iTesla
Innovative Tools for Electrical System
Security within Large Areas

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Deliverable D2.1:
Definition of required external data needs

Dissemination level		
PU	Public.	**X**
TSO	Restricted to consortium members and TSO members of ENTSO-E (including the Commission Services).	
RE	Restricted to a group specified by the consortium (including the Commission services).	
CO	Confidential, only for members of the consortium (including the Commission services).	

EUROPEAN COMMISSION
SEVENTH FRAMEWORK PROGRAMME

Document Name:	Definition of required external data needs
Work Package:	WP2
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CONTENT

0. GLOSSARY:

Glossary:

CIM: Common Information Model (electricity)
CIM v1: corresponds to CIM v14, 1st edition of the ENTSO-E profile
CIM v2: corresponds to CIM v16, 2nd edition of the ENSTO-E profile (not yet validated by ENTSO-E)
FACTS: Flexible AC Transmission System (examples of devices: TCSC, STATCOM etc.)
HVDC: High Voltage Direct Current
Native Format: Refers to the original dynamic format used by a TSO to describe its validated dynamic data (example: EUROSTAG for ELIA)
PMU: Phasor Measurement Unit
PST: Phase Shift Transformer
PV Generation: Photovoltaic generators
STATCOM: Static Synchronous Compensator
SVC: Static Var Compensator
TCSC: Thyristor Controlled Series Compensator
TSO: Transmission System Operator

1. Generalities:

1.1 Introduction/aim of the document:

This document is the result of the work made in the task WP2.1 of the iTesla project. This task aimed at defining all the external data needs. The present document provides a set of requirements from the iTesla project concerning the external data provided by the TSOs and expected in input of the iTesla platform.
In section 1.2 are presented the different identified data sets. The rest of the document is organized according to those defined data sets.
Section 2 expresses more in detail the recommendations of each data set. It is recommended having a special attention to all topology aspects.
Section 3 then deals with recommended associated formats to carry the information described in section 2. Some recommendations may have an impact on the way TSOs may want to provide their data in the associated formats, in particular in CIM format.
Section 3 also makes some long term propositions on the way the existing formats may be extended to carry additional information that is not yet included.

This document does not describe internal data management and how external data will be processed inside the iTesla toolbox. This work will be part of a next task of the iTesla project.

1.2 General description of the sets of Input Data:

This table describes the needs in terms of devices and in terms of grid description. One main need of the iTesla platform is to run accurate dynamic simulations (for example simulating a contingency and its associated preventive or curative actions) on a full European network.

Subset:	**Comments and examples of data included in the subset**
System data set:	
Steady state (static)	The subset contains data needed for a load flow. The basic data format is the one used within ENTSO-E for data exchanges: UCTE DEF (data exchange file) and (in the near future) CIM/RDF-XML static data (ENTSO-E profile)
	In a short term scope, Bus-Branch-Switch Topology is the preferred topology, but Bus-branch will also be supported, but will make limitation on some of possible analysis. For a long-term scope, Node-breaker Topology is the most complete way to describe topology.
Dynamic	Additional system data needed for dynamics. It has to be consistent with static data iTesla will also support some dynamic "native format". This includes System Protection Schemes defined through automata
“User Defined”	MODELICA template dynamic models: it is a way to design specific models with flexibility.
	It is also a way to transmit a model that does not exist in the 2 previous subsets

Contingencies data set:	
Contingencies	Complex contingencies should be expressed with a list of outage devices. Examples, for each contingency: fault type (three-phase, single phase etc., permanent vs. temporary), with/without automatic reclosure; fault location (busbar, line with fault distance from end), clearing time. outaged elements, sequence of events.
	The probability of occurrence should be associated here also taking into account e.g. the seasonal/weather context. To this aim, some default values of probabilities could be defined e.g. relevant to good/bad weather conditions. In this case, the situational input data would only consist of the weather forecast condition.
Actions data set:	
Preventive actions	A list of actions to prevent harmful effect of contingency. For example, a list of topological alternatives, list of available generators for rescheduling/re dispatching (and relevant costs, limitations, probability of not being successful, etc.) Also implementation time is needed (e.g. generators start-up time and ramping rate, time for switching manoeuvres, PST set-point change, HVDC ramping rate).
Curative actions	A list of actions to correct harmful effect of contingency. We should also keep in mind that we may someday be able to use a detailed topology to describe these actions. It must also include the notion of time for implementation. This also includes similar actions as described in the preventive subset such as re-dispatching or set-point modification
	The probability of failure should be associated here.
Security rules data set:	
Security requirements	Some criteria will be defined and computed by iTesla, some others are expected as an input. These are the conservative “static” security criteria used in WP5. The criteria computed by the iTesla platform should be consistent with security requirements specified by the TSO, e.g. acceptable steady-state violations in the post-fault state, maximum overshoot of frequency, maximum risk indices.
Time records data set:	
Time records	Records (PMU records, FDR records, and EMTP simulations), they will be used in WP3.
	These have to be consistent with the "system" data that will be used as a starting point to run dynamic simulation that will be compared with these records.
“Other” data set:	
Weather	Weather data
info	date, origin of data
scope	Time frame of analysis such as D-2,D-1,D, real time
Market	Cost etc. (It will be investigated later)

2. General recommendations for the identified data sets:

2.1 Needs in the "system" set:

2.1.1 Topology description:

Different levels of details of topology descriptions are available resulting from specific levels of aggregation of physical devices. A high level of topological aggregation will simplify drastically the complexity of the data contained in the system set, in the same time it will not allow the study of some specific actions such as complex topology changes.
In the same way, a low level of aggregation might not be possible mainly due to exchange formats limitations.

2.1.1.1 The detailed topology:

Detailed topology model or node/breaker topology or full topology:

The detailed topology connects "physical" devices together. The description model may include components such as isolator switches[1] (e.g. Busbar Isolator Switches (BIS) and Line Isolator Switches (LIS)), breakers (B), busbars and connection nodes. Some components might be omitted if never used by operators but as long as we refer to "physical" devices, this description has to be described as detailed topology.

An example of substation with two busbars and a line using this modelling approach is shown in Figure 2.1 where LIS stands for Line Isolator Switch, B for Breaker and BIS for Busbar Isolator Switch. It can be seen clearly that, with the information contained in this model, it is possible to connect a line to one or the other busbar but also to operate the two busbars together or separated. This modelling approach is very close to the real topology. Only grounding switches (i.e. switches used to guarantee maintenance worker safety) are removed from the complete topology. The main drawback from this modelling approach is that:

- The amount of data needed is large as compared to other models describing simplified topology description (see below).
- The TSOs won't be able to make it available and consistent for a given data format in the few coming years. The only format that should be handled by TSOs and that will be capable to describe such detailed topology will be the CIM v2 (see glossary for definition of CIM v2).
- The CIM v2 is not yet approved by ENTSO-E as required supported modeling format. CIM16 is not yet published. It will not be published before HVDC is included. This is scheduled for February/March 2013.

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[1] In the context of this work, switches are not able to be operated on load. These devices are used to change the network topology and can be either operated on site or from the dispatching centre. In case of fault, these devices will not open to isolate the fault and cannot be used for automated corrective actions.

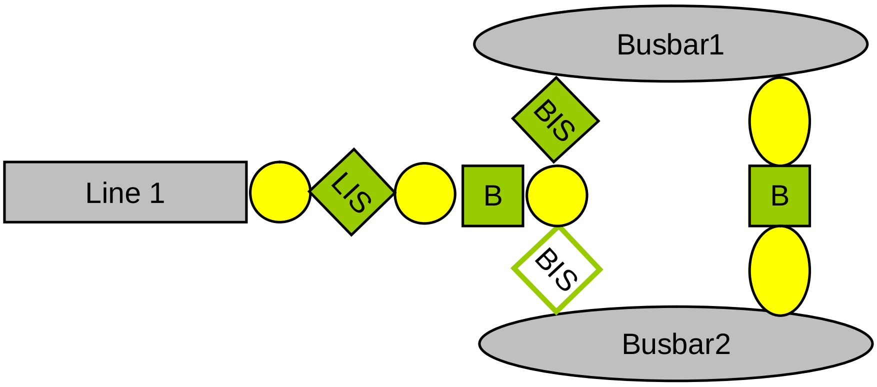


Figure 2.1: Example of detailed topology

2.1.1.2 The Bus-Branch-Switch topology:

Bus-Branch-Switch topology model:

This topology is the result of a simplification of the detailed topology where some physical devices may have been merged together. Therefore, this topology should not link to "physical" devices but to topological computation objects. For example, two busbars that cannot be physically disconnected might have been merged into one "CIM topological node".

This model only contains the objects needed to simulate the behavior of the network without taking into account all elements that have either no influence on the impedance of the network (e.g. switches) or that have no impact on security calculation.

