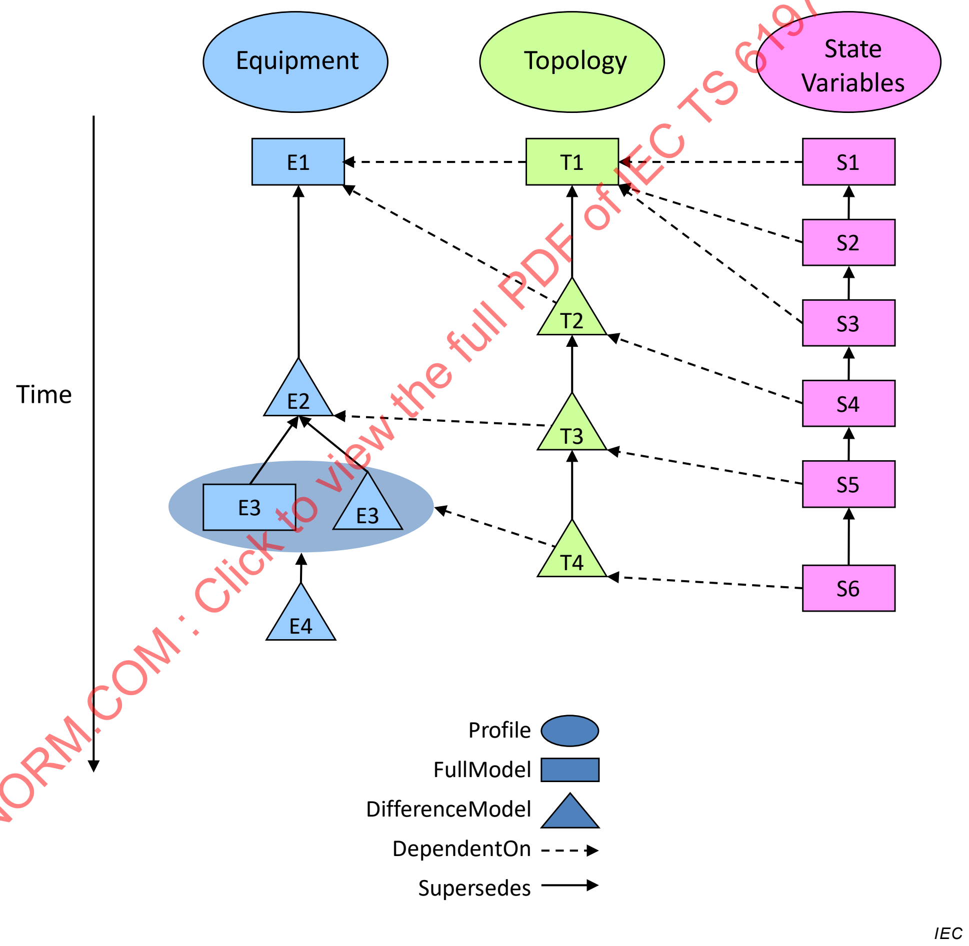


Figure C.1 – Example work flow events

C.3 Examples

C.3.1 Example 1: File header of full model

This example is for full model E1 from Figure C.1.

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 of 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> 2030-01-15T17:00:00.000</md:Model.scenarioTime>	This is the date and 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>2014-05-15T17:48:31.474</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 HREF1). 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 Figure C.1.

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> 2030-01-15T17:00:00.000</md:Model.scenarioTime>	This is the date and 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>2014-05-15T17:48:31.474</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 HREF1). 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 Figure C.1.

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> 2030-01-15T17:00:00.000</md:Model.scenarioTime>	This is the date and 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>2014-05-15T17:48:31.474</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 HREF1). 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 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/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.3.4 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 Figure C.1.

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 note 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> 2030-01-15T17:00:00.000</md:Model.scenarioTime>	This is the date and 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>2014-05-15T17:48:31.474</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 HREF1). 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.

Syntax	Comment/Explanation
<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 IEC 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 Figure C.1.

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 note 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> 2030-01-15T17:00:00.000</md:Model.scenarioTime>	This is the date and 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>2014-05-15T17:48:31.474</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.

Syntax	Comment/Explanation
<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 HREF1). 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 IEC 61970-452.
</dm:DifferenceModel>	

Annex D
(normative)

PST transformer modelling

D.1 General

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 annex 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 annex, the mapping to CGMES classes is presented in Table D.1:

Table D.1 – Mapping of phase shift transformers to CIM classes

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

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.

The symbols used in formulas within this annex are mapped to CIM classes as described in Table D.2.

Table D.2 – Mapping of symbols used in formulas to CIM attributes

Power Shift Transformer 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

NOTE

– 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.

D.3 Reactance formulas summary table

The impedance variation depending on tap position on a phase shift transformer is described in Table D.3 and a description of the variables given in Table D.4.

Table D.3 – Impedance variations in a phase shift transformer

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	$X(r,\alpha) = X_r(r_{nom})\left(\frac{r}{r_{nom}}\right)^2 + X_\alpha(0) + \left(X_\alpha(\alpha_{max}) - X_\alpha(0)\right)\left(\frac{\sin(\alpha/2)}{\sin(\alpha_{max}/2)}\right)^2$
In-phase transformer and asymmetrical phase shifter	$X(r,\alpha) = X_r(r_{nom})\left(\frac{r}{r_{nom}}\right)^2 + X_\alpha(0)$ $+\left(X_\alpha(\alpha^0_{max}) - X_\alpha(0)\right)\left(\frac{\tan\alpha}{\tan\alpha_{max}(r)} \frac{\sin\theta - \tan\alpha_{max}(r)\cos\theta}{\sin\theta - \tan\alpha\cos\theta}\right)^2$ with $\alpha_{max}(r) = \arctan\left(\frac{\sin\theta}{\frac{r}{r_{nom}\tan\alpha^0_{max}}\left(\sin\theta - \tan\alpha^0_{max}\cos\theta\right) + \cos\theta}\right)$ and $\alpha^0_{max} = \alpha_{max}(r_{nom})$

