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Formalization of the overall problem encountered by TSOs

Dissemination level		
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Table of contents

0. ABBREVIATIONS 3

1. GENERAL PURPOSE 3

1.1. ABOUT THE ITESLA PROJECT 3
1.2. ABOUT THIS PAPER: D1.1 - FORMALIZATION OF THE OVERALL PROBLEM 4

2. SECURITY ANALYSIS (SA) 5

2.1. TIMEFRAME AND PERIMETER 5
2.2. HUMAN RESOURCES 6
2.3. STABILITY PROBLEMS COVERED 6
2.4. CONTINGENCIES/EVENTS ANALYSIS 7
2.5. OPERATIONAL DECISION PROCESS 7

3. DYNAMIC CONSIDERATIONS 9

3.1. DYNAMIC SIMULATION IN OPERATIONAL PROCESSES 9
3.2. DYNAMIC DEVICES EXISTING OR FORESEEN ON THE TSO'S GRIDS 14
3.3. DYNAMIC RELATED TO RENEWABLES AND CONTROL SCHEMES BY TSOS 16
3.4. KNOWN OR EXPECTED SPECIFIC DYNAMIC ISSUES ON EACH TSO'S GRID 18
3.5. DYNAMIC TOOLS 20

4. RISK BASED APPROACH 21

4.1. CONTINGENCY ANALYSIS 21
4.2. PROTECTION SCHEMES AND CASCADING EFFECTS ON MANAGEMENT 24
4.3. PROBABILITY KNOWLEDGE 25
4.4. IMPACT ANALYSIS 27
4.5. SEVERITY SCALE 28
4.6. SPECIFIC RISK ASSESSMENT ON CROSSBORDER CAPACITIES 29

5. EXTERNAL COORDINATION 30

5.1. CURRENT STATUS 30
5.2. EXPECTATIONS IN ITESLA 30

6. DATA AND TOOLS: 32

6.1. DATA SOURCING: 32
6.2. POWER SYSTEM MODELING: 34
6.3. SIMULATION TOOLS 34

7. DEFENSE PLAN AND RESTORATION 39

7.1. DEFINITION 39
7.2. DATA 40
7.3. COORDINATION 41

8. CONCLUSION 43

8.1. WORKING AT A EUROPEAN LEVEL 43
8.2. AN OPEN PLATFORM 43
8.3. RISK ASSESSMENT AND PROBABILISTIC APPROACH 43
8.4. DYNAMIC SECURITY ANALYSIS 43

0. ABBREVIATIONS

CIM	Common Information Model – platform for data exchange agreed internationally among TSOs
D-2	Operational planning 2 days ahead
D-1	Operational planning days ahead
D	Intra-day operation planning
D2CF	2 Days ahead Congestion Forecasts
DACF	Day Ahead Congestion Forecast
DSO	Distribution system operator
EHV	Extra high voltage
N-k	Contingency involving the loss of k devices
HV	High voltage
H-1	Hour ahead operation planning
IDCF	Intra Day Congestion Forecast
OLTC	On load tap changer
NTC	Net Transmission Capacity
PST	Phase shifter transformer
SN	Snapshot

1. GENERAL PURPOSE

1.1. About the iTesla project

The iTesla (Innovative Tools for Electrical System Security within Large Areas) research and development (R&D) project addresses the call ENERGY.2011.7.2-1 (Innovative tools for the future coordinated and stable operation of the pan-European electricity transmission system).

It aims at developing a flexible toolbox able to support the future operations of the pan-European electricity transmission network, thus favoring increased coordination and harmonization processes for the operating procedures of transmission network operators in EU27. Its benefits are validated through a set of progressive tests with the TSO consortium members.

iTesla will provide the technical means to address the common future challenges of the European TSOs regarding:

- The renewables development and integration, warranting a probabilistic approach of congestion forecasting, taking into account the increasing amount of uncertainties, and offering risk based approach tools,
- The dynamic behaviors understandings over the power grids for an efficient security assessment, (in particular regarding new devices such as FACTS, HVDCs, renewable generation like wind, solar, tidal, ocean wave etc.)
- The increasing cross boarder connections and energy market integration of the TSOs power grids requiring more coordination especially through shared tools and practices in operation from D-2 to real time,
- An efficient assessment of all preventive and remedial actions so as to offer the maximum efficiency to all the players in the electrical energy value chain (Meaning: all players like: generators, TSO, DSO, End-Users, Whole Sellers, Aggregators, etc.).

iTesla will, to some extent, help to fulfill the 2020 EU commission objectives as far as the TSOs are concerned by the environment goals and the energy efficiency to be achieved by the electrical sector in Europe.

1.2. About this paper: D1.1 - Formalization of the overall problem

The first Work Package **WP1: Objectives, methodology, toolbox architecture and use cases** aims at:

- Formulating the pan-European security assessment problem,
- Defining the methodology to tackle the previously defined problem,
- Setting the requirement for the toolbox architecture, contents and validation use cases.

This document is the **Deliverable 1.1 (D1.1): Formalization of the overall problem**.
It is the first part of the work of the **Work Package 1.1 (WP1.1): Formulation of the problem and formalization of a potential solution to the overall challenges with plausible implementation schemes**.
This document was prepared on the basis of a survey sent to all project participants with a special highlight to the TSOs participants given their position as the potential main end users of the platform.
It covers the current state and the expectations regarding the main topics of the iTesla project:

- Security analysis,
- Dynamic considerations,
- Risk based approach and probabilistic analysis,
- External coordination,
- Data and tools,
- Defense plan and restoration.

D1.1 will serve as an input for **Deliverable 1.2 (D1.2): Formalization of a plausible functional solution**. This D1.2, as a functional design document, will as best as possible, stick to the expectations and needs expressed in D1.1.

2. SECURITY ANALYSIS (SA)

2.1. Timeframe and perimeter

2.1.1. Current status

"Security Analysis" (SA) is the process within which the transmission system operator (TSO) designs, plans and operates the Transmission Network according to pre-agreed criteria duly documented and acknowledged by the Regulatory bodies. It is most prevalent in processes closer to real-time to determine whether outages, generation trading patterns and network configurations present unacceptable security risks to the networks.

The goal of security analysis is to comply with the doctrine of security for the operation. Security analysis covers:

- N, N-1 and some N-k static security assessments (taking into account preventive and curative actions) regarding limit violation of :
    - Thermal current limit (overload),
    - Voltage acceptable values (high and low voltages),
    - Short- circuit power (high and low limits),
    - Load loss.
- Dynamic security analysis (voltage collapse, cascading outages, transient and small-signal stability phenomena, loss of synchronism)
- Market issues (NTC calculation, …)
- Other issues (island operation, angles to close circuit breaker)

Security analyses are performed from long time planning (multi-year) to real time. They are run manually but also automatically in real time.
Up to now, some TSOs are using tools in D-2 that may not be compatible with tools used in real time operation. Therefore, they have to use different tools in the timeframe covered by iTesla.

2.1.2. Expectations in iTesla

iTesla is expected to cover the actual needs for security analysis expressed above by the TSOs. Additional functionalities are also expected from this new platform: one of these is the possibility to work on an ENTSO-e power grid. This will be of great help for studies of coordinated actions.
iTesla should provide probabilistic security analysis taking into account uncertainties such as renewable generation (wind and photovoltaic generation) and other stochastic parameters. Most of the TSOs are already taking into account dynamics and transient stability in their SA, but it is expected to have it in an automatic way, from D-2 to Real Time (event triggered) using all available files (D2CF/DACF/IDCF/SN/…) updated regularly.
Given the requests above, it is expected from iTesla to provide a set of efficient (cross-border) remedial and preventive actions, relevant with the timeframe at the moment of the SA; their associated implementation time and effectiveness could make them inapplicable. For example, iTesla should provide output information about generation re-dispatching, and if needed, to propose an optimized solution of this re-dispatching. An optimized solution could also be provided for some other kinds of actions, such as optimal tap positions, optimal topology, HVDC link power setpoints etc.
The CIM data format compliance is expected. The associated CIM profile is the ENTSO-E profile.

The fact that we will all use the same tool on the same data with the same computation model will be welcomed by all TSOs. This latest statement will not prevent any TSO from using its own computation tool plugged into the iTesla platform as an external module.

2.2. Human resources

2.2.1. Current status

The TSOs are organized in various ways. One common point is the fact that SAs are run on a regular base, in the operational planning phase and during on-line operation.
It has to be outlined that the management of renewable energy is sometimes done by specific teams. Not all operators are experts; there are dedicated teams for specific studied issues. There are regional and national teams; their scope of work are different, regional teams are generally dealing with more local issues.

2.2.2. Expectations in iTesla

If the future arrival of iTesla among TSOs restructures their internal organization, this will remain their own responsibility. iTesla aims at being a common tool for the different TSOs.
However, training needs will emerge with the insertion of this operational tool. A set of clear documentation about principles and limitations of the toolbox has to be built. A user guide would be appropriate and could include a tutorial with some basic examples. Training courses could then be provided for users willing some advanced knowledge on iTesla prototype.

In order to alert on its own limitations, the tool could generate clear messages and alarms when limitations are reached. iTesla could provide an online “Help” section giving access to documentation on the functionalities and on the output results. The tool should be user friendly, presenting only the necessary information/messages to operators and keep more detailed information for analysts.

2.2.3. Expectations beyond the iTesla prototype:

After the prototyping phase, the tool is also expected to be internally the reference tool used for SA by TSO operators. User friendliness should be improved and training should also be expected for an easier use of the final tool.

2.3. Stability problems covered

2.3.1. Current status

In the present procedures, fast dynamics as well as slow dynamics are covered.
For more details, see the dedicated chapter “Dynamic consideration”, especially 3.1.1..