Furthermore, in this model, the possibility to connect one line to one busbar or to another is removed from the model. This is done for the following reasons:

- It reduces the complexity of the models provided by TSOs,
- It is a conservative approach as curative actions cannot use this solution to solve a problem in planning but this maneuver may be available in real-time.

This topology description is a middle way between a detailed topology and a bus-branch topology. The kept switches mostly aim at describing topology actions by closing or opening the switches or modeling the actions of protections schemes such as automatons that opens and close circuit breakers (which become switches in a Bus-Branch-Switch topology):

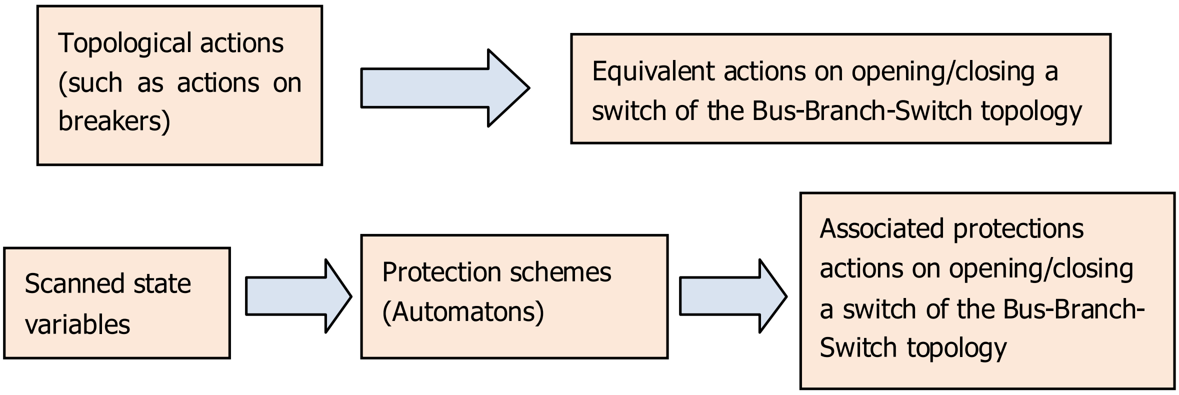


Figure 2.2 illustrates the Bus-Branch-Switch topology model for the same substation as the one of 2.1.

Furthermore, from a more practical point of view, this model is easier to be exchanged between TSO using common models. The CIM approaches should be able to handle this type of description in the near future as its requirements are less demanding than the Node/Breaker description. It is possible to describe the Bus-Branch-Switch topology in both CIM v1 and CIM v2 formats whereas it is not possible to refer to "physical" devices in the CIM v1.

This model is typically used by software computing load-flow with security analysis such as N-1 or N-2 security analysis.

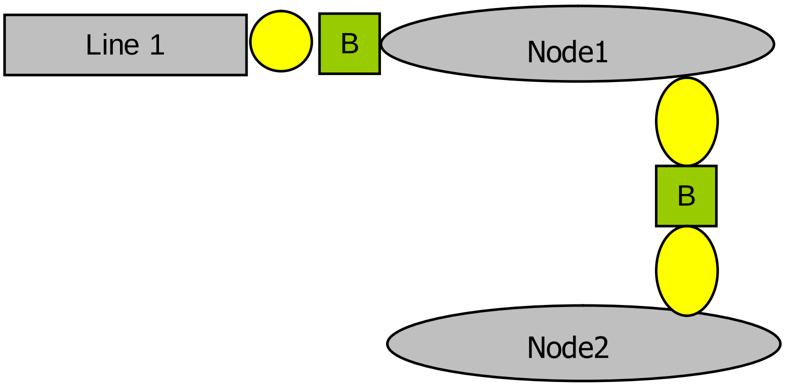


Figure 2.2: Corresponding Bus-Branch-Switch topology to figure 2.1

Comments on Figure 2.2:
Busbars are not physical devices anymore but computed nodes "Node1" and "Node2".
The breaker between "Line 1" and the non-physical node "Busbar 1" is optional and operating on this breaker is equivalent to opening/closing on end of "Line 1".

<u>Illustration of the figure 2.2 in terms of CIM elements:</u>
Figure 2.3 illustrates how we recommend sending data of figure 2.2 in CIM format:

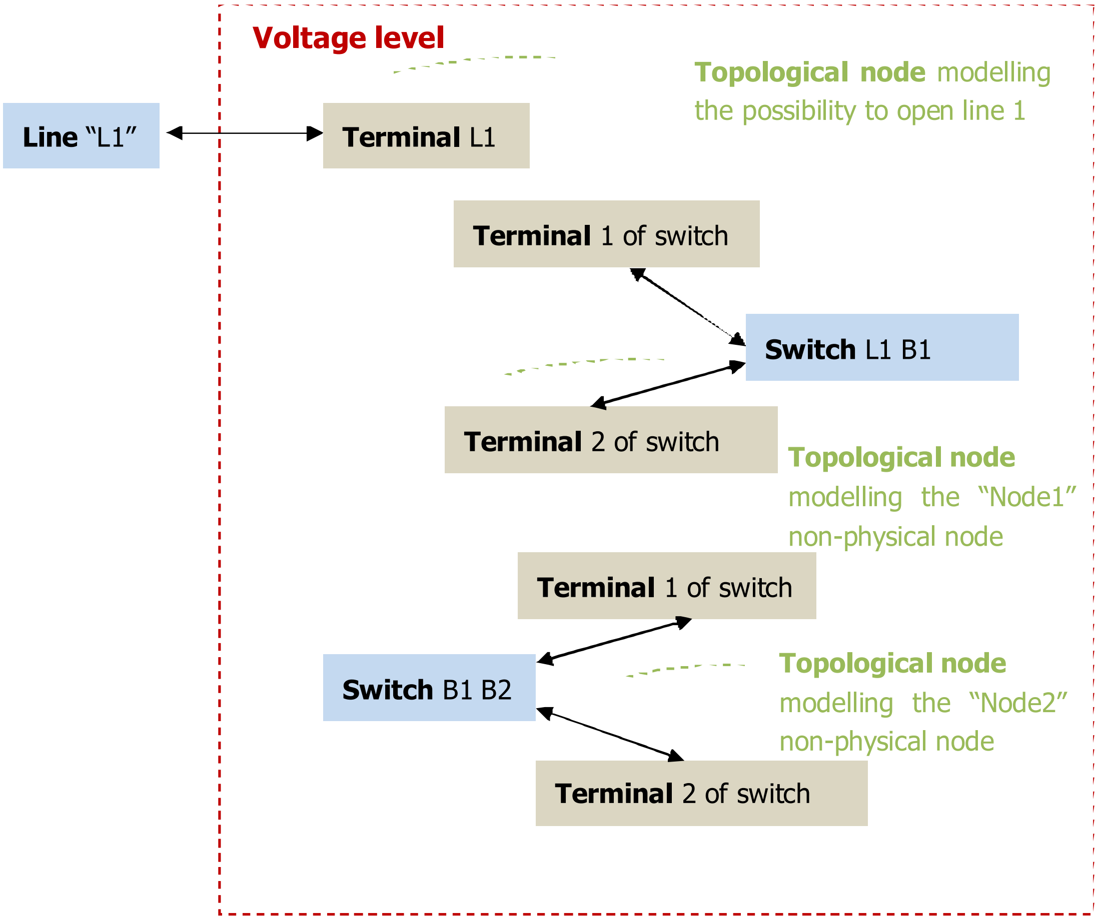


Figure 2.3: CIM equivalent of Figure 2.2

In Figure 2.3, there is no reference to "CIM physical devices" such as "BusbarSection" or "ConnectivitylNode" since it is part of the detailed topology description of 2.1.1.1.

2.1.1.3 Bus/branch topology:

Simple topology model or bus/branch topology model or consolidated model:

This is the highest level of simplification of the topology description. All non-impedant elements are skipped. This topology can be deduced from the Bus-Branch-Switch topology and of course from the node/breaker topology.

This model is internally used by the network calculation tools (load-flows (without security analysis), constrained power flows, optimal power flows etc.). In this model only buses and elements with impedances (branches) are modeled. They are made as simple as possible to speed up network calculations, removing all unnecessary (because no impact on result of calculation) elements. Figure 2.4 illustrates this model for the same substation.

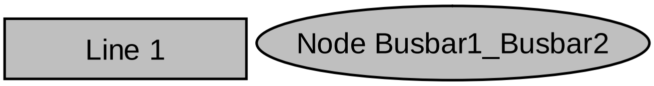


Figure 2.4: Corresponding simple topology of figure 2.1

The level of detail is clearly insufficient in input of the iTesla platform in order to make accurate dynamic simulations.

2.1.1.4 Topology recommendation for the iTesla project

The recommendation below is of very high priority. The level of accuracy of dynamic simulations will directly depend on the level of detail of description of the topology.