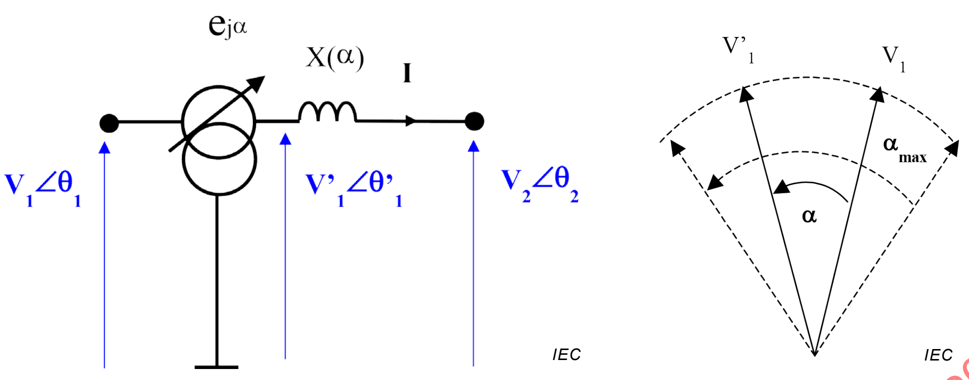
Table D.4 – Description of variables

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^0_{max}	Maximal phase shift when the in-phase transformer ratio is nominal

D.4 Symmetrical Phase shifters

D.4.1 Single phase diagram and equations

Figure D.1 shows a single phase diagram and equations.



$$V'_1 = V_1\left(1 + 2j\sin\frac{\alpha}{2}e^{j\frac{\alpha}{2}}\right) = e^{j\alpha}V_1$$

$$V_2 = V_1 e^{j\alpha} - jX(\alpha)I$$

Figure D.1 – Single phase diagram, phasor diagram and equations

D.4.2 Expression of the angle and ratio per tap

Based on Figure D.1:

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

$r = 1$

D.4.3 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 for non delta-hexagonal technologies (see proof in D.9.1):

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

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 $\alpha=\alpha_{max}$

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: $X(0)=0$. An example of impedance variation is shown in Figure D.2.

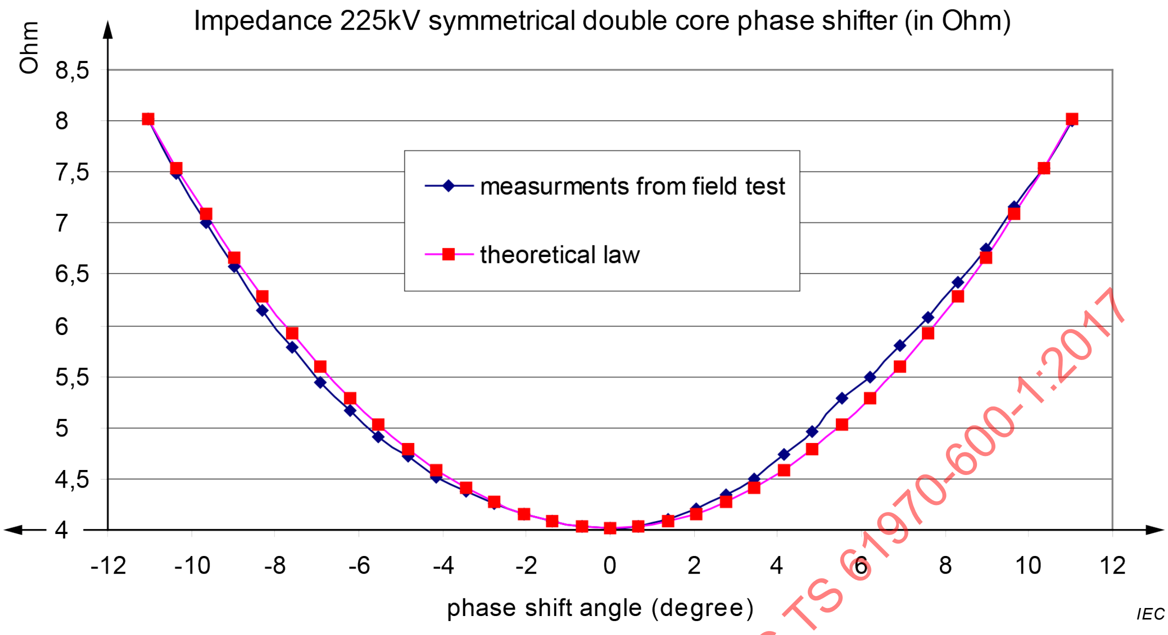


Figure D.2 – Example for symmetrical double core phase shifter

D.4.4 Three-phase diagrams

Figures D.3 and D.4 give examples of three-phase diagrams.

Dual core: Single core:

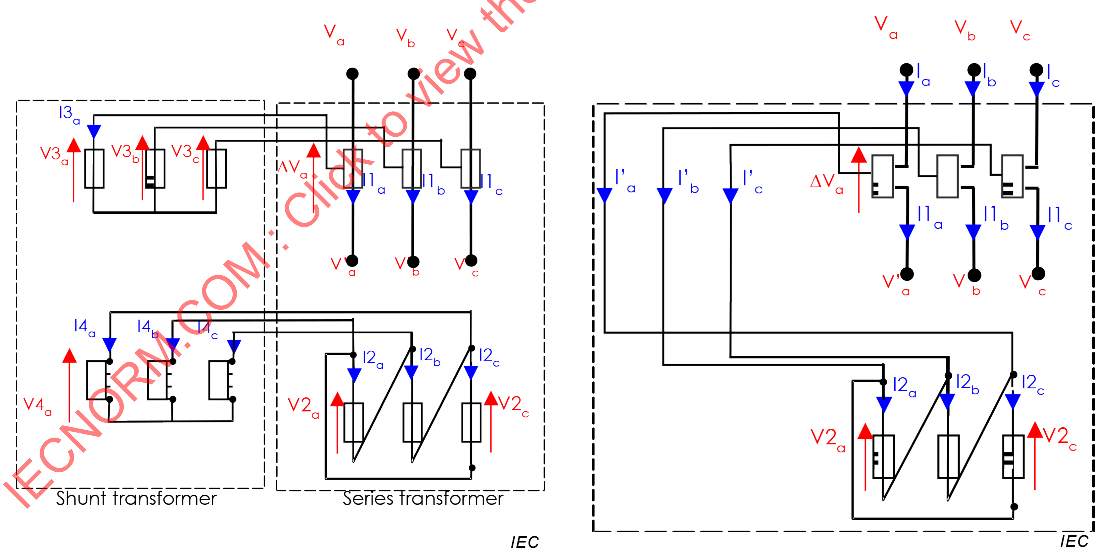


Figure D.3 – Dual core and single core

Single core, delta hexagonal:

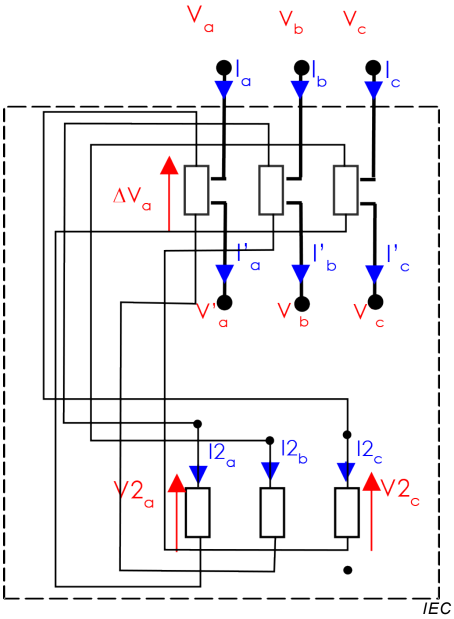
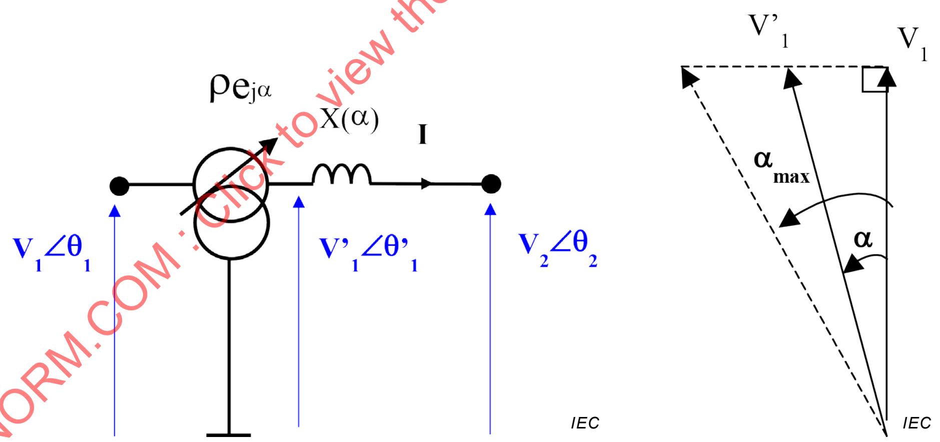


Figure D.4 – Single core, delta hexagonal

D.5 Quadrature booster

D.5.1 Single phase diagram and equations

Figure D.5 shows a single phase diagram and equations.



$$V'_1 = V_1(1 + j\tan\alpha) = \rho e^{j\alpha} V_1 \qquad V_2 = V_1 \rho e^{j\alpha} - jX(\alpha)I$$

ρ and α vary with ρ.cos α = constant.

Figure D.5 – Single phase diagram, phasor diagram and equations

D.5.2 Expression of the angle and ratio per tap

Based on Figure D.5:

$$\alpha = \arctan((n - n_0) \cdot \delta u)$$

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

D.5.3 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 of the quadrature booster can be written as follows (see proof in D.9.2):

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

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

Variable:

- α: current phase shift

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

D.5.4 Three-phase diagrams

Figure D.6 gives examples of three-phase diagrams.

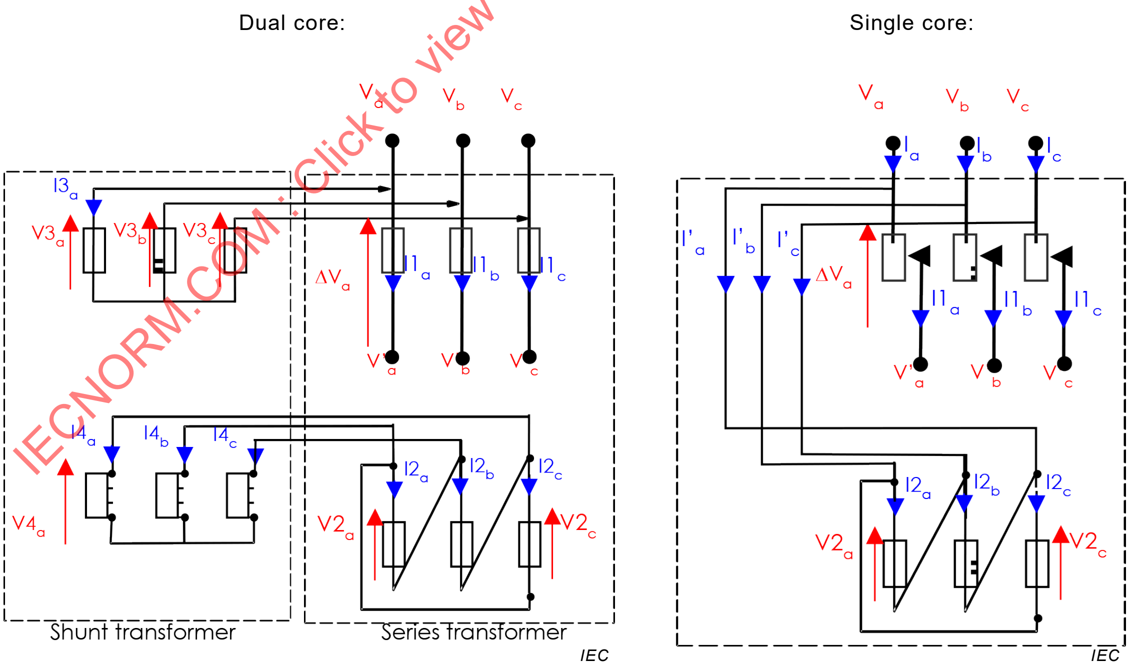
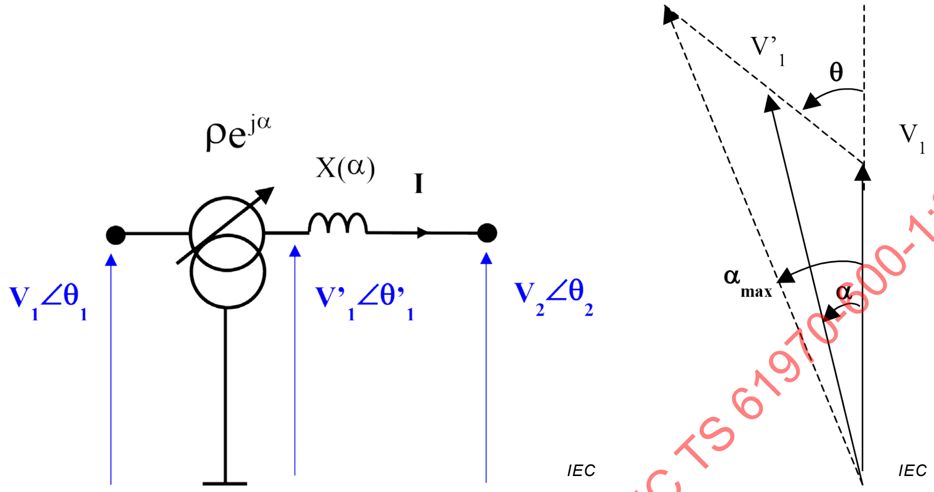