2.3.2. Expectations in iTesla

The expected area of studies in dynamics is wide: transient stability, loss of synchronism, fault clearing computation, slow and fast voltage stability, frequency analysis, oscillations analysis and damping, congestion and all in N and N-k, with or without consideration of remedial actions.
For more details, see the dedicated chapter “Dynamic consideration”, especially 3.1.2.

2.4. Contingencies/events analysis

2.4.1. Current status

The “Risk Based Management” part (4 and 4.1) of this document will provide more detailed information and expectation concerning contingencies and events analysis.

Up to now, TSOs can handle lists of contingencies containing all N-1 (Overhead lines, generators, transformers, PSTs, busbars …) and some relevant N-2.

The results of the simulation of all these contingencies can be sorted by different criteria: thermal, voltage or short-circuit violations are very common criteria, some tools are flexible enough to provide weighted calculation of various criteria (I%, V%, Q%). Criteria related to transient and dynamic stability are also in use. Results can also be sorted depending on the characteristics of the devices, such as their type, their voltage level and their geographical location.

Such lists can be automatically built: they can depend on some given criteria such as a set of lines at a given voltage level. Contingency lists can also be built manually; each device has to be defined.

Maintenance can be taken into account from long term planning (Y-1) to operation and covers issues such as opportunistic rescheduling, replacement or even maintenance canceling with associated costs.

2.4.2. Expectations in iTesla

iTesla should offer different options to manage lists of contingencies since those functionalities are already available for most of the TSOs. This should involve automatic lists (based on criteria: for instance on voltage criteria such as “only EHV N-1 Line”) and also lists tunable by users and adaptable for a given scope of studies: iTesla should offer an easy mean of sharing such lists among TSOs if they wish to for a bilateral or a multilateral collaboration or for common activities in a coordination center for instance.

In addition, taking into account cascading effects and having the possibility to associate suggestions of remedial actions would be welcome.

Results are expected to be sorted by severity (according to tunable criteria). The “Risk Based management” part (4 and 4.1) will contain more details on it.

2.5. Operational decision process

2.5.1. Current status

In order to keep the system safe, TSOs have a list of available actions they are responsible to apply if needed. The most common are topological actions; the associated cost is low but the number of possible efficient actions may be reduced for some critical cases. TSOs have also control actions such as modifications of voltage set points and tap positions of transformers; HVDCS and FACTS also provide some new ways to act on the power grid.

Some actions are only used in a second time if the previous actions listed above are inefficient. Generation reallocation is one possibility; the associated cost is of course much higher. Load monitoring is also used (minor overloads are tolerated if their duration is limited). Load shedding can be used in real time, mainly for peak load management and in situation with low frequency in the power system.

Some of the above actions are done with the cooperation of third parties (e.g. load shedding in cooperation with DSO).

2.5.2. Expectations in iTesla

To assist them, TSOs would like iTesla to ensure they can carry out pan-European studies with a good description of neighboring power grids. The pan-European description should help to avoid problems such as finding an accurate equivalent description of the neighboring grids.

It is also expected to take into account costs and somehow to be able to prioritize some actions.

One of the main expectations is to give information to the operators for decision making (preventive and remedial actions). This information has to be consistent with the TSO’s scope of studies.

2.5.3. Expectations beyond the iTesla prototype:

Solutions related to efficiency and energy market impact would also be an added value for the Partners involved in iTesla.

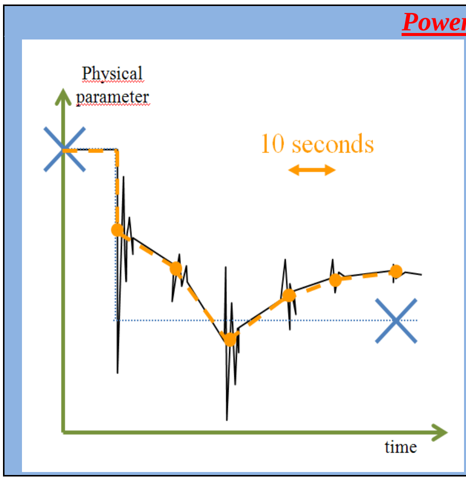
3. DYNAMIC CONSIDERATIONS

Taking into account the effect of dynamic issues on the power grid in the future transmission system operation is one of the major outputs assigned to the iTesla project and its expected platform.
Such a need is obvious given the impact of the renewable development and the integration into the power system (onshore and offshore wind, PV, etc.) and their behaviors, the increasing number of power electronics based technologies on the power grid (DC links and their converters for instance, SVCs) and all the devices with a more or less fast dynamic behavior (phase shifters, system or local controls, protections, etc.).
The increasing interconnection level of the European power grids emphasizes those issues as well as the electricity market development (with the European adequacy challenge rather than independent national balancing) and the load control policies under studies (impacting the load curve and making it possibly more volatile).

An efficient security assessment thus requires a more regular time domain simulation assessment at the operating timeframes, from D-2 up to real time, and potentially from a local geographical perimeter up to the pan-European one.
The survey addresses those issues through the following topics, giving a view of the current practices among the TSOs and above all, the expectation in iTesla:

- Dynamic simulation in operational process,
- Dynamic devices existing or foreseen on the TSO’s grids,
- Dynamic issues related to renewable generation and control schemes by TSOs,
- Known or expected specific dynamic issues on each TSO’s grid,
- Dynamic simulation tools,
- Internal knowledge of dynamic issues by each TSO.

Power system simulation: time domain simulation



The static power system simulation assumes a stable final post-event/contingency state of the system. With a shorter time step (seconds), a quasi-steady dynamic simulation may capture slow transient phenomena like voltage collapse, but none of the fast phenomena (like generator instability, short circuits problems, oscillation phenomena, etc…).A full time domain simulation (ms) can capture almost all the dynamic phenomena affecting the system and then cover a wider range of possible disturbances threatening the system. Besides, new power electronic based technologies with fast dynamic behaviors are expanding fast within the network (DC link, FACTS, etc.); they make dynamic assessment more and more mandatory to keep risk assessment realistic.

3.1. Dynamic simulation in operational processes

3.1.1. Current status

We focus first on the dynamic simulation (time domain simulation) integration in the operational process of the different TSOs of the Consortium (ELIA, NG, Statnett, REN, IPTO, RTE) and CORESO.

The first question that comes is: do they perform dynamic simulations in operations (from D-2 to real time)?
All have experience on dynamic studies but only a few in operations, rather at a farther timeframe, weekly for some, only at transmission planning stage and for energy studies and operator training for others. Real-

time tools barely have dynamic functionalities and separate software is generally used. In case of unplanned outages/stressful situations, some TSOs can, on demand, request dynamic studies made by dedicated experts at their national control centers in operations. Some TSOs have also an ongoing project of integrating dynamic capabilities into their tools in operations.
One TSO has a more developed dynamic assessment in operation (D-2 and D-1 for short term and long term transient stability with dedicated team) and in real time for voltage constraints with a quasi-steady state simulator.
Another TSO performs automatic Dynamic Voltage Security Assessment every one hour; its dynamic stability analysis is done off-line due to the time-consuming procedure needed to transfer data from the SCADA/EMS to the dynamic model in PSS/E.

Dynamic tools for operator’s training are also used by 2 TSOs. There are no dynamic studies in operations at a European coordination level so far.

For those having dynamic assessment capabilities, they rather use them for transient stability problems (loss of synchronism, critical time computation of fault clearing to choose the right topology and tune protections, rotor stability and their impacts on the N-1 (sometimes N-2) security criteria, oscillation damping), for frequency analysis and for voltage stability. One TSO runs slow dynamic simulations in real-time (especially for voltage collapse prevention through a quasi-steady state simulator). One TSO assesses overload problems in dynamic.
A single TSO uses dynamic simulation for its operators’ training only. On the energy simulator they can study the frequency control for high and low frequencies. However, no stability issues are simulated and only a limited number of scenarios is available. For example, they can simulate a morning demand pick up and trainees can control the system’s voltage setpoints. For these operators’ trainings, a single snapshot of the real system is built up once a year.
For TSOs performing dynamic studies, there is no automatic process implemented in operations, except for one TSO assessing voltage dynamics every hour. An expert involvement is always required to perform the corresponding activities and it is most of the time a separate activity from the regular static security analysis in real time. One TSO mentions its ongoing project to include into its automatic online security analysis process (every 15min) a dynamic simulation. Another TSO mentions its capabilities to make automatic simulations but stresses how complex it is and thus not used.
The corresponding tools used for those activities are generally considered poorly user-friendly and handy by the TSOs that are using them. Consequently, such activities are complex to drive.
Some TSOs have a limited grid modeling for their dynamic simulations (generally the EHV part and sometimes the HV partially or totally given the TSO). They generally include into their contingency lists those in EHV, more rarely in HV.

Most of the TSOs performing dynamic simulations have separate experts for that, in separate processes from the classical static security analysis except for one which has the same people doing both. Those people work at the national control centers; one TSO has also a R&D department with experts on dynamics as a backup for the teams/engineers at its national control center.
Two TSOs mention their use of the commercial fast dynamic simulator EUROSTAG and PSSE/E for their transient stability studies, frequency control analysis, loss of synchronism studies, short-circuits faults clearing, oscillations damping. One TSO uses Siemens-PTI PSS/E software for an automatic cyclical voltage dynamic analysis but mentions the difficulty to make the data from SCADA/EMS compatible with PSS/E software.
One TSO mentions its “almost home-made” quasi-steady state simulator (10s time step) integrated in the operator’s tools. This simulator is dedicated to voltage stability studies even on real-time operations.
When the TSOs declare to do some dynamic studies, it is only performed at a national level. There is no dynamic expertise and analysis at a local level.
One TSO mentions that its dynamic studies are generally initialized on a static simulation output.

