Translation to Modelica

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# Introduction

Researchers and educators perform power system dynamic analysis such as phasor simulations using the Open-Instance Power System Library (OpenIPSL) which is a library of power system component models written in the [Modelica](http://modelica.org) language. Prof. [Luigi Vanfretti's](https://github.com/lvanfretti) research group [ALSETLab](https://github.com/ALSETLab) at [Rensselaer Polytechnic Institute](http://rpi.edu), Troy, NY, collaborators and friends, such as [Dietmar Winkler](https://github.com/dietmarw) and [FOSSEE](https://om.fossee.in/fellowship2018) currently develop and main OpenIPSL.

Modelica's ability to create one model of many types of systems allows extensibility for researchers not available with other modeling software such as [PSS/E](https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/pss-software/pss-e.html) and [PSAT](https://www.mathworks.com/matlabcentral/answers/91079-power-system-analysis-toolbox-psat). Also, its ability to "drag-n-drop" pre-built components into the model is enlightening for students. Model creation and modification is simple in OpenIPSL.

Model validation can be an individual journey by comparing what the person knows to be true and the new model. Translations will make Modelica universal for modeling. Many researchers have data from PSS/E and PSAT. Therefore, moving these known models to Modelica is a good starting point. This paper will focus on moving a known PSS/E model into OpenIPSL and comparing the results.

First, a PSS/E tool will export the model parameters into a XML format. Then, XSLT translates XML to a Modelica file. Finally, we will compare results. XSLT is an extensible style-sheet language for transformations specifically for mapping XML to other formats. This paper will begin by providing a background understanding the file structure in terms of XML and database modeling paradigms, introduce XML and XSLT, and show the mapping workflow.

# Durable and Accountable File Translation Process

The direct route of translating proprietary files from PSS/E or PSAT to Modelica is not the best way since the process is brittle. Software vendor's file formats can be changed at any moment without notification or accountability.

The best way to translate is to use a certified file exchange, a contract, that requires complete accounting of model parameters. This begins with a hierarchical set of standards that describes how model parameters are stored. Certified standards also allow any software vendor to participate, and the model data is ubiquitous.

[IEC TC57 WG13](https://www.iec.ch/dyn/www/f?p=103:14:0::::FSP_ORG_ID:2392) provides these standards with liaisons from European Network of Transmission System Operators [ENTSO-E](https://www.entsoe.eu/) Common Grid Model Exchange Standard ([CGMES](https://cgmes.github.io/)) and do conformance testing UCA International Users Group ([UCAIug](https://www.ucaiug.org/default.aspx)). Therefore, the translation will begin with the parameter descriptions from CGMES from ENTSO-E.

CGMES is a set of standards that begins with XML. Extensible markup language (XML) is a standardized data structure like HTML without pre-defined tags. Common Information Model ([CIM](https://www.dmtf.org/standards/cim)) refines the XML standard by creating and defining tags. XSLT is an XML document. Therefore, you must understand the basics of XML to parse the documents that depend on it.

As you move from XML to CGMES CIM, you move from a generic xml data structure to CGMES power systems groupings. PSS/E adopts most if not all groupings from CGMES. OpenIPSL uses the same CGMES parameters within their components. Therefore, it is a direct map from the CGMES CIM to Modelica OpenIPSL components.

The Resource Descriptor Framework (RDF) from W3C specifications is part of CGMES. [RDF](https://en.wikipedia.org/wiki/Resource_Description_Framework) uses statements about resources in expressions of the form subject-predicate-object called triples. The subject denotes the resource, for example Synchronous Machine. The predicate denotes traits, for example Synchronous Machine q percent representing the coordinated reactive control in percent. The object denotes an aspect of the resource. Here, it is the value, for example 100 percent.

The translation moves CGMES triples into Modelica parameters. While RDF can represent more complicated data structures, CGMES uses something like relational database associations. Therefore, we'll use the rules and techniques for relational databases to transform with XSLT.

# Translation Workflow

The [CGMES equipment (EQ from IEC 61970-452) and dynamics (DY from IEC 61970-302) files](https://www.entsoe.eu/digital/cim/cim-for-grid-models-exchange/) translate to MO files using GenMO.xsl (called GenMO) and CompleteMO.xsl (called CompleteMO). The result is a two-part model like the OpenIPSL examples. GenMO creates synchronous machine models CompleteMO creates the rest of the model. GenMO uses both EQ- and DY-files while CompleteMO only uses the EQ file.