Figure D.6 – Dual core and single core

D.6 Asymmetrical Phase Shifter

D.6.1 Single phase diagram and equations

Figure D.7 shows a single phase diagram and equations.



$$V'_1 = V_1\left(1 + e^{j\theta}.\frac{\tan\alpha}{\sin\theta - \tan\alpha\cos\theta}\right) = \rho e^{j\alpha} V_1 \quad V_2 = V_1.\rho e^{j\alpha} - jX(\alpha)I$$

θ is fixed, only α and ρ vary.

Figure D.7 – Single phase diagram, phasor diagram and equations

D.6.2 Expression of the angle and ratio per tap

Based on Figure D.7:

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

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

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 D.9.3):

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

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

Variable:

- α: current phase shift

D.6.4 Three-phase diagram

Figure D.8 gives an example of a three-phase diagram.

Dual core:

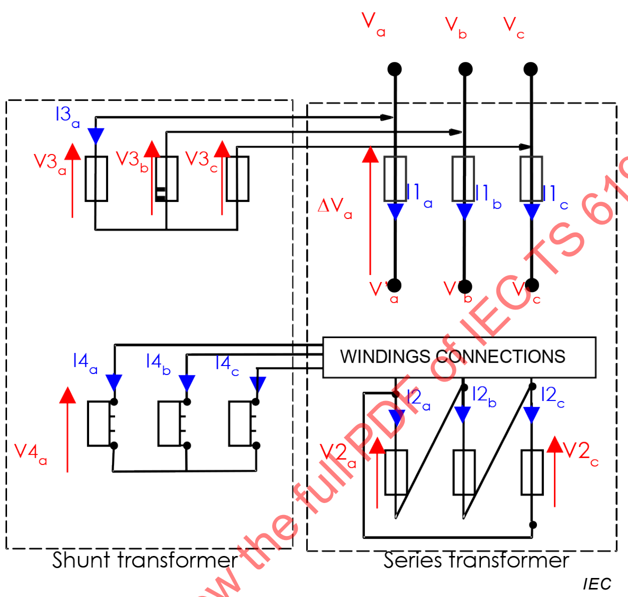
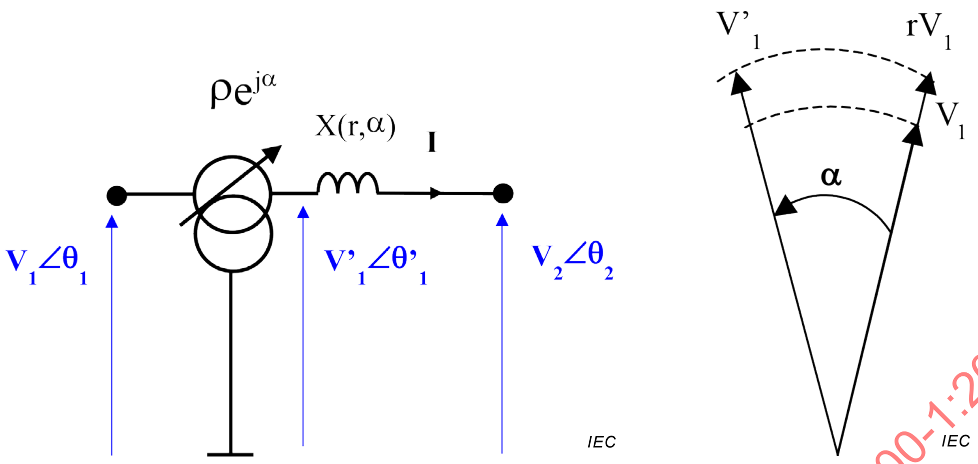


Figure D.8 – Dual core

D.7 In-phase transformer and symmetrical phase shifter

D.7.1 Single phase diagram and equations

Figure D.9 shows a single phase diagram and equations.



$$V_2 = \rho V_1 e^{j\alpha} - jX(\alpha)I.$$

$$V'_1 = rV_1\left(1 + 2j\sin\frac{\alpha}{2}e^{j\frac{\alpha}{2}}\right) = \rho e^{j\alpha}V_1$$

r and α vary, and $\rho = r$

Figure D.9 – Single phase diagram, phasor diagram and equations

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

Assumptions:

- 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:

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

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})