Recommendation 1: *(topology description by TSOs)*

- *Short term recommendation:*

As long as the CIM v2 (see glossary in section 0 for definition of CIM v2) is not officially released, iTesla would recommend describing the topology in the ***Bus-Branch-Switch mode*** *as described above (in CIM v1 format).*
From a practical point of view, this approach ***should model****:*

  - *All breakers (only breakers between feeders and busbars are optional)*
  - *All physical elements should have a stable associated CIM ID.*

Furthermore, this approach ***should not contain****:*

  - *Lines with more than two extremities. Lines with more extremities should be divided into 2 extremities elements connected through (virtual) switches and (virtual) busbars. The name of each line should be linked to the name of the physical element and the name of the virtual elements should be easily recognized.*
  - *Busbar Isolator Switches and Line Isolator Switches except the ones mentioned in the previous bullet.*

The recognition of virtual elements through name should be used to flag the network parts that are described in bus-branch topology models if it is not possible to describe these parts of the network in Bus-Branch-Switch topology. However, it should not be allowed to describe a substation in the two modes, since it is possible to compute bus/branch topology from Bus-Branch-Switch topology.

- *Long term recommendation:*

This long term recommendation is the ultimate target of the iTesla project. We strongly recommend TSOs following this recommendation if they have this possibility:
Once the CIM v2 is officially released, if some TSOs are capable to provide ***detailed topology*** *in CIM v2 (ENTSO-E profile only), then iTesla will be capable to handle it. However,* ***Bus-Branch-Switch*** *topology with similar requirements as described in the short term recommendation in CIM v2 format will be the minimal recommended input.*
Simple topology will not be sufficient *in input of the iTesla project. Areas described in simple topology will not provide realistic dynamic simulation results.*

2.1.2 Symmetric versus asymmetric:

The main pros and cons are the same as in bus/branch versus detailed topology.
Asymmetric description will not be used in the iTesla project and therefore, unbalanced operation will not be taken into account.

Recommendation 2: *(asymmetric description by TSOs)*
It is not necessary to deal with asymmetric description issues.

2.1.3 Multi-generation at a given bus:

Even if a bus/branch description is used, a certain level of detail for some given devices describing the "system" set is expected, for example: if several generating units are connected at one node, it is expected to have the details of the connected components. One generating unit could be on and its neighbor off.

Recommendation 3: *(generating units aggregation by TSOs)*
As far as possible, it is recommended TSOs not aggregating generating units. If several generating units are connected to a same bus, they should be defined separately, never aggregated and with their own permanent and same ID (such as unique CIM IDs).
A disconnected generating unit must be provided. Its generated power should then be set to zero.

Current availability of the generating units data from TSOs:
Given the voltage levels described in the next part, generating units physically connected to lower and non-modeled voltage levels which are not represented in the data files provided by the TSOs, are aggregated.

The abbreviations used in the Tables below stand for the initials of the TSOs' names, i.e.

RT: RTE
EL: ELIA
RE: REN
IP: IPTO
NG: National Grid
ST: Statnett

Level of aggregation of generation in TSOs' forecast files		
Type of aggregation	**yes**	**no**
aggregated Wind generation units separately from loads and other generating units	**ST**	**RT, EL, RE, NG**
aggregated PV generation units separately from loads and other generating units		**RT, EL, ST, NG**
aggregated renewables separately from loads and other generating units	**ST**	**RT, EL, RE, NG**
Non aggregated machines over 100MW separately from any other injection	**RT, ST, RE, EL**	**NG**
Non aggregated machines over 20MW separately from any other injection	**RT, ST, EL**	**RE, NG**

Level of aggregation of generation in TSOs' snapshot files		
Type of aggregation	**yes**	**no**

aggregated Wind generation units separately from loads and other generating units	**ST, RE**	**RT, EL, NG**
aggregated PV generation units separately from loads and other generating units	**RE**	**RT, EL, ST, NG**
Non aggregated machines over 100MW separately from any other injection	**RT, ST, RE, EL**	**NG**
Non aggregated machines over 20MW separately from any other injection	**RT, ST, RE, EL**	**NG**

2.1.4 Multi-load at a given bus:

The above remark also applies to the loads connected at the same node. This will increase the precision in data mining for example.

Recommendation 4: *(load aggregation by TSOs)*
As far as possible, it is recommended to TSOs not to aggregate loads and possibly separate loads of different types (renewables modelled as a negative load, "classical" load etc.). Then it would be appreciated if TSOs could tag the type of the load and identify them with a stable ID (such as unique CIM IDs). This remark is also valid for loads at lower voltage levels and reattached to voltage levels exported by TSOs.

Current availability of the load data from TSOs:
Respectively, the level of aggregation of the load follows a similar pattern of detail.

Level of aggregation of the load in TSOs' forecast files		
Type of aggregation	**yes**	**no**
The possibility to model several loads per bus	**RT, ST, NG**	**EL, RE, IP**
Physical loads separated from flows of non described voltage levels	**RT, EL, ST, NG**	**RE, IP**
Loads separated from distributed generation		**RT, EL, RE, IP, NG, ST**
Remarks: ***RTE:*** *This level of detail is available if the CIM format is used; for the "no" answer please refer to the previous question.* ***NG:*** *the "yes" data is available if the CIM format is used.*		

Level of aggregation of the load in TSOs' snapshot files:		
Type of aggregation	**yes**	**no**
The possibility to model several loads per bus	**RT, ST, RE, NG, IP**	**EL,**
Physical loads separated from flows of non described voltage levels	**RT, EL, ST, RE, NG**	**IP**
Loads separated from distributed generation		**RT, EL, RE, IP, NG, ST**
Remarks: ***RTE:*** *This level of detail is available if the CIM format is used; for the "no" answer please refer to the*		

previous question.
***NG:** the "yes" data is available if the CIM format is used.*

2.1.5 Composite load:

It should be possible to specify that a "load" is a **composite** one, consisting of different shares of:

- "real" loads, with static and dynamic behavior according to voltage and frequency
- Distributed Generation (DG): it should be possible to specify some dynamic performance of the DG including frequency response and protection. Also, it should be possible to define the shares of different DG types (e.g. wind, photovoltaic), as they may exhibit different response (e.g. with respect to frequency dynamics)

It should be possible to specify the above quantities either in absolute terms or as shares of the individual components, making up the "equivalent load" seen from the HV grid.

Recommendation 5: *(composite load description by TSOs)*
It should be possible to describe composite loads with data extensions. The extra data describing the shares should refer to the IDs of the impacted loads (such as the CIM IDs).

2.1.6 Detail of Voltage levels description:

Regarding dynamic simulations different levels of detail are expected in data depending on the voltage level. The following tables indicate some standard voltage levels. In respect to data which can be exchanged by TSOs within the iTesla project, data can be distinguished into two different types, namely the so-called Forecast System Files (i.e. (D-1) data) and Snapshot data.

Following input from TSO partners, the level of detail for each part of the power system is defined based on the sensitivity impact in the overall power system operation. Especially as it relates to voltage stability studies, tap changers would need to be included in the HV level.

The following tables summarize the voltage level which can be provided by each TSO in the electrical system files.

Voltage levels you can provide in TSOs' forecast system files:			
Voltage level	**yes**	**no**	**Not used**
380kV (and above)	**RT, EL, ST (280-320 kV), RE, IP, NG**		
220-230kV	**RT, EL, RE, NG**		**IP**
150kV	**RT, EL, ST, RE, IP, NG**		
110-100kV	**ST**	**RT, NG**	**EL, RE, IP**
100-70kV		**RT, EL, NG**	**RE, IP**
70-50kV	**ST, IP**	**RT, EL, RE, NG**	
50-20kV	**ST, RE**	**RT, EL, IP, NG**	
20-10kV	**ST, RE**	**IP**	**RT, EL, NG**

Voltage levels you can provide in TSOs' <u>snapshot</u> system files:			
Voltage level	**yes**	**no**	**Not used**
380kV (and above)	**RT, EL, ST (280-320 kV), RE, IP, NG**		
220-230kV	**RT, EL, RE, NG**		**IP**
150kV	**RT, EL, ST, RE, IP, NG**		
110-100kV	**ST**	**RT, NG**	**EL, RE,IP**
100-70kV		**RT, EL, NG**	**RE,IP**
70-50kV	**ST, RE,IP**	**RT, EL, NG**	
50-20kV	**ST, RE**	**RT, EL, IP, NG**	
20-10kV	**ST, RE**	**IP**	**RT, EL, NG**

2.1.7 Requirements for generating units/rotating machines modeling (dynamic):

We have to put here the level of detail expected in the modeling of the generating units.