The xsl-files copy the triple to the Modelica parameter. The translation must copy the required Modelica parameters. The CGMES subjects align with UML or relational models. The major result is that one table does not duplicate the data in another. The PSS/E separates files into static and dynamic triples as specified in ENTSO-E models. Modelica uses parameters by component.

## Generator

The equipment PSS/E file (ending in EQ) contains static triples. The dynamic PSS/E file (ending in DY) contains dynamic triples. Let us work through the OpenIPSL PSSE GENROU Machine (Solid Rotor Generator represented by equal mutual inductance rotor modeling). Table 1 is from the DY file.

Table . Map from Modelica OpenIPSL GENROU parameters to PSS/E predicate for the dynamic triples of resource 'SynchronousMachineTimeConstantReactance'. The predicates used in this table have a prefix with the same name as the resource or 'RotatingMachineDynamics'. A period separates the prefix from the tables PSS/E predicate name. For example, the table shows 'RotatingMachineDynamics.damping' is 'damping'.

|  |  |
| --- | --- |
| **Modelica parameter description (name) unit** | **PSS/E Predicate** |
| d-axis transient open-circuit time constant (Tpd0) s | tpdo |
| d-axis sub-transient open-circuit time constant (Tppd0) s | tppdo |
| q-axis sub-transient open-circuit time constant (Tppq0) s | tppqo |
| Inertia constant (H) s | inertia |
| Speed damping (D) | damping |
| d-axis reactance (Xd) | xDirectSync |
| q-axis reactance (Xq) | xQuadSync |
| d-axis transient reactance (Xpd) | xDirectTrans |
| d-axis sub-transient reactance (Xppd) | xDirectSubtrans |
| q-axis sub-transient reactance (Xppq) |  |
| leakage reactance (Xl) | statorLeakageReactance |
| Saturation factor at 1.0 pu (S10) | saturationFactor |
| Saturation factor at 1.2 pu (S12) | saturationFactor120 |
| Armature resistance (R\_a) |  |
| q-axis transient reactance (Xpq) | xQuadTrans |
| q-axis transient open-circuit time constant (Tpq0) | tpqo |
| Sub-transient reactance (Xpp) | equal to Xppd by default. |

Finally, there is only one initialization: Initial speed deviation from nominal (w0). The overall model provides any other parameters or initializations.

Modelica parameters compared with CIM triples

Modelica OpenIPSL Directory Path: Examples->Machines->PSSE->GENROU

CIM File File and Element: …\_DY.xml

Top Element: cim:SynchronousMachineTimeConstantReactance

Sub-Element: cim:SynchronousMachineTimeConstantReactance.modelType is equal to

<http://iec.ch/TC57/2013/CIM-schema-cim16#RotorKind.roundRotor>

# Data Structure

The website <https://www.w3schools.com/xml/> provides more extensive tutorial on XML. The structure is human and machine readable. We will start with CGMES defined equipment and dynamics files which have names that end in EQ and DY, respectively.

## Elements

XML Elements provide the basic structure of the XML. Opening ('<') and closing('>') tags surround an element. The closing tag has a '/'. Empty tags are elements that contain nothing, and they do not require closing tags. They have a '/' just before the '>'. For example,

*<lily age="13">This text is not here!</lily>* is the same as *<lily age="13" />* when removing 'This text is not here!' (an empty tag).

CGMES files are trees of elements. The elements form triples. The complete document is the triple's subject, which is the equipment or the dynamics files. We will look at the equipment file first. The triple's synchronous machine predicate starts with an element named "SynchronousMachine" and looks like:

<cim:SynchronousMachine …

The triple's object looks like:

<cim:SynchronousMachine.maxQ …

We will cover "cim" later within the namespace section.

## Tree Structure

According to the W3C tutorial, "XML documents form a tree structure that starts at 'the root' and branches to 'the leaves'. When looking at XML in a tree view, which is called the document object model (DOM), there is a single root node which contains all other nodes. '/rdf:RDF' is the root node of all CIM file types.

After the document element /rdf:RDF, a limited tree of elements is only two layers deep within the constraints of CGMES. The top element is comparable to a table within a database. The second layer is comparable to properties within each table. These constraints simplify the XML and make the well-known design rules from relational databases easier to use the CIM.