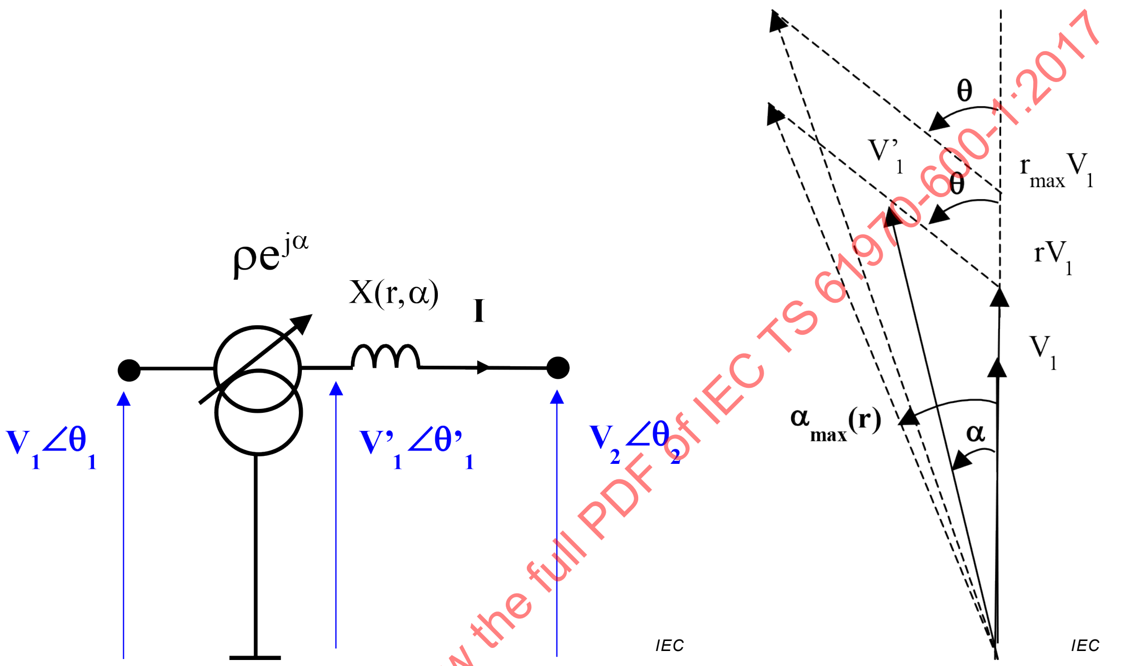
Variables:

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

D.8 In-phase transformer and asymmetrical phase shifter

D.8.1 Single phase diagram and equations

Figure D.10 gives an example of a single phase diagram and equations.



$$V'_1 = rV_1\left(1 + e^{j\theta}.\frac{\tan\alpha}{\sin\theta - \tan\alpha\cos\theta}\right) = \rho e^{j\alpha}V_1$$

$$V_2 = \left(V_1 - jX(\alpha)I\right)\rho e^{j\alpha}$$

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

Figure D.10 – Single phase diagram, phasor diagram and equations

D.8.2 Expression of the equivalent series reactance given the angle and the in-phase transformer ratio

Assumptions:

- 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 Xr and the reactance of the phase shifter part $X\alpha$,

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

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

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

Parameters:

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

Variables:

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

For $\theta = \pi/2$ (quadrature booster): $\alpha_{\max}(r) = \arctan\left(\dfrac{r_{\text{nom}}}{r}\tan\alpha_{\max}^{0}\right)$

D.8.3 Technology principles

Figure D.11 shows an in-phase regulating auto-transformer.

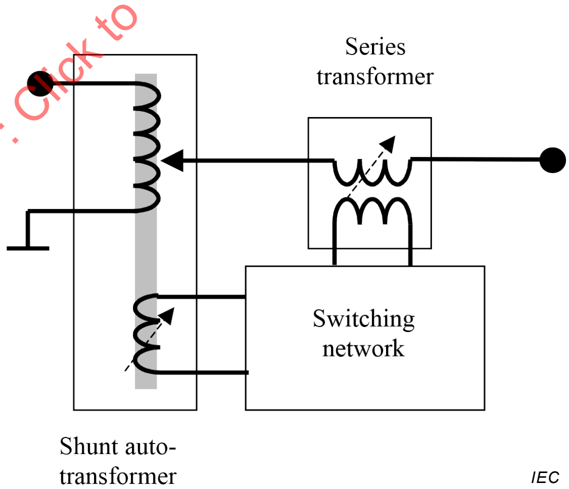


Figure D.11 – In-phase regulating auto-transformer

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

Figure D.12 shows symmetrical phase shifters with two cores.

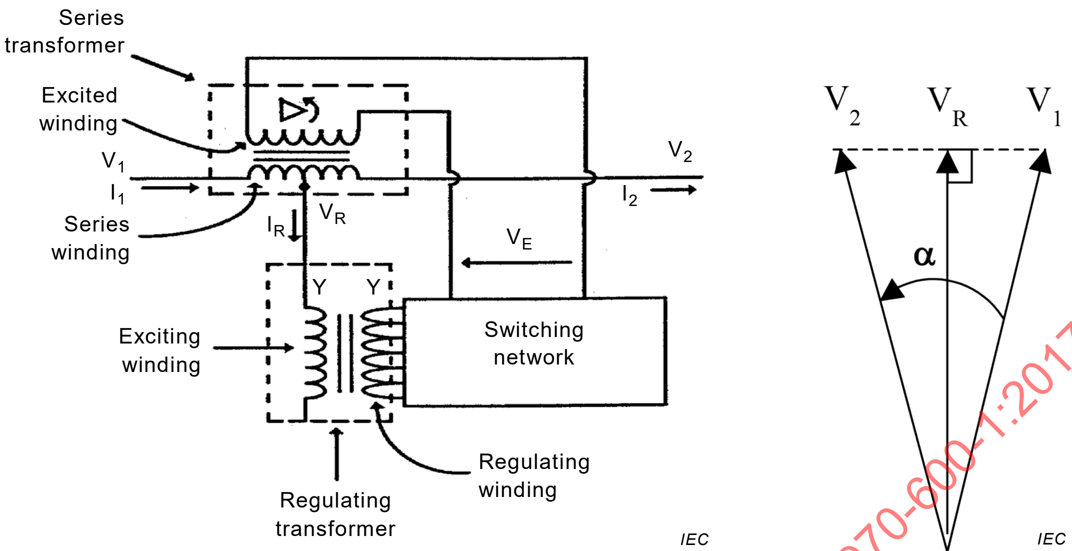


Figure D.12 – Symmetrical phase shifters with two cores

Figure D.13 shows a detailed three phase diagram.