Only a few TSOs have dynamic assessment in operation (from D-2 to D). But many mention it on a regular week basis (maintenance scheduling in case of transient stability problem detection, etc.) and closer to D-2, D-1 and D only on demand and on specific identified constraints and/or unforeseen stressful situations.
One TSO mentions its dynamic activities from D-2 up to D:

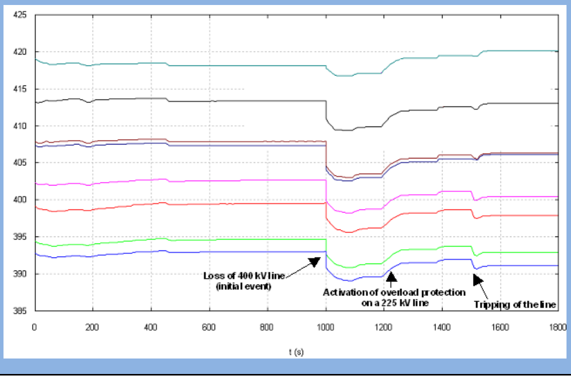
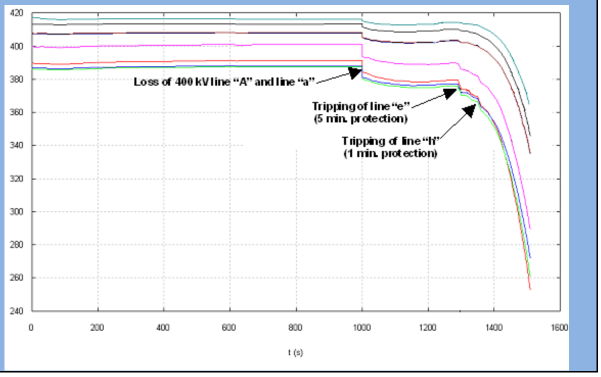
- Slow dynamic simulations (10s time step): it is made mainly during constrained periods and only for voltage constraints, on a D-1 and a D basis at the national control center, by operators or D-1 planning engineers. Generation imposition may be based on such dynamic studies for voltage constraints. (Caution: generation imposition to alleviate congestion constraints is still based on static simulation).
- Fast dynamic simulation (ms time step): it depends on expected transient stability constraints. It is only run on short-circuits, on a D-2 and D-1 basis.

3 TSOs mention that a dynamic simulation output may result in operational decisions like forced startup of generation, remedial action (preventive or curative).
One TSO gives details on its practices in terms of remedial actions specifically activated on dynamic assessment. For voltage constraints and after a quasi-steady state simulation it can activate:

- Possible topology modification for voltage constraints,
- Generation imposition for voltage constraints,
- -5% on load transformer voltage set up,
- OLTCs preventive blocking,
- Load shedding criteria for voltage collapse prevention evaluation,

In the case of this TSO and in a D-1 scope, preventive actions might be decided based on fast dynamic studies in case of detected transient stability risks such as specific topology schemes or reactive power absorption limitation on generators to be respected, re-tuning of protection relays etc.

Many tools are used for dynamic simulation, in D, D-1 andD-2. One TSO answers that it uses an annual snapshot for operator training in a tool not usable for studies in operation. One TSO bases all its studies on the EUROSTAG fast dynamic tool, another one on the tool ARISTO and PSS/E. One TSO mentions both a fast dynamic simulator (EUROSTAG as a stand-alone software and its own format generated by dedicated conversion tools) and an internal quasi-steady state simulator specific for slow voltage constraints (integrated into the operator platform tool); there is low compatibility between these two computations modules. This last TSO also mentions a separate activity to maintain a dynamic database of the generator characteristics and the device characteristics on the grid (the database is integrated in the operator's platform; it is automatically updated with the latest validated data).

Contingency example handled in security with some remedial actions (no voltage collapse, normal voltage conditions restored)	*Initial event + aggravating event (losses of lines A + a) leading to a collapse of the system*
	

3.1.2. Expectations in iTesla

iTesla should not aim at giving to the TSOs directives on how to operate their grids but rather to propose technical means to integrate in their activities dynamic capabilities to address common challenges, either on their own or coordinated, for instance in a coordination center like CORESO or TSC.

iTesla should propose an easy way to perform dynamic simulation at all timeframes in operations preferably with the same tool. iTesla, as a platform, should propose the adequate framework to easily plug in an external dynamic simulator, which may have the necessary adaptation during the project to do so. Simulators from the PEGASE European project or any other private simulator could be alternatives. Of course, the goal of iTesla platform is to become a tool shared by the TSOs. We can also expect that within the TSOs, iTesla could be the tool used by the different services from D-2 to D. iTesla has to offer a common database accessible by the different users (with rights management) and the different modules plugged-in. iTesla will have an internal format wealthy enough to handle all the expected functionalities and be compliant with external data exchange formats such as CIM by default (among WP2 objectives).

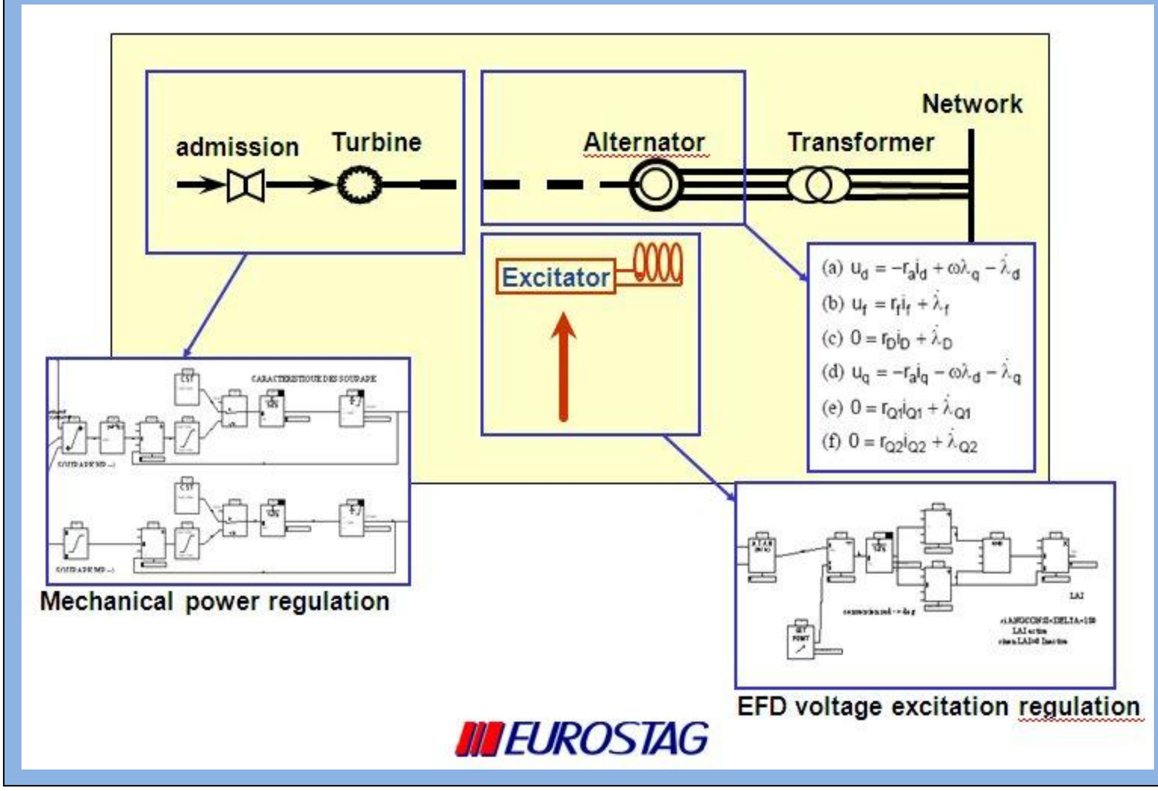
The expected area of studies in dynamics is wide: transient stability, loss of synchronism, fault clearing computation, slow and fast voltage stability, frequency analysis, oscillations analysis and damping, congestion and all in N and N-k, cascading and interaction phenomena due to the automatisms and protection systems taking into account in simulation, with or without consideration of remedial actions.

iTesla should provide the means for automatic processing. Dynamic assessment has to be the default choice during the project but iTesla should also leave the possibility for a quasi-steady or a static computation. TSOs consider the dynamic simulation only in major deviation from the planning operation stages and the static assessment or during the closer-to-the limit constrained situations bound to breach the static limits.

Given the complexity that can be generated by a dynamic computation, the TSOs stress the need of an easy-to-use tool with simple procedures with easy-to-interpret results for the operators. The need of a flexible selection of the perimeter to handle in dynamic (EHV only or partially/totally with the HV, European, Regional or national limits) is also stressed. The simulation codes have to be robust and avoid simulation divergences due to small local irrelevant problems or mathematic numerical problems.

The operational decisions to be made in operations are up to the TSOs and the operators. iTesla should provide enough flexibility to integrate preventive and remedial actions, providing help to operators on how and when to activate them. Manual preventive and corrective actions should be handled by the tool if needed and asked by the operators, an updated list/catalogue of such actions could be included and be used manually or automatically by the tools and be shared among TSOs or with coordination centers if TSOs wish it.

Generation modeling



3.1.3. Expectations beyond the iTesla prototype:

Even if not in the scope of the iTesla project, some TSOs have expressed the need to run on demand dynamic simulations.

3.2. Dynamic devices existing or foreseen on the TSO's grids

3.2.1. Current status

We now try to focus on which specific assets the different TSOs have required dynamic assessment on their grids.