In a first stage, we consider the following standard models (IEEE, WECC, etc.) interconnected in a standard way:

- Generators (including wind turbines)
- Motors
- Excitation systems, limiters, and compensators
- Turbine/governor models
- Stabilizers

<u>Recommendation 6:</u> *(level of detail of generating units):*
*If possible, we recommend providing the same validated models (same format) than those used by TSOs for their own dynamic simulations (for example we will recommend EUROSTAG files for RTE, PSS/E files for those dealing with these files etc.). This data in its own format is what we call in this document **native format** from TSOs. The parameters of the rotating machines, the associated controls must be provided in order to perform accurate dynamic simulations.*
Special protections such as UELs, OELs should also be provided.

2.1.8 Requirements for load modeling (dynamic):

Based on the level of detail of non-aggregation of the load defined in the static part, an accurate dynamic modeling is expected for the load, with an equivalent model consistent with the global behavior of the load connected at one given voltage level.

<u>Recommendation 7:</u> *(level of detail of loads modeling):*
Dynamic modeling of the load is expected in consistence with the voltage level of connection of the load. The expected format is the same as for recommendation 6.

2.1.9 Requirements for model validation of renewable sources:

Required data for aggregated Wind and PV Power Plants will need to follow the 3 levels approach indicated in WP3, i.e.:

- *The component level, to validate a specific device*
- *The cluster level, to validate aggregated models*
- *The whole system level, for overall validation*

Confidentiality of TSOs' available data restricts the level of detail of the modeling representation of the components, clusters and the system as well as the amount of the data which can be exchanged within iTesla project.

Therefore, in the case of the validation process (WP3), we may need different levels of modeling the renewable, from a detailed description (the reference model) to a cluster level (the equivalent model to be validated). Those specific data requirements will be addressed during the construction of test cases and directly with the involved TSO.

2.1.10 Requirements for description of DC transmission:

HVDC uses direct current to transmit bulk electrical power. HVDC system has some advantages over AC transmission. When underwater transmission distance is larger than 30 km AC transmission has some drawbacks due to high capacitance of the cable that requires intermediate compensation stations. HVDC is a good alternative in such case. HVDC can ensure power transfer between several asynchronous ac systems. Rapid control of the transmission power is another advantage for HVDC in terms of maintaining stability of the associated ac power systems.

Two different technologies are used for HVDC: the most mature and exploited technology consists of the current source converter "CSC" based on thyristors (components which can only be turned on), whereas voltage source converter "VSC" HVDC, based on components which can also be turned off such as IGBTs and GTOs, is more recent and still allows lower performances in terms of voltage levels and transmitted power. VSC-HVDC presents several advantages over CSC (such as reactive power control, black start capability etc.), however, and it is rapidly evolving in terms of voltage and power levels.

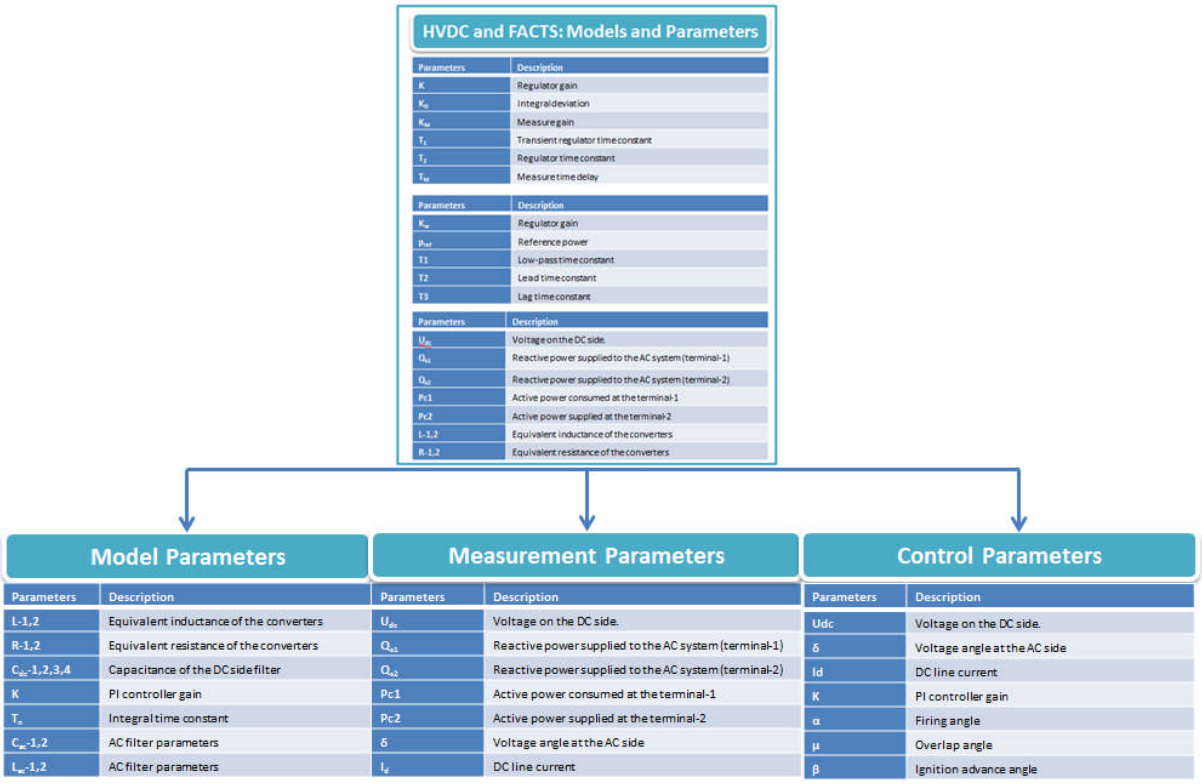
HVDC transmission systems are composed of several components. The first component is the converter station or the bridge of valves. The converters perform AC/DC and DC/AC conversion. DC capacitors serve as filters to smooth DC voltage. These also decrease harmonic voltages and currents in the DC line. High power transformers are used to match the AC system voltage as well as converter reactor to separate AC fundamental frequency from the raw PWM waveform. High frequency harmonic filters are also placed both in the AC and DC side and circuit breakers are also included in the system.

There are three kinds of HVDC links; Monopolar, Bipolar and Homopolar. Most of the HVDC networks are point to point connection. But there are also multi terminal HVDC systems. In a multi terminal HVDC system a number of converters are connected to a common HVDC circuit. Along with several benefits a multi terminal HVDC poses several challenges such as fault handling, control scheme, etc. Below the parameters are listed which can be used to model the VSC-HVDC.

Table 2.1: Parameters of HVDC devices

Parameters	**Description**
Udc N	Nominal voltage on the DC side.
IdN	DC nominal current
IdM	DC current margin
L-1,2	Equivalent inductance of the converters
R-1,2	Equivalent resistance of the converters
RLDC	DC lines resistance
LLDC	DC lines inductance
CLDC	DC lines capacitance (optional)
Cdc-1,2,3,4	Capacitance of the DC side filter (optional)
ImaxVTH	Maximum allowable current for reduced voltage (<VTH)
VTH	Voltage threshold for reduced current
Imin	Technical minimum current
αN	Nominal rectifier firing angle
αMIN	Minimum rectifier firing angle
γN	Nominal inverter extinction angle
γMIN	Minimum inverter extinction angle
LS	DC smoothing reactor inductance
Lc	Commutation inductance (or alternatively converter transformers short circuit reactance)
Cac-1,2	AC filter parameters
Lac-1,2	AC filter parameters
RCOMP	Compound resistance/s for compensating DC voltage drops (remote voltage control)
VN+n %	Rated voltages of converter transformers and tap position (number and value)
KP	Proportional gain for converter transformers tap control
KI	Integral gain for converter transformers tap control
VDCL	Static characteristic I-V for Voltage Dependent Current Limit implementation
MC	Block diagram and control parameters (permanent/transient droop…) of eventual Master Control (frequency control etc.)
PSS	Block diagram and control parameters (input type, gain, washout time constant, lead-lag filters time constants etc.) of eventual Power System Stabilizers
I control	(Fast) control of DC current: block diagram and parameters (optional)

The parameters can be segmented further in different categories for better understanding of their operation and control.