## Attributes

Elements can contain attributes. The only attributes used in ENTSOE CIM is an ID or resource, which are closely related, and enumerations. The ID/resource attributes are a database structure used to associate two tables of information using the primary key and foreign key links. Here, one main node from the CIM EQ file used for storing static properties:

*<cim:SynchronousMachineTimeConstantReactance rdf:ID="\_d712e95b-25db-11e7-afca-b46d83638f70">*

Here, a property within main node GovHydro1 links to the synchronous machine static node:

*<cim:TurbineGovernorDynamics.SynchronousMachineDynamics rdf:resource="#\_d712e95b-25db-11e7-afca-b46d83638f70" />*

ENTSO-E defines enumerations that identify different synchronous machine model types in this example:

*<cim:SynchronousMachineTimeConstantReactance.rotorType rdf:resource="http://iec.ch/TC57/2013/CIM-schema-cim16#RotorKind.salientPole" />*

## Namespace

Namespaces provide a way to avoid name collisions when two XML elements have the same name. In XSLT '<xsl:stylesheet xmlns:rdf…' identifies a 'rdf' namespaces near the beginning of the document. Then, 'rdf:' differentiates RDF from other uses of RDF:

*<xsl:template match="/rdf:RDF" >*

'cim', 'entsoe', 'pti', 'md' are other common namespaces within ENTSO-E CIM.

# XSLT

An API engine translates XSLT. Common programming languages such as .NET or Python have their own API for XSLT version 1.0. The file size of the 500 bus CIM model has forced the use of XSLT version 2.0. For XSLT (and XML) development, JAPISOFT provides an IDE called [EditiX](https://www.editix.com/). It uses the [Saxonica](https://www.saxonica.com) engine. Ultimately creation of a .NET interface by using the home edition API downloaded from <http://saxon.sourceforge.net/> .

The XSL documents are a list of rules that copy information from the XML document to various output styles. We will use GenMO to operate on the CIM EQ file directly and the CIM DY file with a coded command. Here, the following method identifies a text file for the output :

*<xsl:output indent="no" method="text" />*

*MO files are text files.*

## Template Rules

In GenMO, after the document node, the first table is 'cim:SynchronousMachine'. The following method and command **xsl:apply-template** within the xsl element:

*<xsl:template match="/rdf:RDF" >*

*<xsl:apply-templates select="cim:SynchronousMachine" />*

*</xsl:template>*

Jumps to the corresponding scope limiting element **xsl:template** via because select = match:

<xsl:template match="cim:SynchronousMachine">

The match is not always evident.

## Local Variable

**xsl:variable** creates a variable named 'GName' that creates a text followed by a property called **cim:IdentifiedObject.name**.

*<xsl:variable name="GName">*

*<xsl:text>SM</xsl:text>*

*<xsl:value-of select="cim:IdentifiedObject.name" />*

*</xsl:variable>*For example, GName='SM3000\_1'.

The first piece of output is text generated from:

*<xsl:text>model </xsl:text>*Anything between the **xsl:text** tags goes directly to the output and is followed by a copy of the variable GName. The total output is: model SM3000\_1

## Global Variable

A global variable is a variable that is placed prior to first xsl:Template tag. At the top of the file, find the statement:

*<xsl:variable name="dynamic" select="document('IEEE\_9bus\_DY.xml')" />*

This sets the variable **dynamic** equal to the CIM DY file.

## Function

**xsl:call-template** is the equivalent of a function. The following code uses parameters **code** and **GenName** within the calling function:

*<xsl:call-template name="MakeMachineForCode">*

*<xsl:with-param name="code" select="concat('#',@rdf:ID)" />*

*<xsl:with-param name="GenName" select="$GName" />*

*</xsl:call-template>*

The function is:

*<xsl:template name="MakeMachineForCode" >*

*<xsl:param name="code" />*

*<xsl:param name="GenName"/>*

## Looping Through Entities

**For-each** loops are more traditional methods of coding the **template-apply** and are used in these circumstances:

*<xsl:for-each select="cim:BusbarSection">*

*<xsl:for-each select="cim:ACLineSegment"><xsl:for-each select="cim:ConformLoad"><xsl:for-each select="cim:PowerTransformer">*

This is a pull versus push style (template-apply) of programming. Some believe push is less efficient.

# Actions

## Associations

The rdf:ID attribute is used like a primary key. Use Foreign keys to associate data in another table. Foreign keys use the same identifier with a prefix '#' in front of the primary key. This is created with the following statement:

*concat('#',@rdf:ID)*

In CompleteMO a simpler technique of associating tables is used. A global key is assigned to a particular primary key table:

*<xsl:key name="node" match="cim:ConnectivityNode" use="@rdf:ID"/>*

The foreign key table can then link to the primary key table with the **key()** function and use a single property within it:

*<xsl:value-of select="normalize-space(key('node',cim:Terminal.ConnectivityNode/substring(@rdf:resource,2))/cim:IdentifiedObject.name)"/>*In this case the property is **cim:IdentifiedObject.name**.