They all mention that they model in their tools:

- ***[fast dynamic]*** Generation Control: speed & primary voltage control, current & voltage & speed protections, loss of synchronism protection (on units and on the grid), overcurrent and internal angle protection (rotor & stator),
- ***[slow dynamic]*** Reactors and Capacitors (possibly multiple banks) and their control (possibly based on multi voltage levels monitoring).
- ***[Fast dynamic]*** DC link with their AC/DC converters actually existing and many to come in the future.
- ***[Slow dynamic]*** Automatic voltage control and OLTCs (one TSO declare it doesn't model it in its tool though), generally tap changers on all transformers to DSOs with automatic control but not necessarily on all the transformers on the transmission grids which are often manually handled.

Then:

- 3 TSOs mention that they have some SVCs (Static Var Compensators); one especially mentions its project to have more SVCs in the future *[fast dynamic]*.
- 3 TSOs also mention that they have many phase shifter transformers (PSTs) but not necessarily modeled in their dynamic tools when they have dynamic simulation capabilities and even no necessary automatic control associated with (neither local nor global) *[fast dynamic]*.
- One TSO mentions that its "Secondary Voltage Control" is a system based on voltage control that goes beyond the usual local voltage control on generation *[slow dynamic in s to min]*
- One TSO also has overcurrent protections on branches with automatic tripping on variable thresholds *[fast dynamic – in min]* and another one has a selected line tripping procedure.
- One TSO is using specific automata of load shedding on voltage collapse risks and also overcurrent protections on loads *[slow dynamic]*.
- Under frequency load shedding procedures and PSS are also mentioned by TSOs.

Among the TSOs having dynamic simulation capabilities, most of them declare being able to simulate all the devices they mentioned above except the following exceptions:

- One TSO, which performs only fast dynamic simulations with EUROSTAG for transient stability does not model the devices with a big time step like the voltage control on the grid assets. For the remaining devices and also for the regulations of the generators, they are modeled according to characteristics provided by the producers.
- One TSO uses two different models for some devices: one for slow dynamics (10s time steps, mainly for voltage constraints) and one in fast dynamics with Eurostag. The models are consistent with the simulator's time step. Sometimes, generation modeling aggregates generation units and their transformers (like wind turbines at distribution level converted at the HV level).

One TSO mentions the difficulty to simulate DC links which still requires improvement and validation. Another TSO highlights the difficulty to transfer SCADA/EMS data to the dynamics analysis software. When such a process does exist, it is still difficult to assess the accuracy of the simulation results without measurements from several PMUs. It also stresses the lack of reliable data from neighboring systems.

Two TSOs fully rely on the devices' owners (producers) and manufacturers and the modeling they provide with their characteristics.

Two TSOs declare they have dedicated teams to build up the required dynamic modeling for their devices and one also mentions that it sometimes uses default modeling. These TSOs stress the complexity of such modeling and also the difficulty related to the unfriendly user interfaces of the tool.

All TSOs declare to have static equivalents of their devices with no real consistency with the dynamic equivalents (most of the time, they do not check that consistency). For generation, they can use simplified PQ diagrams (trapezes) at nominal voltage instead of the full 3D PQV diagram;

For load, different models can be used:

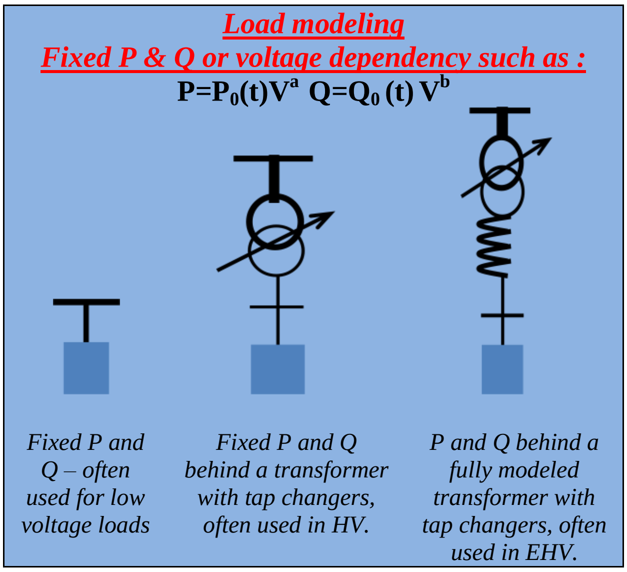
- In static: constant P and Q,
- Slow dynamic: dependency of P and Q to the voltage,
- Fast dynamic: dependencies to the voltage and the frequency possible.

For DC links, there are actually some simplified models tested in planning essentially, still requiring refinement and improvement for operations (fixed PQ injectors to model converters, etc.).

The modeling and the associated parameters provided by the manufacturers are generally quite satisfactory, even if it is sometimes difficult to have all the asked information. It is generally provided at the connection to the grid requests, at the purchasing level or during the planning studies stages.

Two TSOs stress that they monitor producer's performances and check if measurements on their generating unit are in accordance with the requirements.

Two TSOs even mention a post control of the devices characteristics by comparison to PMU data recorded during oscillations or incidents.



Load modeling

Fixed P & Q or voltage dependency such as :

$P=P_0(t)V^a \quad Q=Q_0(t)V^b$

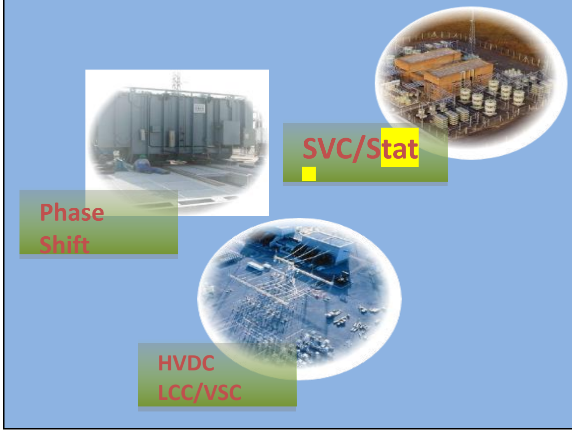
Fixed P and Q – often used for low voltage loads

Fixed P and Q behind a transformer with tap changers, often used in HV.

P and Q behind a fully modeled transformer with tap changers, often used in EHV.

3.2.2. Expectations in iTesla

Added value of taking into account corrective actions



New controllable devices are installed in the power system to ensure an acceptable level of reliability, when it becomes more and more difficult to build new overhead lines. Such devices can act very quickly, hence enabling their use as corrective actions. Security assessment must address such capabilities, which in turn maximizes their added value.

Existing operating rules are based on some manual corrective actions that have to be modeled for an efficient operation of the system. Moreover the development of demand response will also give new opportunities for corrective actions.

iTesla should be able to take into account all the devices on the TSOs grids listed above and it should also be flexible enough to welcome new ones not yet mentioned (a user model definition capability); more generally, iTesla should manage all the actual and coming power electronics based technologies. The ideal would be for all the TSOs to share the same modeling for a given device.

iTesla should be able, if necessary, to provide default modeling with standard parameters. Moreover, iTesla should be able, if relevant, to manage for a given device, a multi-modeling level from a static simple equivalent to the most detailed one required for fast dynamics simulation.

iTesla may include a validation procedure (to be run within the platform) for data and modeling (device validation or system validation), it might also have a validation/quality index associated, a static/dynamic consistency checking, a real time results comparison or any other, all this according to WP3 works and conclusions.

All the data and modeling should be handled in a “Dynamic database” accessible by the partners (with rights management). To make a “black box” of a device modeling and characteristics for confidentiality reasons might be an option.

Many TSOs mention the necessary compliance with the CIM standards which is of course an objective. However, we should also notice that from a dynamic modeling aspect, the CIM standards are not yet advanced enough. We should adapt according to the evolution of the CIM data format but iTesla should not make its structure CIM-dependant. The CIM standard will be for iTesla an exchange format that should be managed, but iTesla must have its internal format adapted to its way of working (especially integrating the needs concerning events management, remedial actions and risk based assessment requirements: cf. the corresponding part of the document).

The TSOs stress the absolute necessity of an easy-to-use tool, i.e. the accurate modeling should be considered automatically as much as possible without operators intervention required. Especially as the different devices have different time steps, the relevance of its modeling should not bother the operators and the tools should be able to manage all this automatically without long and tricky parameterization; interactions from operators should be minimized. However, a certain level of expertise will still be required for configuration of the toolbox such as validation of models.

3.3. Dynamic related to renewables and control schemes by TSOs

3.3.1. Current status

Handling the increasing renewable integration over our more and more interconnected grid and its associated challenge is one of the main motivations of the iTesla project as well as handling the different protection schemes on the system (1.1).

The tools currently in use by the surveyed TSOs do not show a high degree of internal compatibility. The situation about compatibility standards is best summarized by the information provided by the survey:

- TSOs develop their own converter modules,
- Some TSOs try to choose a limited number of tools to maximize the compatibility.

Regarding to the possibility for each TSO to make their tools evolve, all of them have the capability to adapt them:

- Some TSOs develop their own tools and therefore can adapt them at wish. It is only a matter of internal resources. Some of them cooperate with other TSOs having similar needs,
- Some have specific maintenance contracts or agreements with the vendors to extend system if necessary.

All of the TSOs have trained people to deal with dynamic issues but not necessarily at the Control Centers. This knowledge may be placed at different departments but they all have at least one dedicated team for dynamic expertise.

To be specific about the training of the operators on dynamic issues, the situation is the following: in general, the operators have limited knowledge of dynamic models but user-oriented trainings are being given. In some cases, operators using dynamic simulation have trainings, and within those trainings, the tools' limitations are highlighted.

3.3.2. Expectations in iTesla

Regarding the compatibility that the iTesla tools should provide, the TSOs are expressing the following requirements:

- iTesla should be able to accept all generic formats asked by TSOs (Eurostag, PSS-E, UCTE, CIM, etc) and provide tools for conversion,
- iTesla should provide to have in its internal format "user defined" models and propose a set of generic ones (the ideal would be for the TSOs to eventually use the same formats for those not specific to their grids),
- iTesla tools compatibility should allow results comparison among the different partners.