HVDC and FACTS: Models and Parameters

Parameters	Description
K	Regulator gain
K_0	Integral deviation
K_M	Measure gain
T_1	Transient regulator time constant
T_2	Regulator time constant
T_M	Measure time delay

Parameters	Description
K_w	Regulator gain
P_{ref}	Reference power
T1	Low-pass time constant
T2	Lead time constant
T3	Lag time constant

Parameters	Description
U_{dc}	Voltage on the DC side.
Q_{s1}	Reactive power supplied to the AC system (terminal-1)
Q_{s2}	Reactive power supplied to the AC system (terminal-2)
Pc1	Active power consumed at the terminal-1
Pc2	Active power supplied at the terminal-2
L-1,2	Equivalent inductance of the converters
R-1,2	Equivalent resistance of the converters

Model Parameters

Parameters	Description
L-1,2	Equivalent inductance of the converters
R-1,2	Equivalent resistance of the converters
C_{dc}-1,2,3,4	Capacitance of the DC side filter
K	PI controller gain
T_n	Integral time constant
C_{ac}-1,2	AC filter parameters
L_{ac}-1,2	AC filter parameters

Measurement Parameters

Parameters	Description
U_{dc}	Voltage on the DC side.
Q_{s1}	Reactive power supplied to the AC system (terminal-1)
Q_{s2}	Reactive power supplied to the AC system (terminal-2)
Pc1	Active power consumed at the terminal-1
Pc2	Active power supplied at the terminal-2
δ	Voltage angle at the AC side
I_d	DC line current

Control Parameters

Parameters	Description
Udc	Voltage on the DC side.
δ	Voltage angle at the AC side
Id	DC line current
K	PI controller gain
α	Firing angle
μ	Overlap angle
β	Ignition advance angle

Figure 2.5: Data management for HVDC and FACTS devices

Recommendation 8: *(CSC HVDC and VSC HVDC):*
It is not possible to describe in the current format of CIM v1 the HVDCs (as well as SVC devices discussed below). We recommend describing them in the TSO's native format for the dynamic part.
For the static part, an extension of the CIM v1 with the syntax of the CIM v2 might be a solution once the DC model has been added in CIM v2..

2.1.11 Requirements for FACTS devices:

FACTS are power electronics based devices focusing on enhancing controllability and power transfer capability. FACTS are static devices. These have significant impact on power system stability. FACTS devices are mainly of three kinds shunt (controlling injected current), series (controlling inserted voltage) and shunt-series devices. There are several advantages of using FATCS devices; such as power control, grid security, improved transient stability, limiting of short circuit and overload restrictions, limiting cascading blackouts, reduction of electromagnetic oscillations. In general FACTS devices use three kinds of switching schemes; mechanical switching, Thyristor controlled switching and power electronic converter based fast switching using IGBT/GTO. Two of the common FACTS devices are TCSC and SVC.
An SVC is a variable shunt reactance. SVC controls the reactive power injected to the node. Reactive power control put an impact on the node voltage. The common shunt elements of the SVC are Thyristor-controlled reactor (TCR), Thyristor-switched capacitor (TSC), Thyristor-switched reactor, mechanically switched reactor. The SVC is mostly used to dampen oscillations, to maintain a constant voltage profile, to provide voltage support. Below the parameters are listed which can be used to model the SVC.

Table 2.2: Parameters of SVC

Parameters	Description
K	Regulator gain
K_D	Integral deviation
K_M	Measure gain
T_1	Transient regulator time constant
T_2	Regulator time constant
T_M	Measure time delay
vref	Reference Voltage
x_L	Reactance (inductive)
x_C	Reactance (capacitive)
α_{max}	Maximum firing angle
α_{min}	Minimum firing angle

A Thyristor controlled series capacitor is a series controlled capacitive reactance. TCSC provides continuous control of power of the AC line. TCSC is consists of a series capacitor with a Thyristor controlled reactor in parallel to it. By partially compensating the line impedance TCSC can control the power flow through the line. Below the parameters are listed which can be used to model the TCSC.

Table 2.3: Parameters of TCSC

Parameters	Description
K_w	Regulator gain
p_{ref}	Reference power
T1	Low-pass time constant
T2	Lead time constant
T3	Lag time constant
Tw	Washout time constant
x_C	Reactance (capacitive)
x_L	Reactance (inductive)
x_{max} **TCSC (α_{max})**	Maximum reactance (firing angle)
x_{min} **TCSC (α_{min})**	Minimum reactance (firing angle)

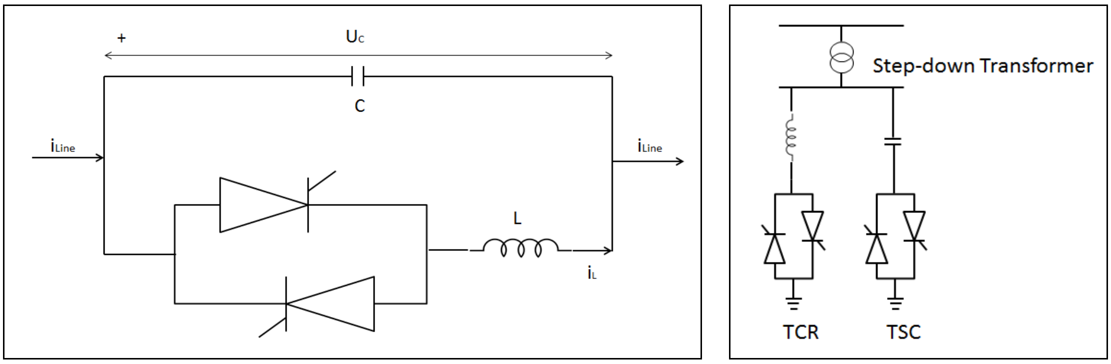
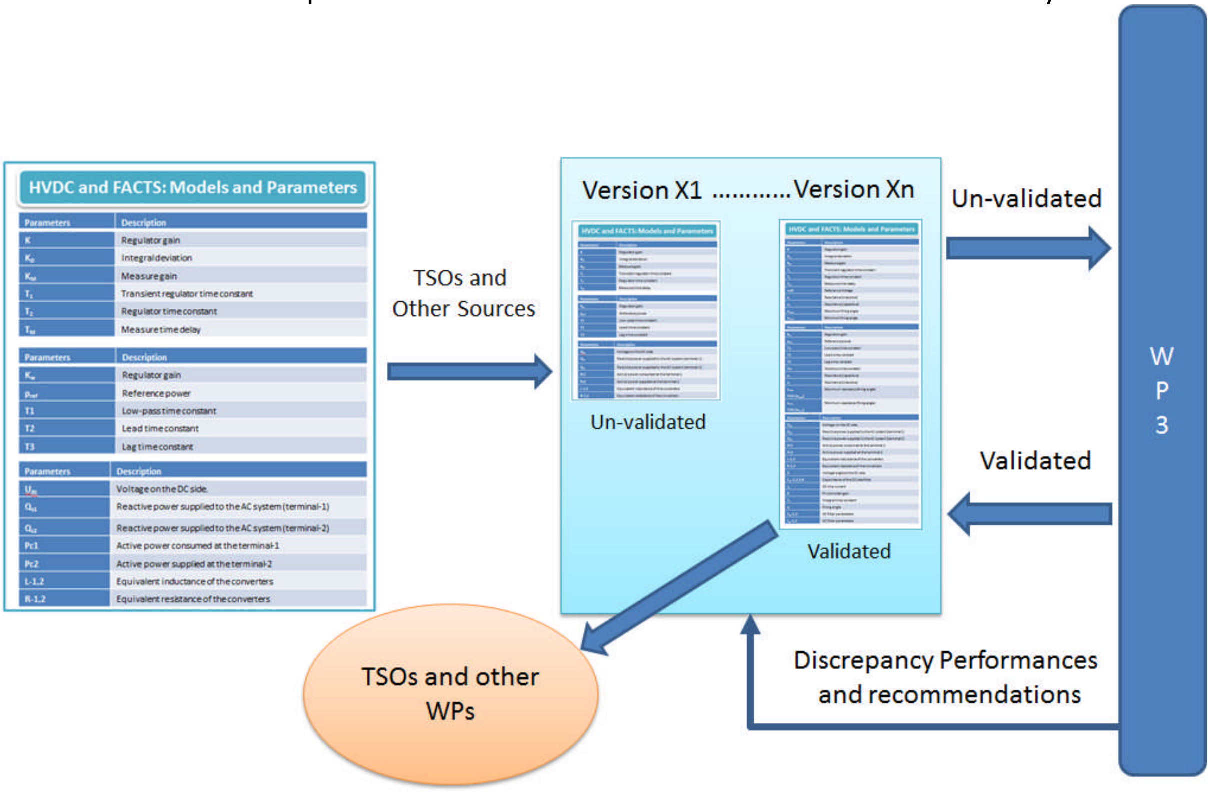


Figure 2.6: Models of TCSC and SVC

The device models and parameters can be obtained from TSOs and be verified by WP3



HVDC and FACTS: Models and Parameters

Parameters	Description
K	Regulator gain
K_0	Integral deviation
K_M	Measure gain
T_1	Transient regulator time constant
T_2	Regulator time constant
T_M	Measure time delay

Parameters	Description
K_w	Regulator gain
P_{ref}	Reference power
T1	Low-pass time constant
T2	Lead time constant
T3	Lag time constant

Parameters	Description
U_{dc}	Voltage on the DC side.
Q_{s1}	Reactive power supplied to the AC system (terminal-1)
Q_{s2}	Reactive power supplied to the AC system (terminal-2)
Pc1	Active power consumed at the terminal-1
Pc2	Active power supplied at the terminal-2
L-1,2	Equivalent inductance of the converters
R-1,2	Equivalent resistance of the converters

Figure 2.7: Data exchange, model/parameter validation of HVDC and FATCS devices

The FACTS parameters can also be further categorized into segments based on their operation and control (Figure 2.7).