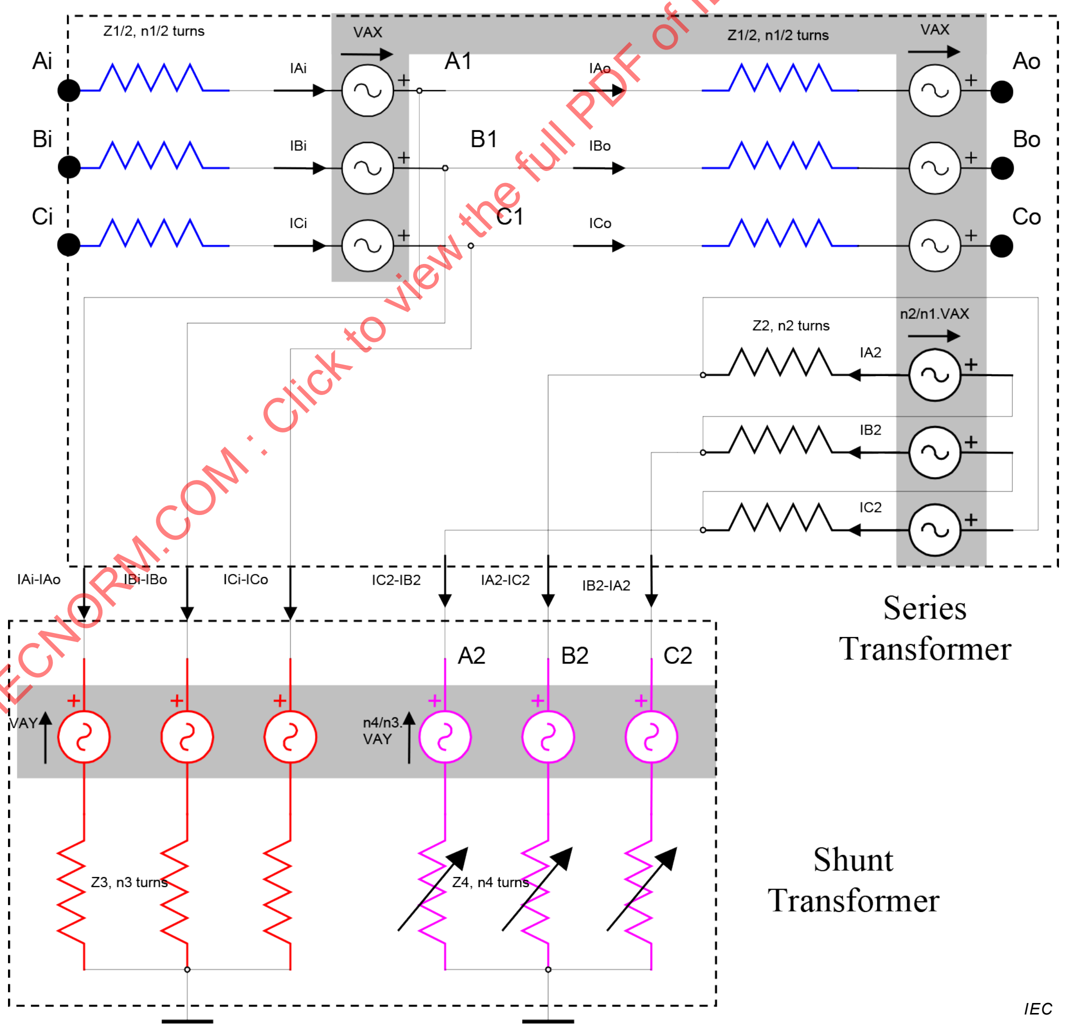


Figure D.13 – Detailed three phase diagram

Only n4 varies.

Example of numerical values:

n1=120

n2=318

n3=680

$n4_{max}$=182

X1=1,23 Ω

X2=8,64 Ω

X3=101 Ω

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

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

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

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

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

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:

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

$$X(\alpha_{\max}) - X(0) = 4(\sin(\alpha_{\max}/2))^2 \left(X3 + X4_{\max} \frac{n3^2}{n4^2_{\max}} - \left(\frac{n1}{2n2} \right)^2 X2 \right)$$

Remark: only α varies.

D.9.2 Quadrature boosters

D.9.2.1 Quadrature booster with two cores

Figure D.14 shows a detailed three phase diagram. The single phase diagram is shown in Figure D.15.

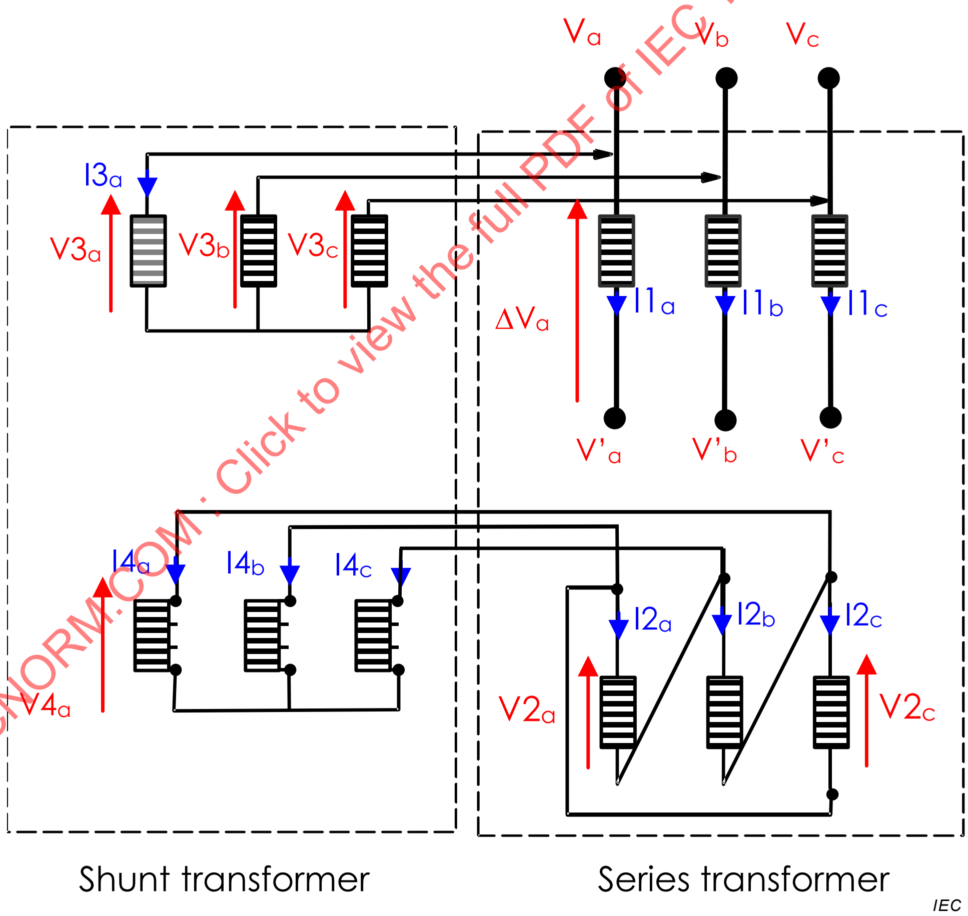


Figure D.14 – Detailed three phase diagram

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:

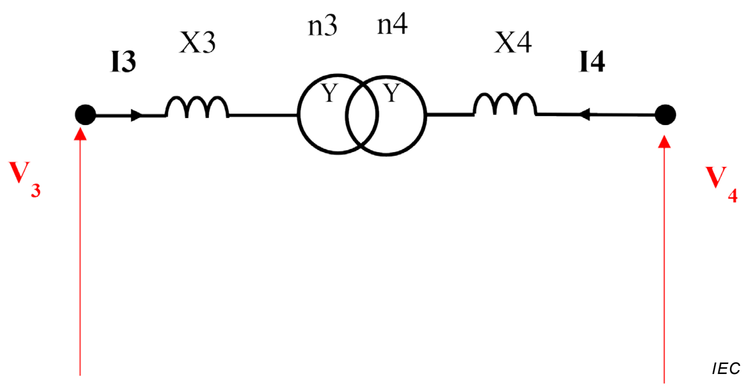


Figure D.15 – Single phase diagram

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

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

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:

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

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

At no load conditions (I=0):

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

And geometrically, shown in Figure D.16:

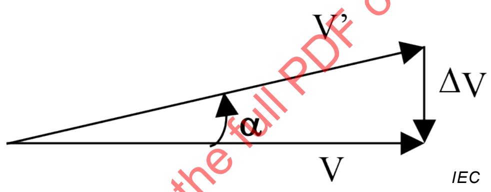


Figure D.16 – Phasor diagram

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

Hence $\frac{n4}{n4^{max}} = \frac{\tan\alpha}{\tan\alpha_{max}}$

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

comes:

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

D.9.2.2 Quadrature booster with a single core

Figure D.17 shows a detailed three phase diagram.

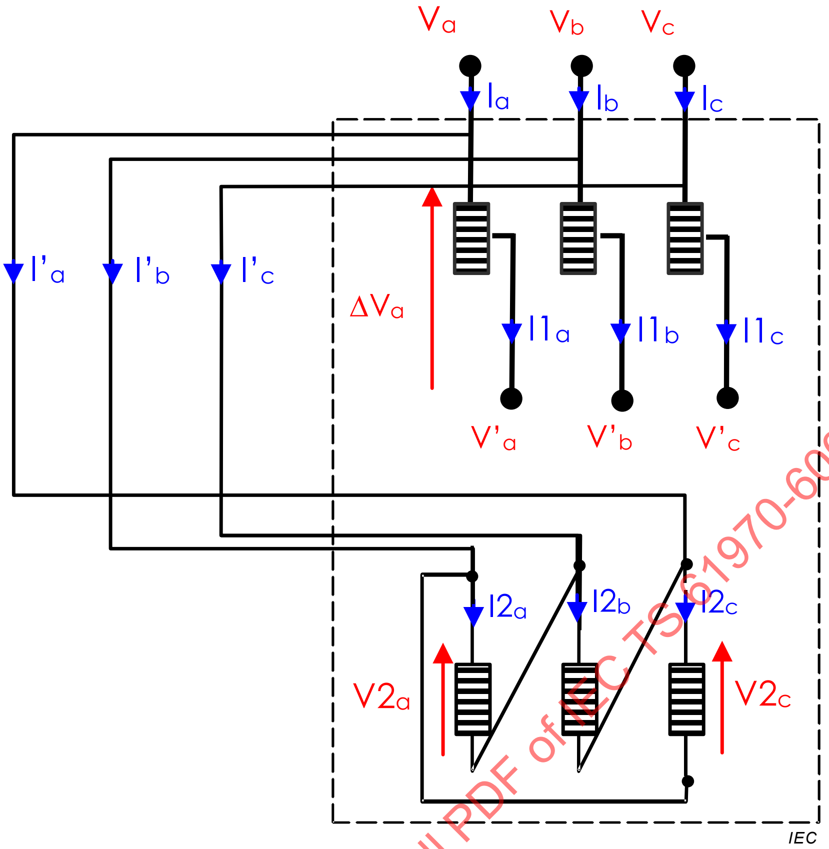


Figure D.17 – Detailed three phase diagram

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

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

At no-load: $\Delta V = -j\sqrt{3}\frac{n1}{n2}V$

And geometrically, shown in Figure D.18:

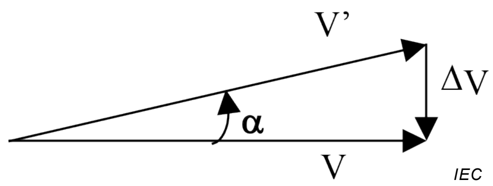


Figure D.18 – Phasor diagram

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

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

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

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

D.9.3 Asymmetrical phase shifter

D.9.3.1 Asymmetrical phase shifter with two cores

Figure D.19 shows an asymmetrical phase shifter with two cores.

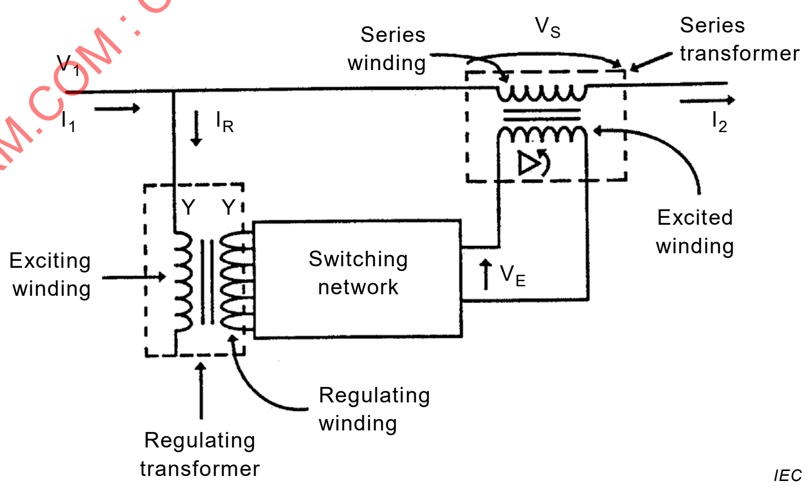


Figure D.19 – Asymmetrical phase shifter with two cores

Figure D.20 shows a detailed three phase diagram:

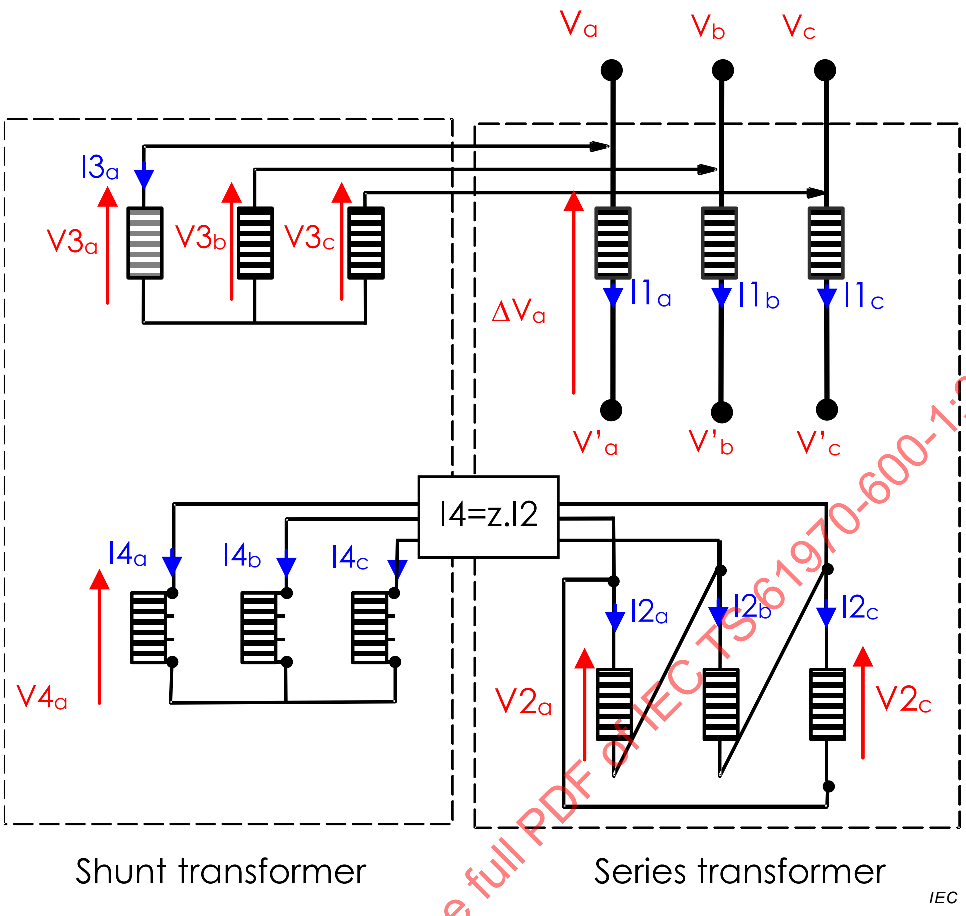


Figure D.20 – Detailed three phase diagram

For each physical value X (X=V or I) $X = X_a = aX_b = a^2X_c$ 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 X2 reactance varies like the square of the k1 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, shown in Figure D.21:

$$\Delta V = -e^{j\theta}.V \frac{\tan\alpha}{\sin\theta - \tan\alpha\cos\theta}$$

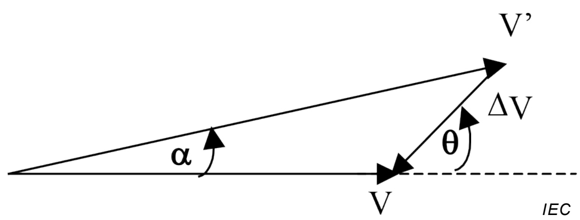


Figure D.21 – Phasor diagram

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

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

comes:

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

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

D.9.3.2 Asymmetrical phase shifter with a single core

Figure D.22 shows an asymmetrical phase shifter with a single core.

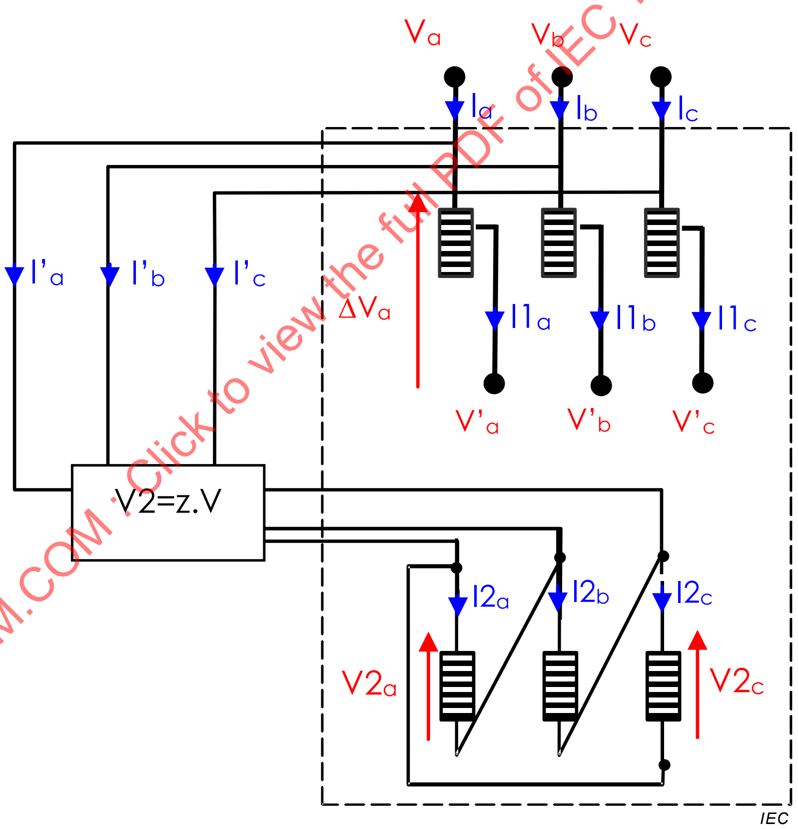


Figure D.22 – Asymmetrical phase shifter with a single core

Only n1 varies.

$$I' = -z.I2$$

$$V2 = z.V$$