About the capacity of change and adaptation what is sought is:

- Openness and flexibility of the platform, using standards and open interfaces as much as possible so that each TSO's user can easily plug in its own modules.

The requirements from dynamic experts and operators are the following:

- iTesla should be friendly enough for non-expert operators but should also offer advanced features and flexibility for experts,
- When stability/dynamic assessment will be included in the processes, it is obvious that dedicated training will be given to operators in order to develop their skills,
- Of course, everybody will have to reach the minimum requirements asked by the activities he will be responsible for and we will not ask everybody to become an expert in stability issues.

From the point of view of operators as "standard users" of iTesla what is sought is that:

- iTesla tools should be friendly enough for non-expert operators,
- The information should be easy to understand,
- Maybe we could expect specific warning/help from the tools (in output) so that they do not misinterpret the results,
- The tools should be robust,
- The tools should offer advanced features and flexibility for experts.

3.4. Known or expected specific dynamic issues on each TSO's grid

3.4.1. Current status

All TSO's are concerned by dynamic issues specific to their individual power grid beyond all the general and shared issues previously mentioned. iTesla should be able to address them in the desired way for the corresponding TSOs. Those issues are related to specific voltage stability and sensitivity, weather impact sensitivity, oscillations, transient stability, DC link reliability and renewable integration.

Concerning **voltage instability**, some TSOs mention their experience linked to the cross border exchanges linked with flows on tie lines especially linked with volatile and important wind generation in some regions. Another TSO mentions its voltage sensitivity in zones poorly meshed and with small local generation but increasing load. Other TSOs stress the arising of voltage issues because of a lack of distribution of generation with reactive reserves on their grid.

The **weather** may impact the operation of the grid and the risks faced; a TSO especially highlights its thermal sensibility in winter during cold waves resulting in high load levels and intensive peak load to deal with. Specific operations linked to a risk of flooded areas, or risk of (forest) fires area might locally endanger the security of supply.

TSOs have identified for some of them, specific power **oscillation** issues that might cause problems and/or contribute to reach stability limits. It has especially been mentioned:

- Inter area oscillations: England-Scotland; Nordic countries; Portugal and Swiss network, Turkey link.
- off-shore wind farms connected to the grid as it increases the distance between the generation gravity center and the load increasing the risk of power oscillations;
- North-South power oscillations between thermal generation mentioned by one TSO on its power grid;
- Frequency disconnections at 50.2Hz of domestic PV installations.

Some TSOs, with undergoing and forthcoming **DC link** projects, specify their own concern about their operation and their associated dynamic issues and their reliability. This is a potential increasing risk factor they wish to specifically handle:

- DC link reliability due to low short circuit level.
- Integration of future DC links (2 TSO's)
- Wind power plants (on and off-shore 5 TSO's)

Eventually, the renewables development might be of some concern regarding dynamic instability risk incurred for some TSOs, especially:

- The distributed generation (small hydropower),
- The Increase in electricity generation by solar,
- The offshore wind development.

Of course long-term ahead dynamic studies are carried out in order to assess the impact of these issues by each TSO in the years to come and to ensure that investments are compatible with dynamic security, however the TSOs expect from iTesla means to handle those issues in operation as well.

3.4.2. Expectations in iTesla

The expectation of the TSOs concerning dynamic issues in operations have already been well described previously and will also be in the remaining paragraphs of this chapter. Here, let's put the focus on those specific issues detailed in 3.3.1, not necessarily concerning all the partners, often very specific to a TSO and its grid but for which specific functionalities in iTesla are expected to handle them.

The surveyed TSO's placed their expectations with respect to the current issues asking iTesla to provide:

- The possibility to define specific alarms for well-known issues as part of a user profile,
- The possibilities of tackling pan-European inter-area oscillations problems,

- The means for TSO's coordination, in a bilateral or multi-lateral way, for the best available solution,
- The possibility to handle their specificity on all stability issues at all-time scales in operations.

iTesla is also expected to provide the following tools and/or functionalities to enable to analyze/manage the foreseeable problems:

- Openness in format and modeling to face new technologies being developed on the grid.
- Enable TSOs to co-perform studies on important tie-line issues. Model and simulate effects of future installations, How to operate DC links incorporated in AC grids,
- Provide the needed alarms to understand the stress of the grid and take the right actions,
- Provide system operators with tools to understand congestion on the grid**.**

3.5. Dynamic tools

3.5.1. Current status

With respect to the use of simulation tools by the surveyed TSO's it is getting obvious that there is a lack of uniformity due to its different structures. Two of the surveyed TSOs are not performing dynamic simulations on a regular basis (cf. 3.1.1).

Others perform dynamic simulations on a vendor provided tool:

- Full replica simulation of one TSO's grid system on a new simulator used only for operator training and not for operational activities and studies,
- PSS/E (Siemens) for fast dynamic simulation.

Others have developed internally simulation tools with or without collaboration:

- EUROSTAG for fast dynamic simulation (EUROSTAG is a commercial tool),
- Internally developed simulation codes, or through collaboration with universities, for slow dynamic simulation (ASTRE) for instance and short-circuits computation,
- ARISTO – internally developed by Nordic TSOs.

Those simulation tools are either stand-alone applications or integrated in the operational platforms.

3.5.2. Expectations in iTesla

The technical expectations regarding the tool are closely linked to the operational activities envisioned with it and detailed previously especially in 3.1.2.

They are summarized by the following requirements

- Openness of the standard platform to plug-in external modules,
- A dynamic model satisfying CIM standards,
- Compatibility with all generic formats asked by TSOs (Eurostag, PSS-E, UCTE, CIM, etc.) providing tools for conversion,
- Internal format of iTesla with the possibility to have user-defined models and a proposed set of generic models,
- All functionalities integrated in the same platform but where the algorithms used could be from different tools,
- Unique platform for all parties and for any time horizon from D-2 to real time operation. .

We refer to part 3.1.2 for further details on those aspects.

3.5.3. Expectations beyond the iTesla prototype:

The TSOs mentioned the will of a tool covering larger time horizons.

4. RISK BASED APPROACH

4.1. Contingency analysis

Guidelines for contingency classification and operational security management in Europe are provided by ENTSO-E Operation Handbook (Appendix 3 operational security). In particular, *normal* and *exceptional and out of range* contingencies are distinguished. These contingencies are considered by a TSO depending on its own risk assessment policy. It is worth recalling for instance that busbar trip is encompassed within exceptional contingencies.

4.1.1. Current status

A **contingency** is defined as the unforeseen trip of equipment such as transmission elements or generating units. Contingencies are referred to as N-1 in case of the loss of a single power element (transmission or generation), N-k in case k elements are simultaneously lost.

Transmission elements considered for contingencies are overhead lines (single and double circuit) and cables, conventional transformers and phase shifting transformers (PST), shunt devices. Busbars are explicitly mentioned in some of the answers.
The type of fault causing the outage is specified in some answers. In particular, single-phase and three-phase short circuits are considered for lines.
Probability is an integral part of the definition of contingency in one answer.

Contingency lists include all **N-1** contingencies (lines, generation) and some **N-k** events according to different criteria. Examples are:

- Double circuit line simultaneous fault (one TSO specifies this case is considered only if the lines share the towers for a minimum length; another TSO considers this type of contingencies only in case of severe weather conditions; other TSOs consider them in any situation)
- N-2 line contingencies for specific, known critical cases
- N-2 of generator and grid element in the vicinity
- N-1-1 contingencies consisting of one fault, re-closure, and a new fault

The set of analysed contingencies generally includes events in the external grid (i.e. the grid the TSO does not control, but is interconnected to), which might affect its own grid. These events are defined between the involved TSOs.
Contingency lists are generally predefined by experts at the control centre, and manually maintained. They are updated every time there is some significant change in the grid model.
The list of contingencies is generally the same in different stages of power system management, i.e. real time, D, D-1 and D-2. However, different lists for off-line and real-time tools are also adopted. In one case it is pointed out that generation contingency is analysed in D-1 in order to safeguard against plant losses in real time.

The **operational limits** following a contingency reflect the different practices by the TSOs. For instance, in EHV, different violation thresholds may be associated with the time limits before disconnections (20 min, 10 min, 5 min, 1 min). Preventive actions may be prescribed when N-1 overloads are larger than a threshold, e.g. 120%. Generally, circuit ratings used to evaluate overloads are updated according to the season. Regarding the sequence of events, one TSO recalls that automatic reclosure is attempted three times before permanent disconnection of a faulted line. Another TSO remarks that stability is checked against contingencies including one relay failure (and one breaker failure in 380 kV network). Intertripping schemes for generation tripping following faults may also be considered.
Steady-state voltage limits are stressed by another TSO. In particular, ±6% voltage change is accepted following N-1 contingencies. The acceptable deviation increases to ±12% in case of N-2 contingencies.
One interviewed TSO explicitly acknowledges the N-2 criterion cannot be met in several cases.

For one TSO, the operator expertise and knowledge of the grid is integrated by iso-risk curves permitted in operation. It especially includes the contingencies known for having major impact.

Different ways are used to present security assessment **results**. Generally, sorting is based on contingency severity filtered by thresholds for each security problem.
For instance, one TSO's answer explains that two alternative forms of displaying results may be used. The former consists in presenting the list of violations associated to contingency, the latter in sorting the violations from the whole contingency list. Other sorting (or filtering) criteria can be superimposed to this basic alternative, e.g. by selecting results by area, then by voltage level. Voltage-based selection is a frequent feature. Sorting is eventually by severity.
In one case, results are sorted by weighting three parameters related to the values (violations) of current, voltage, and reactive power. An impacted severity index is provided in another case, which considers overloads/voltage deviation magnitude, voltage level and impacted load. All overloads are studied and remedied.
Other visualisation solutions provide contingencies sorting by outage device type. Individual contingencies or whole groups of contingencies can be activated/deactivated for analysis.