Recommendation 9: *(FACTS):*
The SVC device does not exist in CIM v1; we recommend providing the equipment file in CIM v1 and the additional SVC device in CIM v2 syntax. An alternative could be to provide the SVC device in the TSO's native format.
For the rest of the FACTS, CIM does not handle such devices; we recommend providing them in TSO's native formats. If none of these are available, appropriate documentation would be needed.

2.1.12 Need of additional "system" requirements

Here is a non exhaustive list of the components that may need to be imported in the iTesla platform:

- Centralized voltage control
- Specific controls over a zone
- Automatons (including relays and protection devices)

Recommendation 10: *(Specific devices):*
Each type of specific device has to be studied case by case.
If a description is available in a native format, we recommend providing the associated files.
If not, and given the number of such devices, it could be provided by a documentation.
In the particular case of an automaton acting on a breaker for example (Bus-Branch-Switch topology, recommendation 1), a link (i.e. a mapping) between the automaton (probably in the native format) and the breaker (probably in CIM format) should be provided.

2.2 Needs in the "action" set:

Unlike the "system" set, there is no standardized format in the ENSTO-E profile capable to describe the "action" set. However, all the data listed below has to be imported into the platform.

It has also to be noticed that the data from the "action" set will have a low update rate: curative actions, preventive actions or contingencies will be configured once and then a data administrator might want to make occasionally some updates or corrections.

Therefore a possible appropriate solution could be to have a simple and flexible format to describe the data in input such as CSV tables (with references to "system set" IDs). Those tables could then facilitate the import of massive data into the platform (such as the first time configuration) and then, in a second step use a graphical interface to make updates on this data.

2.2.1 General description:

Given the assumptions in the "system" part above (see recommendation 1), any topological action has to be consistent with this description. If a more detailed description is used, such as the CIM equivalent Bus-Branch-Switch topology in Figure 2.3 we should then be able to take it into account through actions on switches (i.e. opening or closing a CIM switch).

2.2.2 Topological actions:

This includes the description of contingencies, preventive and curative actions if they are topological.

If a Bus-Branch-Switch topological description is used during the project (as explained in recommendation 1), it is proposed to use the Bus-Branch-Switch model for describing and selecting the contingencies as well as the possible actions (through a list of activated CIM switches plus a list of lost devices) and to convert the obtained topology in a bus/branch model for a system computation module. In this case, the conversion from Bus-Branch-Switch to bus/branch model will be made by the computation module himself, making the simplifications in consistence with its needs.

Recommendation 11: *(topological actions):*
For consistency with recommendation 1, it is highly recommended to provide ***Bus-Branch-Switch topology descriptions****. Therefore, complex topological actions leading to complex topology changes (with non-obvious fault propagation) should be described with links to Bus-Branch-Switch objects such as actions on CIM switches. It should be also possible to describe associated defaulting breakers.*
For example, a corrective action that operates a breaker (modeled by a CIM switch) must contain a reference to the CIM ID of the CIM switch. It is very important to notice that the CIM ID of a switch must remain constant from one situation to another one so that actions apply on different time steps.

2.2.3 Description of the contingencies and additional required data:

2.2.3.1 Topological description:

It is important to be able to specify contingencies using several selection methods. Among these methods, one can find:

- Generic description: all lines at 380kV, all combination of lines and generators, etc.
- Nominative description: line1, line1&Generator2, etc.
- A list of nominative or generically described contingencies such as the one exchanged between neighboring TSOs as defined in the standards A1-S2 of Policy 3 of UCTE's Operational Handbook.

Furthermore, the **propagation of a contingency** should be automatically detected. This should be the case when several elements are connected together without a breaker. The outage of one element leads to the loss of the adjacent one. This is for example the case of line with 3 extremities which are modeled in software as 3 lines but without breaker at the middle node.
The only solution for that is the description of the device in outage associated with a Bus-Branch-Switch topology description. (Please refer to recommendation 1).

In the case of dynamic simulations, each contingency should be associated to a generically defined **sequence of events**. As an example, the sequence of events could be

- Opening of the 2 extremities at the same time
- Fault at distance of 0.1% of one extremity, opening of the 2 extremities at the same time
- Fault at distance of 0.1% of one extremity opening of the closest extremity after the base time of the protective device and the second end after a longer time corresponding to the second zone.

Recommendation 12: *(definition of sequence of events after a contingency):*

In an ideal situation:
A contingency should be described by a scenario containing the sequence of events linked to the fault. This includes the nature of the fault and the device on which the fault occurs.
Propagation and consequences of the fault should then result from an accurate description of the grid (see recommendation 1) through operation of protections automata modeled in the dynamic data set and linked to devices in the static data set.
For example, if a protection device splits two busbars, then the protection should refer to the switch used in the description of the Bus-Branch-Switch topology. The switch will then be operated during the simulation if some protection thresholds are violated.

In a short term context:
Contingencies could be described through a list of lost devices. However, additional information helping to reproduce a realistic scenario of the associated fault would be appreciated.

2.2.3.2 Probability of failure and unavailability:

Linked to every element of the system, the **probability of occurrence of a contingency** should be defined either:

- In a generic way. As an example, the probability of failure of a line (including exterior causes (lighting etc.), false tripping (imprecise settings of protective devices) etc.) per unit length and as a function of the element state (per unit loading, per unit voltage etc.) and as a function of the element type (XLPE cable, mass impregnated cable, Fluid filled cable etc.)
- In a nominative way.

2.2.3.2.1 Point estimates

There exist for development studies point estimates on several components of the network:

- Overhead lines ,
- Underground cables,
- Transformers,
- Busbars.

The data associated to the components of the network are:

- Failure rate, λ
- Duration of failure, D, or **MTTR(Mean Time To Repair)**=1/ **μ(repair rate)**
- Unavailibilty, **U**.

Failure rate is the frequency with which an engineered system or component fails, expressed for example in failures per hour or failures per year (often for network data). It is often denoted by the Greek letter λ (lambda) and is important in reliability and safety (security) engineering.

The failure rate of a system usually depends on time, with the rate varying over the life cycle of the system. For example, an automobile's failure rate in its fifth year of service may be many times greater than its failure rate during its first year of service. One does not expect to replace an exhaust pipe, overhaul the brakes, or have major transmission problems in a new vehicle.

In practice, the mean time between failures (MTBF, 1/λ) is often reported instead of the failure rate. This is valid and useful if the failure rate may be assumed constant - often used for complex units / systems, electronics - and is a general agreement in some reliability standards (Military and Aerospace). It does in this case *only* relate to the flat region of the bathtub curve, also called the "useful life period". The reason of the preferred use for MTBF numbers is that the use of large positive numbers (like 150.000 hours) is more intuitive and easier to remember than very small numbers (like 1.3e-4 per hour).

In I-Tesla, we will assume that λ is constant for all components.

Unavailability can be defined as the probability that an item will not operate correctly at a given time and under specified conditions. It opposes availability.

Numerical values associated with the calculation of availability are often awkward, consisting of a series of 9s before reaching any significant numerical information (e.g. 0.9999999654). For this reason, it is more convenient to use the complement measure of availability, namely, unavailability. Expressed mathematically, unavailability is 1 minus the availability. Therefore, a system with availability 0.9999999654 is more concisely described as having an unavailability of 3.46E-8.

Unavailability may be expressed mathematically as the ratio,

$$\mathbf{U = MTTR/(MTTR+MTTF)}$$

where MTTR is the mean time to repair, and MTTF is the mean time to failure. Alternatively, this can be written as

$$\mathbf{U} = \boldsymbol{\lambda/(\lambda+\mu)}$$

Usually, MTTR is much smaller than MTTF, and we can write:

$$\mathbf{U} = \boldsymbol{\lambda/\mu} \quad \textbf{or} \quad \mathbf{U = MTTR/MTTF}$$

The data on transformers, overhead lines and underground cables can be either national or averaged on one year or defined more precisely:

- Season of the year (for instance it will be available at RTE with the 4 seasons),
- Regional (for instance it will be available at RTE with 7 regions),
- Depending on the forecast of abnormal events like storms

2.2.3.2.2 Uncertainties

Until now, we never used uncertainty data on contingencies. Given the operational feedback, it seems possible to associate to point estimates one of the following data:

- Confidence intervals,
- Probability distributions.

In statistics a **confidence interval** (**CI**) is a kind of interval estimate of a population parameter and is used to indicate the reliability of an estimate. It is an observed interval (i.e. it is calculated from the observations), in principle different from sample to sample, that frequently includes the parameter of interest, if the experiment is repeated. How frequently the observed interval contains the parameter is determined by the **confidence level** or **confidence coefficient**. More specifically, the meaning of the term "confidence level" is that, if confidence intervals are constructed across many separate data analyses of repeated (and possibly different) experiments, the proportion of such intervals that contain the true value of the parameter will match the confidence level; this is guaranteed by the reasoning underlying the construction of confidence intervals.