When multiple properties are required, a function the passes in the primary key should be passed as shown in the Function section.

<xsl:key name="node" match="cim:ConnectivityNode" use="@rdf:ID"/>

|  |  |  |  |
| --- | --- | --- | --- |
|  | **name** | **match** | **use (default: @rdf:ID)** |
|  | node | cim:ConnectivityNode |  |
|  | busbar | cim:BusbarSection |  |
|  | terminal | cim:Terminal |  |
|  | powertrans | cim:PowerTransformer |  |
|  | acsection | cim:ACLineSegment |  |
|  | conformload | cim:ConformLoad |  |
|  | nonconformload | cim:NonConformLoad |  |
|  | syncmachine | cim:SynchronousMachine |  |
|  | basepower | cim:BasePower |  |
|  | shunt | cim:LinearShuntCompensator |  |
|  | PTend | cim:PowerTransformerEnd/ cim:PowerTransformerEnd. PowerTransformer | substring(@rdf:resource,2) |
|  | basevoltage | cim:BaseVoltage |  |
|  | voltagelevel | cim:VoltageLevel |  |
|  | tapchanger | cim:RatioTapChanger/ cim:RatioTapChanger. TransformerEnd | substring(@rdf:resource,2) |
|  | regulator | cim:RegulatingControl |  |

## Enumerations

Different actions are performed with enumerations because in this case they are different types of models and send different parameters to the MO file. The code below tests the equivalency of the rdf:resource attbribute with a particular enumeration and changes the text accordingly:

*<xsl:if test= "cim:SynchronousMachineTimeConstantReactance.rotorType/@rdf:resource='http://iec.ch/TC57/2013/CIM-schema-cim16#RotorKind.roundRotor'">*

*<xsl:text>GENROU</xsl:text>*

*</xsl:if>*

*<xsl:if test= "cim:SynchronousMachineTimeConstantReactance.rotorType/@rdf:resource='http://iec.ch/TC57/2013/CIM-schema-cim16#RotorKind.salientPole'">*

*<xsl:text>GENSAL</xsl:text>*

*</xsl:if>*

## Selecting Particular Nodes

The global variable **dynamic** connects to the CIM DY file. Then, like path information, the table is set with the following statement:

/rdf:RDF/cim:SynchronousMachineTimeConstantReactance/cim:SynchronousMachineDynamics.SynchronousMachine[@rdf:resource=$code]/..

The path leads down the tree, starting with the document node **rdf:RDF**, followed by the table **cim:SynchronousMachineTimeConstantReactance** and ending in the property **cim:SynchronousMachineDynamics.Synchronousmachine**. The attribute data **@rdf:resource**:

*<cim:SynchronousMachineDynamics.SynchronousMachine/@rdf:resource="#\_703939f0-9562-11e7-9e89-b46d83638f70" />*

requires the variable **$code** to be equal. In this way, it steps through each unique machine. The **$code** is the ID:

<cim:SynchronousMachineTimeConstantReactance rdf:ID="\_87e144f5-9562-11e7-9e89-b46d83638f70">

By adding '/..' to the end the top node will be the table node. The total function call code is:

*<xsl:apply-templates select= "$dynamic/rdf:RDF/cim:SynchronousMachineTimeConstantReactance/cim:SynchronousMachineDynamics.SynchronousMachine[@rdf:resource=$code]/.." >*

*<xsl:with-param name="MainName" select="$GenName" />*

*</xsl:apply-templates>*WorkFlow

Code entry begins with the first template:

*<xsl:template match="/rdf:RDF" >*

*<xsl:apply-templates select="cim:SynchronousMachine" />*

*</xsl:template>*

Opening the second template that creates the machine names:

<xsl:template match="cim:SynchronousMachine">

…

<xsl:call-template name="MakeMachineForCode">…

</xsl:template>

Opening the third template to gather all the dynamic parameters:

*<xsl:template name="MakeMachineForCode" >*

*…*

*<xsl:apply-templates select= "$dynamic/rdf:RDF/cim:SynchronousMachineTimeConstantReactance/cim:SynchronousMachineDynamics.SynchronousMachine[@rdf:resource=$code]/.." >*

*<xsl:with-param name="MainName" select="$GenName" />*

*</xsl:apply-templates>*…

</xsl:template>

Opening the fourth template to gather all the static parameters:

*<xsl:template match="cim:SynchronousMachineTimeConstantReactance" >*

*…*

*</xsl:template>*

# Summary

Understanding ENTSO-E CIM in terms of database modeling techniques simplifies the paradigm for translating the CIM to Modelica. This paper relates the XSLT commands to data modeling structures which can systematically be used to map CIM to Modelica.