The severity of a contingency might be considered higher if the violated components are close to HV grids (especially of cities or industry districts), because of possible higher impact on the customers. However, this aspect is not considered as a sorting criterion for severity evaluation. It is implicitly considered by the operators.

Contingencies may require preventive and/or curative (corrective) **actions**. Both kinds of actions may imply a **cost**. A clear distinction should be made between costs of handling contingencies and the cost of load loss (meant as penalty cost). For instance, one TSO answered that they have to take into account the cost for not delivered energy, and to give sufficient power capacity to the market. Costs in operation are addressed in the operational policy.
Similarly, other TSOs do not consider costs of handling contingencies in operation. Cost of load loss appears an interesting indicator however. One TSO has no direct cost consideration but relies on a severity index.
One TSO explicitly states that selection of remedial actions may consider their different costs.

Preventive and/or curative actions vary according to the geographical zone and voltage level. The most important actions can be classified as follows.

Actions on the grid:
- Topology change,
- Phase Shifter setting,
- Change in reactive power production (shunts or generation),
- Maintenance scheduling delay,
- Transfer load from one substation to another,
- OHL or transformer opening (for over-voltage phenomena management);

Actions implying coordination with other TSOs:
- Bilateral support action with other TSO, e.g. change the schedule interchange flow with the neighbour TSOs,
- Cross-border capacity restriction;

Actions on generation:
- Redispatching,
- Generation forced up to Pmax or limited,
- Maintenance scheduling delay,

- Reactive power management or limitation for voltage or transient stability management – Contractual protocols actionable only for specific situations,
- Generator put in synchronous condenser mode (mainly gas turbines);

Actions on loads:

- Reduction of the voltage setpoint of some points of delivery,
- On-Load Tap Changer (OLTC) blocking,
- Contractual load shedding / load management agreement (interruptible customers),
- Frequency or under-voltage load shedding at the transmission level,
- Frequency or under-voltage load shedding at distribution level (one of the interviewed TSOs specified that the distribution load is organized in 5 levels of increasing priority: load shedding on one or several of those levels can be sent to the distributors)
- Compensation means management located distribution grids in accordance with distributors;

Actions on protection systems and automatisms

- Re-tuning of short-circuit protection relay parameters (action time vs selectivity compromise),
- Changing of thresholds of overload protection system according to risk analysis (based on local weather/wind conditions…),
- Put in operation specific automatisms to face specific or ultimate situations to avoid voltage collapse or loss of synchronism;

Actions are **prioritized** based on the principle of minimizing the consequences on customers and, secondly, activating the least costly actions. Further elements affecting the decisions are:

- Efficiency of the action (not only the efficiency to solve the initial problem but also the fact that it will not move the risk somewhere else),
- Complexity of application;

In particular, “non costly” measures such as topological actions are first considered. Curative measures are first considered when possible, prior to preventive actions. Redispatching is generally the second on the list. Internal measures are considered before cross-border actions; counter-trading or capacity curtailment comes after, while load-shedding is the last resort.

Remedial actions need to be evaluated on grid **analysis tools**. Some of the interviewed explain that simulation of the control action is integrated in the tools, i.e. the action is automatically analysed. This especially applies to the remedial actions based on automata. In several other cases, however, the control action, which is part of the knowledge of the operator, is simulated on demand.

Specific remedial actions are often defined for specific contingencies, based on studies and experience. However, actions are generally defined and prioritised based on the actual situation. Both **event- and system-based remedial actions** are scanned. **Maintenance scheduling** is one of the options (i.e. maintenance can be delayed or cancelled for system security purposes). One interviewed recalls that plans to cope for severe outages exist, and specific preventive actions can be activated in N-k conditions.

4.1.2. Expectations in iTesla

Expectations in iTesla about contingency analysis are in view of integration, flexibility, ease of use, enhancement of functionalities.

In particular, contingency lists should be easily defined and updated. iTesla should be able to handle all kinds of contingencies: three phase line faults (single phase faults should be optional), on sub-station and its different part (bus bar, coupling device, transformer), on generation. iTesla should also be able to handle complex contingencies: N-2, N-k, groups of several contingencies. The same contingency list should run for all applications.

Contingency definition, grouping, prioritisation and sorting should be user-definable.

An algorithm to select automatically the relevant contingencies should be provided. Actually, which contingency to consider and how is matter of methodology and TSOs choice. iTesla should provide technical means to do so. It is up to TSOs to agree on similar doctrines for operation. In particular, the contingency of elements of neighbouring networks should be considered. Sensitivity analyses (based on several situations such as peak, off-peak, no-wind, max-wind, etc.) should be performed in order to identify the neighbouring elements that may cause the highest impact.

Contingencies should be associated with probabilities of occurrences (several probability values for a contingency, depending on external factors such as weather conditions). Default probability values should be proposed (the simplest one is 1).

Contingency impact could be defined as a “cost”, maybe as an “absolute” cost in Euros (e.g. for lost load and generation), or maybe as a relative index (metrics) allowing to compare or classify different contingencies. Classical impact metrics such as the degree of violation, and sorting criteria such as “by voltage level”, “by violation” etc. should be maintained.

By combining probability and impact, risk indices (e.g. expected monetary cost for not delivered energy) should be defined for enhanced contingency sorting.
Geographical considerations should be applied (e.g. by mapping the results), as a contingency may locally have major impact, but not so relevant considered at the global system level.

iTesla should be able to handle lists of user-defined preventive and/or curative actions (it is up to the TSOs to define such lists, but it is not up to the iTesla consortium during the project to build up such a catalogue). These lists could be shared by partners through iTesla if wished. It should be possible to prioritize the elements of the lists, manually by the operators.
iTesla should give all the information allowing the operators to discuss the ratio efficiency/cost/complexity of the possible control measures. At minimum, iTesla should give sensitivity of the different remedies regarding a set of critical/constrained branches. It could also be nice if iTesla could allow measures efficiency assessment without pre-defined list but only based on generic description of possible means (e.g. the operator will only have to say that he wants to know the most efficient topological or redispatching measures for the violation he has to manage and the tool will automatically assess them without a pre-defined list of actions).

Preventive or curative (remedial) actions should be evaluated for all violating contingencies. Control actions should be either event based or system based. A geographic characterisation should be made of the control actions, in order to select between internal or “global” system based events (requiring TSO coordination). Remedial actions should also be characterised by timing properties (e.g. time required to become effective, effectiveness duration, probability of its failure). Remedial actions should be automatically suggested based on the severity. They should be adapted for the current situation, for each contingency. Specific user-defined actions should be allowed for special cases. Automatic actions through automata should be modelled in simulation.
Automatic procedures to maintain the “must run” list updated to the model should be considered. Maintenance scheduling should be taken into account among control solutions. Maintenance data should be considered such as devices concerned, start time, duration, end time, return of the device into exploitation, last time for postponing/cancelling. A last-time-to-decide algorithm should handle how to activate the relevant means in operation at the different timescale.

4.2. Protection schemes and cascading effects on management

4.2.1. Current status

Cascading effects are generally not taken into account. Some of the interviewed, however, refer to periodic analyses of cascading (e.g. week-ahead dynamic studies), or to measures aimed to prevent cascading, or to analyses of consequences of cascading (in terms of disconnection risk, voltage collapse, and possible solutions).

In one answer given by a TSO, the risk of cascading is explicitly mentioned as being “manually” considered. The analysis consists of checking whether the loss of any equipment in violation may trigger cascading outages. The analysis includes both the system under its own control (*Area of interest*) and the neighbouring system (*Area of observability*).
This means that cascading must not be caused either on its own controlled area or in the neighbouring one, due to loss of violated components either in its own or in a neighbouring system.

In operation, no contingency should lead to cascading effects; otherwise preventive measures are to be taken. One of the survey answers reports about **System Protection Schemes / Special Protection Schemes** being used to prevent cascading tripping. In this case both static and dynamic effects are taken into consideration. The same answer to the survey reports that the risk of **protection scheme failure** is taken care of by managing the dispatch in order to minimise the risk. Other answers report about failure of protection schemes as reported in previous section, “Contingency Analysis”, at the item “operational limits”.

4.2.2. Expectations in iTesla

iTesla should be able to automatically simulate cascading, considering static and dynamic issues. iTesla should determine control actions in order to guarantee that cascading phenomena are limited and have limited impact on the grid, in risk terms (considering probability of occurrence and impact, the latter possibly measured in real economic terms). No cascading effect should be allowed on 380 kV and 220 kV grids however. In particular, iTesla should enable specific assessment of voltage collapse and frequency collapse.

Analyses would be launched on an automatic and cyclical basis.

Protection devices, specific automatisms or Defence Plan should be modelled in iTesla, possibly also adaptive or “more intelligent” ones. Alternatively, protection system actions could be translated into simulation parameters such as fault clearing time. The potential failure of protections could be analysed in dynamic simulation, by considering it as a specific “N-1 protection device” with associated probabilities of failure (depending for instance on the age of the device). Performance and reliability of the protection system in terms of fault elimination time and selectivity should be accounted for.

4.3. Probability knowledge

4.3.1. Current status

Nearly all TSOs report to have **archives of historical data** of failure events. Specific database applications are used to store and classify them. By processing these data, indications of failure probabilities can be computed. Statistical analyses can be made by contingency, equipment type, voltage level, asset owner, location of substation (geographical area), kind of feature or function. One of the survey’s answers reports that statistics of the compliance of the protection systems with pre-defined behaviour is also available per voltage level.