Confidence intervals consist of a range of values (interval) that act as good estimates of the unknown population parameter. However, in rare cases, none of these values may cover the value of the parameter. The level of confidence of the confidence interval would indicate the probability that the confidence range captures this true population parameter given a distribution of samples. It does not describe any single sample. This value is represented by a percentage, so when we say, "we are 99% confident that the true value of the parameter is in our confidence interval", we express that 99% of the observed confidence intervals will hold the true value of the parameter. After a sample is taken, the population parameter is either in the interval made or not, there is no chance. The level of confidence is set by the researcher (not determined by data). If a corresponding hypothesis test is performed, the confidence level corresponds with the level of significance, i.e. a 95% confidence interval reflects a significance level of 0.05, and the confidence interval contains the parameter values that, when tested, should not be rejected with the same sample. Greater levels of confidence give larger confidence intervals, and hence less precise estimates of the parameter. Confidence intervals of difference parameters not containing 0 imply that that there is a statistically significant difference between the populations.

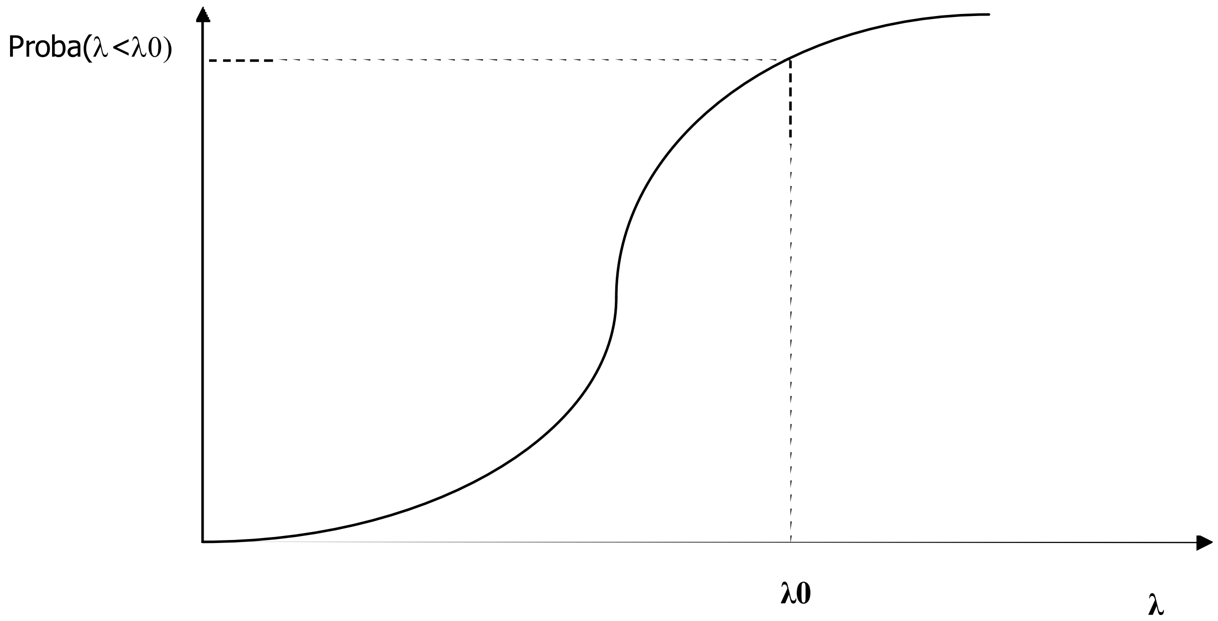
In probability and statistics, a **probability distribution** assigns a probability to each of the possible outcomes of a random experiment. Examples are found in experiments whose sample space is non-numerical, where the distribution would be a categorical distribution; experiments whose sample space is encoded by discrete random variables, where the distribution is a probability mass function; and experiments with sample spaces encoded by continuous random variables, where the distribution is a probability density functions (**that is our case**).

In applied probability, a probability distribution can be specified in a number of different ways, often chosen for mathematical convenience:

- by supplying a valid probability mass function or probability density function
- by supplying a valid cumulative distribution function or survival function
- by supplying a valid hazard function
- by supplying a valid characteristic function

Important and commonly encountered probability distributions include the binomial distribution, the hyper-geometric distribution, and the normal distribution

In our case, for example for failure rates, we can represent it with a cumulative distribution:



Distribution functions are more precise and enable the analyst to compute confidence intervals, but it requires more experimental data.

2.2.3.2.3 Categories of data

Recommendation 13: *(probability of failure and availability):*

To summarize the previous paragraphs, external data regarding contingencies will include data on:

- *Overhead lines,*
- *Underground cables,*
- *Transformers,*
- *Busbars.*

These data will be:

- *Failure rates,*
- *Mean Time To Repair (or duration of failure),*
- *Confidence intervals on the previous data,*
- *Probability distributions on the previous data.*

They will be in particular two seasons and location (regions)

Remark: This is an ideal situation; at least, the data for any country will be the same all over the country and the same for any season; as far as uncertainties are concerned, only confidence intervals may be provided.

2.2.4 Description of the actions and additional required data:

Preventive, automatic and manual curative actions are important information to be taken into account. For each contingency, a list of actions should be taken into account.

2.2.4.1 Curative topological actions:

Curative actions should be provided together with

- The probability of realization versus time. An automatic corrective action will be either immediately applied or will never be applied when the automation fails. A manual curative action will be realized after the given delay necessary for the dispatcher to take action. This delay is subjected to uncertainties and the probability of success of the curative action.
- The description of the topological changes related to the action.

2.2.4.2 Preventive topological actions:

Preventive actions will mainly be used for the online analysis. The determination of the N state should include required preventive actions for the contingency leading to unacceptable state without this preventive action.

2.2.4.3 Non-topological actions:

The non-topological actions include:

- Injection redispatching,
- Start of generating units,
- Change of a setpoint
- Load transfer

Those actions must be described with links to the associated devices. Since the TSOs should provide CIM files, reference to CIM IDs should then be used.

2.3 Needs in "security rules" set:

The security rules will be defined as a "configuration mode" in the iTesla platform. An interface should allow a high level user to define such security rules that should be taken into account.

2.4 Needs in the "time records" set:

In order to ensure satisfactory dynamic simulation results, grid data and PMU measurements (and any other time synchronized measurements, e.g. those from DFRs) are required. These data have to be delivered by TSOs following the specific confidentiality agreements signed within the iTesla project framework.
This set will be used for WP3. Records could be for example PMU measurements, synthetic data generated by EMTP outputs that could be used as a reference for dynamic model validation. The COMTRADE format could be the solution for this set. The COMTRADE format is defined by the international standard **IEC 60255-24**.

These have to be consistent with the "system" data that will be used as a starting point to run dynamic simulation that will be compared with these records. Since CIM data will be used, a link between the COMTRADE data and the CIM IDs should be made.

More details on the WP3's needs for the validation of dynamic models are available in D3.1. The document explains how the time records will be used.

Recommendation 14: *(time records)*
It is recommended exporting the "time records" in the COMTRADE format with a reference to the CIM IDs of the concerned devices in the exchanged CIM files.