Many of these database modeling techniques could be used in something other than a XSLT such as Python or .NET. However, most languages support XSLT version 1.0 and can use it with existing commands with their own XSLT engine.

Rapid translation of ENTSO-E CIM will provide system planners the advantages of Modelica in their work.

# EQ Synchronous Machine

## NYPA\_500

<cim:SynchronousMachine.maxQ>9.97</cim:SynchronousMachine.maxQ>

<cim:SynchronousMachine.minQ>-7.58</cim:SynchronousMachine.minQ>

<cim:SynchronousMachine.qPercent>100</cim:SynchronousMachine.qPercent>

<cim:SynchronousMachine.type rdf:resource="http://iec.ch/TC57/2013/CIM-schema-cim16#SynchronousMachineKind.generator" />

<cim:RotatingMachine.GeneratingUnit rdf:resource="#\_49e4f9f1-6d10-11eb-a65a-74e5f963e191" />

<cim:RotatingMachine.ratedS>28</cim:RotatingMachine.ratedS>

<cim:RegulatingCondEq.RegulatingControl rdf:resource="#\_49e4f9f4-6d10-11eb-a65a-74e5f963e191" />

<cim:Equipment.EquipmentContainer rdf:resource="#\_49b54964-6d10-11eb-a65a-74e5f963e191" />

<cim:IdentifiedObject.description>108894 'Z '</cim:IdentifiedObject.description>

<cim:IdentifiedObject.name>108894\_Z </cim:IdentifiedObject.name>

## IEEE\_9bus

<cim:SynchronousMachine.maxQ>250</cim:SynchronousMachine.maxQ>

<cim:SynchronousMachine.maxU>17.16</cim:SynchronousMachine.maxU>

<cim:SynchronousMachine.minQ>-250</cim:SynchronousMachine.minQ>

<cim:SynchronousMachine.minU>17.16</cim:SynchronousMachine.minU>

<cim:SynchronousMachine.qPercent>100</cim:SynchronousMachine.qPercent>

<cim:SynchronousMachine.r>9.9E-05</cim:SynchronousMachine.r>

<cim:SynchronousMachine.type rdf:resource="http://iec.ch/TC57/2013/CIM-schema-cim16#SynchronousMachineKind.generator" />

<pti:SynchronousMachine.x>0.099</pti:SynchronousMachine.x>

<cim:RotatingMachine.GeneratingUnit rdf:resource="#\_703939ec-9562-11e7-9e89-b46d83638f70" />

<cim:RotatingMachine.ratedS>275</cim:RotatingMachine.ratedS>

<cim:RegulatingCondEq.RegulatingControl rdf:resource="#\_703939ef-9562-11e7-9e89-b46d83638f70" />

<cim:Equipment.EquipmentContainer rdf:resource="#\_7039395a-9562-11e7-9e89-b46d83638f70" />

<cim:IdentifiedObject.description>1 'G1'</cim:IdentifiedObject.description>

<cim:IdentifiedObject.name>1\_G1</cim:IdentifiedObject.name>

# Appendix – CGMES Triples for 500-bus Sytem

## Equipment Resource

The following predicates for readability:

AC Line Segment

Base Voltage

Busbar Section

Conform Load

Conform Load Group

Connectivity Node

Control Area

Current Limit

Geographical Region

Hydro Generating Unit

Linear Shunt Compensator

Load Area

Load Response Characteristic

Non-Conform Load Group

Operational Limit Set

Operational Limit Type

Phase Tap Changer Table

Phase Tap Changer Table Point

Phase Tap Changer Tabular

Power Transformer

Power Transformer End

Ratio Tap Changer

Ratio Tap Changer Table Point

Regulating Control

Sub Geographical Region

Sub Load Area

Substation

Synchronous Machine

Tap Changer Control

Terminal

Voltage Level

Voltage Limit

Wind Generating Unit

## Dynamic Resource

Exc AC1A

Exc AC2A

Exc IEEE AC1A

Exc IEEE AC2A

Exc IEEE DC1A

Exc IEEE ST1A

Exc IEEE ST4B

Excitation System User Defined

Exc SEXS

Gov GAST

Gov Hydro1

Gov Steam0

Gov Steam SGO

Proprietary Parameter Dynamics

Pss IEEE 2B

Synchronous Machine Simplified

Synchronous Machine Time Constant Reactance

# Appendix – Editix Example

I recommend the book *XSLT: Mastering XML Transformations*, 2nd Edition which covers XSLT 2.0 for a more complete coverage. Purchase a used version from Amazon for about $6 including shipping.