Contingency probability is related to **physical sources** of events only to a limited, mostly qualitative, extent. One answer reports that contingency probability and physical sources are not systematically correlated in the statistical analyses of past events, but only analysed on request. Another answer reports about Return of Experience activity carried out after a contingency, in order to link the incident to external events (e.g. weather forecast). This activity provides warnings for future operation in case of similar conditions, but there is no formal calculation of probabilities accounting for weather conditions.

Statistical analyses of failures are directly performed by TSOs within **dedicated departments**. They evaluate and classify faults and interruptions for all components, e.g. computing yearly faults per 100 km power line. One country reports that there are several archives of power system failures (in particular, a database common to TSO and DSO, and a more detailed database internal to the TSO). It is not yet decided which data should be used to define fault statistics.

Contingency probabilities are generally **not used in operation** and in simulation, however. One answer reports that they are calculated only if requested by specific applications such as upgrading or refurbishing devices. In another case, they are used within a prototype risk assessment application for operation.

External data, such as weather (current situation and forecast), are monitored by TSOs and may affect operational decisions. Although probability of failure is often not evaluated in operation, greater readiness to emergency is provided in case of forecasted bad weather.

According to one TSO, forecast and current conditions (temperature, humidity, wind, storms, and forest fires) may be acquired in order to calculate the current probability of contingencies. Another TSO is planning to adopt different failure rates according to the weather conditions.

Based on a more qualitative approach, another TSO simulates some N-2 contingencies only in case of (current or expected) bad weather conditions. Another simplified approach consists of assigning different probability levels of N-2 contingencies, according to a good/bad weather classification. Weather forecast may be used to postpone or cancel planned maintenance.

In one case a subjective evaluation of the probability of overloading of cross-sections (tie-lines, corridors) is performed, together with relevant consequences. This serves for the evaluation of compliance with the TSO operational policy which considers as acceptable the following situations:

- Loss of load of max 200 MW for 1 h with intact system,
- Loss of load of max 500 MW for 2 h when part of the system is already out as a consequence of a fault or due to maintenance.

Security analyses are updated according to the forecast, generally by manual action. Time horizons may be up to 4 hours ahead or referred to the day ahead (maximum 2 days ahead). Load and generation forecasts are taken into account. PV and wind generation forecasts may also be considered. Temperatures may be taken into account only if the forecast is far from seasonal averages. Security analyses may be performed only at the predefined time scales unless large disturbances are detected; in this case new analyses are carried out.

One of the survey answers points out that some data could have big uncertainty even in D-1 and intraday activity. Therefore, based on the stress of the system and estimated level of uncertainty, additional variants are performed to give an idea about potential additional risks and means to manage them. This is fully manual. A tool is able to monitor the evolution of the assumptions on the main impacting data; some triggers for reassessment have been defined in case of strong deviation of the assumption compared to the last study which could lead to unacceptable additional stress.

Maintenance activities are managed by dedicated tools. Security analysis tools are updated accordingly, generally by manual intervention. Semi-automated or automated processes are also available at some TSOs, however.

Probability of failure of remedial actions are generally not considered, or qualitatively accounted for based on operator experience.

4.3.2. Expectations in iTesla

Probabilities of contingencies should be considered by iTesla. In particular iTesla should host, but not compute, probabilities (few exceptions among respondents on this point). For instance, iTesla should allow access to a database to retrieve the probability of each contingency, for each period (D-2, D-1, H-1, etc.).

In fact computation of probabilities is a task of the TSO, and it is up to the TSOs whether to share them or not. To this aim, a shared form to be used by all TSOs to report outages and faults could be agreed (e.g. including physical source of contingencies as well as particularly exposed geographical locations).
A set of standard probabilities, defined by category and possibly by country, could be introduced and used on request of the operator. iTesla should be able to automatically define the list of contingencies based on a given threshold of probability of occurrence.

Probabilities of failure of the remedial actions should be considered, however the analysis functions should be able to run also without these data.

External data such as weather forecast should also be made accessible to iTesla in order to re-evaluate contingency risk each time new forecasts are provided.

Alternatively, in order to monitor some risk levels in operation, iTesla should be able to receive some weather warnings and alerts highlighting the geographical area concerned and the contingencies potentially impacted.

Maintenance management is excluded from iTesla scope as it regards TSO internal business. Maintenance schedule should be accounted for in some way. However iTesla should be able to handle such data in input. If this import of data is automatic, the link between TSOs maintenance tools and the iTesla platform should not be too strong.

iTesla should allow automatic consideration of variants allowing to define the confidence range on the level of security/stress of the grid. Output of this automatic consideration of variants should be the envelope of the grid states (in other words, all the possible scenarios) under a given level of risk (i.e. confidence interval). At the end, iTesla should not only give a statement on a grid situation (deterministic approach) but also give a feasibility domain with information about the probability of occurrence of each state of this domain (i.e. a kind of probabilistic approach).

4.3.3. Expectations beyond iTesla prototype:

Even if it is out of the scope of the iTesla project, some partners mentioned the possibility of computing the probabilities of contingencies by the platform.

4.4. Impact Analysis

4.4.1. Current status

The **impact** of contingencies is evaluated in different ways also depending on the operational context. Consequently, there are several approaches and interpretations for the concept of impact. The loss of load / generation and grid overloads are typical indicators of impact in evaluations performed for current day as well as for D-1 and D-2. Other **cost** impact measures mentioned in the survey answers are the cost of running expensive plants to secure locally a grid, as well as (automatic) generation tripping and generation drop. In ex-post analyses it is possible to assess the specific costs of some measures (e.g. emergency decrease of nuclear power plant due to overload of critical corridor).

Generally, specific impacts are considered manually by the operators (media impacts, ancillary services costs etc.) but no specific model is implemented in the tools e.g. in terms of optimisation applications.

As already mentioned, **maintenance** can be modified according to security analysis results. Some maintenance activities can be easily delayed without major cost as it depends on the TSO, for other it is harder (especially if third parties such as producers are involved). The opportunity to postpone a maintenance operation is manually considered by operators, and its effectiveness/efficiency can be tested in simulation on demand. The decision is not automatically suggested by the operational tools. Maintenance scheduling flexibility may be used in particular as a remedy to overloads. Costs of rescheduling are weighed against cost of other remedial actions to make decisions (e.g. redispatching).

4.4.2. Expectations in iTesla

Impact and risk assessment should be part of iTesla approach.

Risk assessment should be kept updated over a time window from D-2 to D. It is worthwhile to be noticed that the risk associated with an action may vary depending on the fact it is used as a preventive or a curative action.

iTesla should be able to compute stress and risk level.
Stress means the general loading of the system (how the system is close to, or exceeding, static and dynamic limits); Risk means what could be the consequence of not being able to maintain the system within its limits.

Risk computation could differ depending on the tracked issues, TSOs, perimeter…

4.4.3. Expectations beyond the iTesla prototype:

During the risk assessment process, it could be interesting to take automatically into account maintenance data, but this is probably not a priority requirement in the development of the platform.

4.5. Severity scale

4.5.1. Current status

ENTSO-E severity scale principles are known by some TSOs, practical implementation is still an issue.
Other TSOs have their own severity scale. For instance for a TSO, under severe plant shortages, warnings are issued based on a colour code (red, amber, yellow) according to the risk of load shedding. Another colour scale refers to the degree of need for specific coordination and risk that system becomes not N-1 compliant.
Risk metrics for operation are based on load flow results (in terms of amount of overload and indicators of impact/risk). Severity scales are also defined in incident analyses (offline). Within the risk assessment prototype being implemented at one TSO, severity of each contingency is evaluated based on security weights and/or cost of load/generation lost. The historical results obtained by the risk assessment prototype provide a sort of benchmark for the severity scale (the severity indices resulting from a security analysis are compared with the ones obtained by the analyses performed during the last year).

It is difficult to establish a clear and objective **severity scale** which can be applied and understood in the same way by everybody, including different TSOs with different operational principles. TSO coordination entities are going to work on this point.

Iso-risk curves are reported to be known but they are not integrated in the real-time tools. Compliance with them is up to the TSO operators.

4.5.2. Expectations in iTesla

iTesla has to work with severity and risk scale in order to be used for risk assessment and optimization of remedial actions. Comparison of the efficiency of different solutions is particularly interesting. In this regard it is important to have a common scale to measure the efficiency/effectiveness of remedies.

Existing severity/gravity scales should be investigated in order to establish the iTesla ones. In particular, the ENTSO-E severity scale should be analyzed. It is recommended that any adopted scale should be compliant with ENTSO-E regulations. On the other hand, iTesla should provide flexibility for additional TSO-specified metrics (possibly plugged-in as external modules), because (a) the severity scale is related to the definition of (acceptable) risk adopted by each TSO, and (b) a TSO might want to use a more severe scale than the one defined by ENTSO-E. The severity scale might also be different depending on the issues of concern (e.g. the TSOs, the perimeter).

Results should be presented in a clear graphical way e.g. by color indications (green, orange and red) and/or indices (1 to 10). These results should express the severity (i.e. refer to impact alone, before application of probabilities). It should then be possible to evaluate risk indices associated to such severity by combining the latter with probability of contingency occurrence (possibly dependent on external alerts such as weather, etc.).
Relative severity indices (risk parameter) should also be presented. National and local severity indexes relevant at those scales could be introduced.

4.6. Specific risk assessment on crossborder capacities

4.6.1. Current status

Specific security analyses may be adopted **for cross border/interconnection** perimeters. Security levels are the same as with internal lines however. Reference is ENTSO-E Operation Handbook, Policy 3.