2.5 Needs in the "other" set:

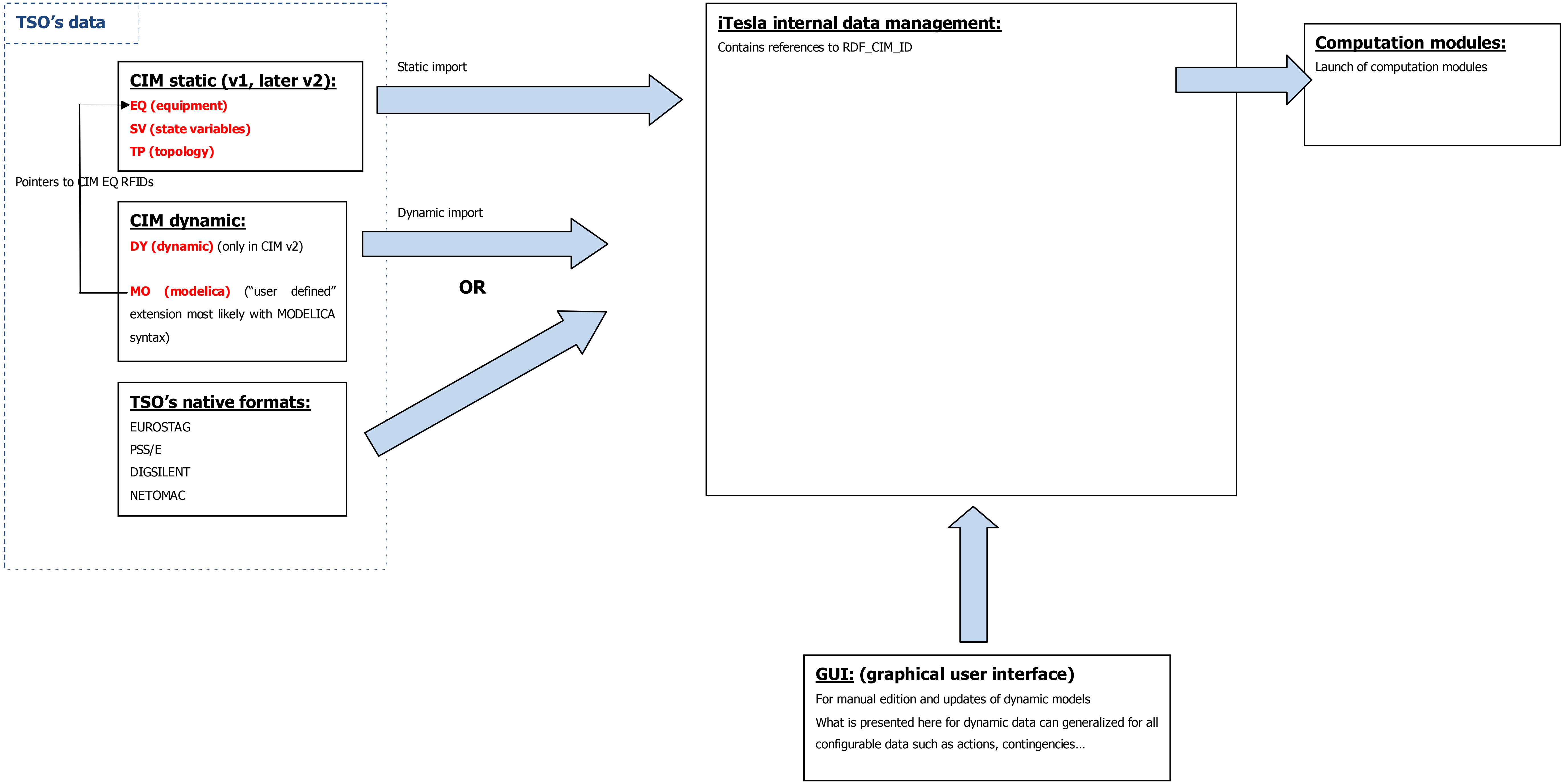
This part will be filled progressively according to the needs of the iTesla project.

3. Supported formats:

3.1 General principle:

A module will be dedicated to the conversion of supported input formats into an iTesla internal data model (**2IDM**). This internal model will cover all the needs for the tool box.

Figure 3.1 presents how the external data is handled in input of the iTesla platform.



For manual edition and updates of dynamic models

What is presented here for dynamic data can generalized for all configurable data such as actions, contingencies…

Figure 3.1: Data flows in input of iTesla

Recommendation 15: *(CIM)*
iTesla requests to import CIM ENTSO-E profile version 14 (called v1 in figure 3.1) for the description of the static part of the network.

CIM static format (ENTSO-E profile v1) can be considered as a stable format and is approved by ENTSO-E for data exchanges. Static data will be described by CIM static (v1) files
The CIM static data format (version v1) will be the base of the input data. The rest of the data (dynamic, user defined, remaining data) will be mapped to CIM attributes but expressed in their original formats.

The newer version (v2) accepts a dynamic extension validated by ENTSO-E which contains a description of the dynamic part of the network. But it is not stable yet. Therefore this version 2 might be used later, once officially released.

Recommendation 16: *(dynamic data)*
iTesla recommends importing dynamic data from TSO's native dynamic formats they use for their own dynamic studies (such as PSS/E, EUROSTAG or DigSilent files) CIM ENTSO-E profile version 14 (called v1 in figure 3.1) for the description of the static part of the network.

Recommendation 17: *(CIM)*
It is very important to keep constant IDs from one CIM situation to another. Most of the mechanisms inside the iTesla platform will rely on this stability (for example in data mining).

3.2 Generalities about CIM format:

We do not intend here to detail all the attributes contained in the CIM. We have to make sure that we will be compliant with the requests expressed in the first part of this document. We should refer to a reference document for the CIM.
Common Information Model – ENTSO-E profile 1st edition, 10 May 2009.

Here are the latest CIM different **profiles**:
- CIM v.14 released in 2009
- CIM v.15 released in 2011
- CIM v.16 work ongoing (ENTSO-E IOP (interoperability tests) in July 2012, plan released in end of 2012)

Here are the associated ENTSO-E CIM **profiles** which can be considered as rules defining a subset of the CIM formats listed above.
- 1st edition, version 1.0, final and approved (based on IEC 61970 CIM14v02 and accepted by ENTSO-E). The resulting dataset corresponds to what we call the **version v1** in this document. More information is available in the "CIM model exchange profile, first edition".
- 2st edition, version 2,3 draft and not yet approved (mainly based on IEC 61970 CIM16v10, geographical data based on IEC 61968). It has not been validated by

ENTSO-E with the CIM v15 and will be used with CIM v16 or a latest version. The resulting dataset corresponds to what we call the **version v2** in this document.

As written in several recommendations above, elements that cannot be described with the CIM v1 should be described with extensions similar to what exist in CIM v2 (for the static part) if the object exists in CIM v2 (for example HVDC devices). If not available in CIM v2, then native format or appropriate documentation might be used.

3.3 Dynamic data format:

RTE and **ELIA** are using the EUROSTAG software. They can both provide files describing dynamics used for simulations. They can also provide the associated regulations (controls) in the EUROSTAG format.
REN can provide the dynamic files in the PSS/E format, with the associated regulations (controls).
IPTO is using PSS/E and can provide dynamic files in this format.
Statnett is using ARISTO and PSS/E but can only provide dynamic files in PSS/E formats. They are currently working on converting this to CIM (including dynamic models).
NG: DigSilent and can provide both dynamic files and regulations except for wind farms and generating units.

As a conclusion, import modules for dynamic formats that must be taken into account in priority are:

- EUROSTAG (high priority)
- PSS/E (high priority)
- DigSilent
- Netomac

3.3.1 Defining “User defined” data in input:

The “native formats” described above does not always offer the possibility to define specific devices with their own equations.

The proposed solution is to use MODELICA language to define the modeling of specific devices. Explicit description of the equations of the models is the key of MODELICA language. This language will be a flexible way to design and upgrade new models, in an adapted language.

The first step is to develop a list and definitions of **control blocks** for user-defined models, and map dynamic case data to the CIM UML.

User-Defined models:

<u>Includes</u>

- User-defined models (such as an exciter) comprising interconnected elementary control blocks
- User-defined connectivity between control blocks

- Various hybrid arrangements
- Algebraic modelling language for devices

Goal

- Provide flexibility to completely specify a new model in a standard way
- Develop list of elementary control blocks
- Use well-known elementary control blocks

Example: time delay, step function, log, sin, etc.

Elementary control blocks defined to represent PTI PSS, EUROSTAG models and others.

Example: Standard model for **generator** must include:

- Name of model
- Associated bus number and unit ID in static network model (bus name and kV optional)
- MVA base (or MW capability) value
- System parameter values
- D-axis transient rotor time constant
- Q-axis transient rotor time constant
- Inertia constant, sec
- Damping factor, pu
- D-axis synchronous reactance
- Q-axis synchronous reactance
- D-axis transient reactance
- Q-axis transient reactance
- Stator leakage reactance, pu
- Saturation factor at 1 pu flux
- Saturation factor at 1.2 pu flux
- Stator resistance, pu
- Compounding resistance for voltage control, pu
- Compounding reactance for voltage control, pu

The long term procedure to achieve this task would be to use the structure of the CIM v2 including the dynamic extension. iTesla will then try to propose to CIM working groups some extensions to the CIM for dynamics standard in order to integrate equation based models made in the MODELICA format. This should hopefully provide more flexibility to the CIM format.

For example, one control used in a standard CIM dynamic file could be replaced by a control described in full MODELICA. This new control would be contained in the "CIM MO file" in figure 3.1. Then we should try to push the integration of these user defined CIM MODELICA extensions into the official CIM format.

3.4 Remaining data:

Proposed solution: use a XML file with syntax close to the CIM format. These new attributes should be mapped with CIM IDs of the CIM static file.

3.5 Probabilistic data format:

To be completed in accordance with the outputs from other work packages.

4. Conclusion:

This document provides to TSO partners a list of recommendations in order to provide data to the iTesla platform.
Among those recommendations, iTesla has a high priority on getting Bus-Branch-Switch topology from TSOs (see recommendation 1) with constant IDs. iTesla also has a strong need in validated dynamic data. That is why we recommend in priority the description of the dynamic part in the "native format" of each TSO.