Editix is an Integrated Development Environment (IDE) for XML and XSLT. It develops the XSLT code for translation.

IEEE\_9bus\_EQ.xml

IEEE\_9bus\_DY.xml

GENMO.xsl

Result.txt

SM1\_G1.mo

SM2\_G2.mo

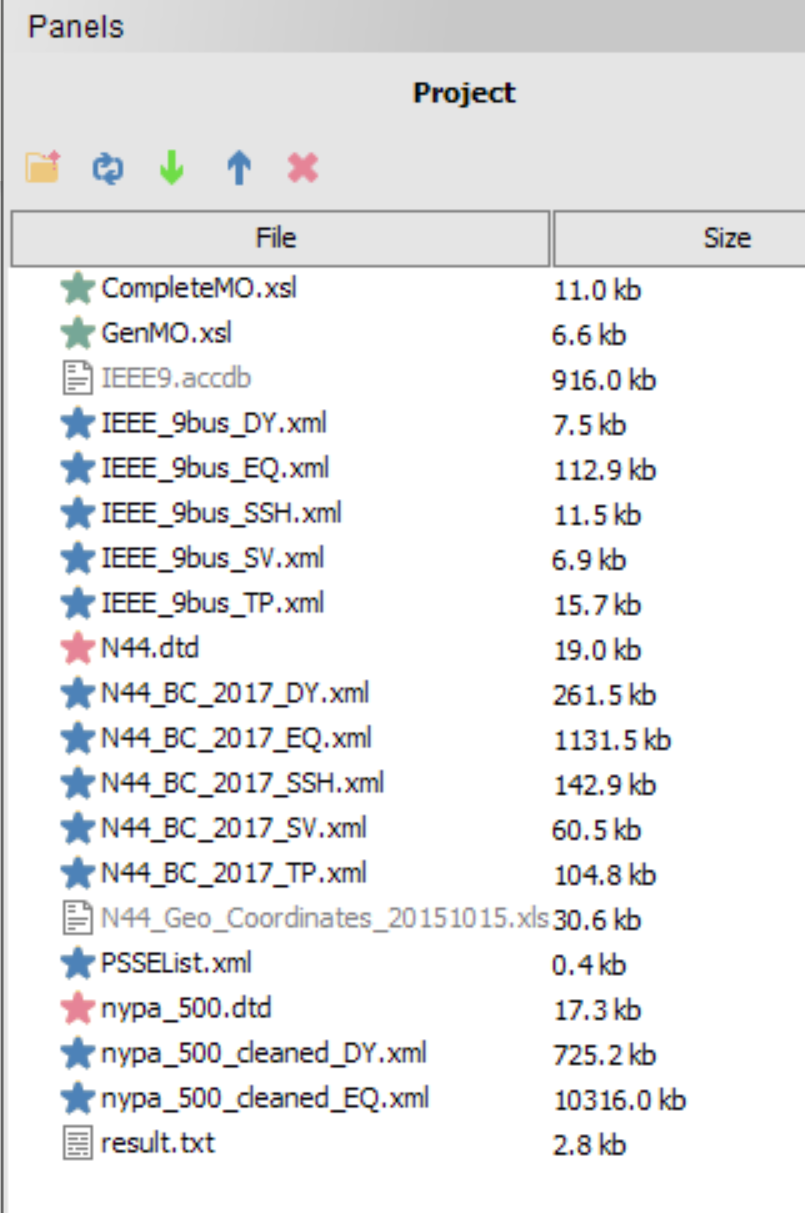
SM3\_G3.mo

IEEE\_9bus\_EQ.xml

CompleteMO.xsl

Result.txt

IEEE\_9bus.mo

1. File -> Open Project -> Dropbox/Deliverable/Final (<https://www.editix.com/doc/manual19/index.html#mozTocId804917> )  
   
2. Double-click on 'CompleteMO.xsl'
3. XSLT/XQuery -> Transform A Document  
   