The **impact of control actions on NTC**[1] is taken into account with different approaches. One survey answer, for instance, states that the NTC value published in the market operator (and validated on D-2) is the limit value of capacity during the remedial actions. Other answers, on the other hand, state that actions must not affect the values of cross-border capacity given to the market; otherwise, reduction of given capacities should be applied, which is not possible (or at least difficult or costly) for the already allocated/ nominated capacity and market impacting for the remaining one.

Specific preventive or remedial actions to secure and maintain cross border capacities are set out by some TSOs (e.g. Automatic Grid Splitting Scheme, Automatic Generator Tripping Scheme; use of PST).

In order to **maximise cross border capacities** through coordination, models are exchanged between TSOs. In particular, within the current activity of CWE[2] market coupling, optimisation is pursued through actions performed in D-2, namely PST coordination and merging of common base case. Optimisation is also pursued through coordinating cross-border limiting outages on the grid with neighbouring countries (not to aggravate the situation by a combination of these outages at the same time).

4.6.2. Expectations in iTesla

In principle there is no need to consider differences in the management between lines, whatever cross-border or internal. The only difference is that cross-border lines have to fulfil the minimum limits according to two TSOs. In order to achieve higher flexibility, however, it should be possible to specifically analyse and to assign different security criteria to the interconnections.
Cross-border capacity should be taken into account in the analyses and in the proposed actions. When assessing the efficiency of remedies, it should be ensured (as far as possible) that the already proposed/allocated/nominated NTCs are feasible. Conversely, it should be possible to identify remedial actions to maintain the NTC value.

4.6.3. Expectations beyond the iTesla prototype:

iTesla could also be the tool allowing computation of cross-border capacities and flow-based parameters.

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[1] Net transfer Capacity (NTC). The maximum exchange program, which can be realized taking into account the N-1 SECURITY PRINCIPLE and uncertainties (Ref. ENTSO-E Operation Handbook - Policy 4: Coordinated Operational Planning).
[2] Central Western European Market Coupling.

5. EXTERNAL COORDINATION

5.1. Current status

All TSOs have operational contacts with their neighbours at a different level. They can be through operating agreements on a bilateral or multilateral basis. Regular phone conferences on different time scales (weekly to day-ahead) are organized between some TSOs and occasional contacts on request for others allow solving specific issues, mostly regarding transfer capacity reduction.

Some entities are members of a centralized regional coordination structure (Coreso) while others are directly dealing with the neighbouring TSOs. According to their relative geographical position, TSOs don't have the same needs in terms of coordination. TSOs that are highly meshed with their neighbours will use daily coordination to solve detected constraints whereas isolated TSOs will mainly coordinate on demand on specific issues. Regional procedures were implemented between TSOs for close coordination such as the CWE PST coordination or the pentalateral reduction concerning the Italian border.

For all TSOs, coordination is effective, at least on a bilateral mode, regarding capacities management. A coordination center can facilitate the discussion between TSOs from D-2 till 1hour before real time. The outputs of the coordination process can be a trigger for the decision making process. TSOs will take into consideration warnings or advice emitted by the coordination center. Coordinated actions are usually simulated by a TSO with its own tools before implementation. The final decision remains at TSO level.

Confidentiality is not an issue raised by answering entities. A Coordination center has a contract with TSOs which guarantee that confidentiality rules are respected. Some dedicated common tools are used to share information between TSOs.

Exchange of data between TSOs is fundamental for grid management. Ahead coordination is based on security analysis results calculated from congestion forecast files (currently UCT format, CIM in the future) exchanged between all TSOs. These files contain the best forecast data (load, renewable energies, generation pattern, outages...) at the TSO's disposal. This input is sometimes completed with exchange of real-time data (snapshots every 15 minutes or distance measures (TASE2)). Centralized coordination centers also provide the participating TSOs with reports containing relevant information regarding cross-border areas management.

Data used for coordination are the same as data used in operational planning and TSOs use the same tools for the coordination process, or to validate a request from a neighbouring TSO as for their operational process.

5.2. Expectations in iTesla

The toolbox developed in the iTesla project should provide a common ground for all TSOs to perform security analyses on the pan-European grid. Existing or new coordination instances could also make use of this central application to perform their studies.

In case stressful situations are detected, the iTesla toolbox should provide the means to perform a ranking between possible coordinated remedial actions, based upon a rigorous risk assessment system. The toolbox can also support the decision making process on one hand, and the validation and reporting of the chosen actions when the decision has been taken on the other hand.

It is stressed that to allow an efficient coordination process, data exchange should be supported by a common, standardized format; preferably the existing CIM format. The question remains whether the iTesla toolbox should be simply a combination of calculation tools or also a database where detailed individual and merged grid models and registers of planned remedial actions are stored.

In the light of the latter option, iTesla could provide a full-fledged pan-European data handling: collecting all individual TSO grid models (congestion forecasts), merging these to a single pan-European common grid model, running security analysis on this model, initiating and facilitating coordination of the results of this analysis, sharing the same data and registering validated remedial actions.

The new devices being installed on the grid such as HVDC links, smart grids devices, and a massive scale of renewables will require more and more coordination, especially between areas not used to this due to not being interconnected so far.

Detailed grid information should therefore be provided by as many TSOs as possible to allow a qualitative representation of the pan-European grid. It should be kept in mind that confidentiality issues have to be tackled as much and soon as possible, to avoid a lack of data impairing the usability of a common iTesla toolbox.

5.2.1. Expectations beyond the iTesla prototype:

Several TSOs also propose that the iTesla toolbox could facilitate the coordination of exchange capacities, taking eventual cross-border redispatching into account.

6. DATA AND TOOLS:

6.1. Data sourcing:

6.1.1. Data organization

6.1.1.1. Current status

Data standards:

The most used formats and standards for internal and external tasks are:

- Proprietary formats,
- PSS/E,
- UCTE DEF,
- Eurostag,
- CIM/XML for model data,
- And also ELCOM 90, ASPEN, CAPE,
- Spread sheets, plain ASCII files are also in use (e.g. for forecast data, internal storage …).

Snapshots and forecast data collection:

SCADA system is either absent, or linked with automatic extraction in PSS/E, UCTE DEF, CIM/XML.

Data from the SCADA system (when present) is imported in either proprietary format, or PSS/E, ELCOM. In some cases, it is made through TASE2 protocol. Eurostag format can be used to export data to the Eurostag simulation platform.

State estimations are produced and stored with a frequency that usually ranges from every 5min to every hour.

Most of the update processes are manual. Some SCADA data imports are automatic and scheduled.

Model data size ranges from a few Mb to hundreds of Mb. State estimations/simulations are each of an order of 10Mb. With an every 5min frequency, that can yield to Terabytes of data per year.

Load and production forecasts are used in day-ahead planning.

Weather forecasts are mostly used for renewable generation forecasts (wind farms), as are demand forecasts and also risks forecasts (these also involve other natural hazard forecasts such as wild fires, storms …)

External data collection:

Real-time measurements, schedules and DACF data from neighboring countries are imported from external sources, using ICCP/TASE2, the Vulcanus platform or proprietary protocols.

Data is exchanged using PSS/E, UCTE DEF or proprietary formats.

Weather data (current and forecasted) is used for production (wind farms), load/demand forecasts, and for risks assessments.

The collected external data (like neighboring DACF data) is stored separately but usually merged with internal data for the sake of simulations/forecasts.

UCTE DEF and CIM/XML (when used) are mostly used to exchange data with external parties.

6.1.1.2. Expectations in iTesla

iTesla should have its own rich internal model, and rely on CIM as much as possible for external exchanges.

Other formats of interest for interoperability include UCTE DEF, PSS/E, and Modelica to cope with CIM limitations in dynamic modeling.

All of iTesla internal data storage should be in databases. In terms of volume of stored data, iTesla should be able to cope with hundreds of Gb per day.

iTesla should provide a plug-in framework, where external plug-in can be added and have access to data and processes of iTesla.
Likewise, a converter framework to add extra adhoc converters should be available.

The iTesla platform should have entry points to import external data in its internal model and database, for later reuse by the various tools of the platform.
Some data is required to be imported in real time, while other datasets must be storable in long-term storage solutions. Regular automatic updates should then be possible.

A standard format/model for various forecast datasets should be devised, if not already available. That format should be supported for import in the iTesla platform.

6.1.2. Data quality, missing data:

6.1.2.1. Current status

Quality of model:
Model data mostly undergoes manual assessment and maintenance.

Quality of data:
When data is missing or likely false, it can be replaced with:

- Previous data,
- Forecast or extrapolated data,
- Data inferred from measuring redundancy.

Simulation data is validated a posteriori, either automatically or manually, to assess the quality of models and data acquisition.

6.1.2.2. Expectations in iTesla

A library of typical values should be available for missing values replacement.
The system should provide quality indicators to flag missing/unreliable data, to notify the owner and to describe results reliability. This is important to be able to delegate to data owners the responsibility to provide quality data.
Quality validation should be an automated process.

6.1.3. Data generation for calculation tools:

6.1.3.1. Current status

Various converters are used to transform internally stored data (usually from databases) into tools-supported formats (e.g. Eurostag, PSS/E …).
Various tools require various input formats, including non-standard ones, thereby requiring extensible and configurable conversion mechanisms.
Furthermore, dynamic models require specific “home made” formats, since required data is out of the band of some regular formats.

6.1.3.2. Expectations in iTesla

iTesla should be built with a pivot model/format that offers all expressivity needed to represent all the data structures involved.

Converters, plugged within a dedicated extensible framework, should provide conversion to the various formats required by the tools.

Likewise, similar converters should be able to bring input data into the iTesla internal model.

Those converters could be private modules.

6.2. Power system modeling:

6.2.1. Current status

The different TSOs have in general a full bus-branch representation of their complete system. In most cases, a more detailed node-breaker model is available as well. However, the detailed representation is only used for specific calculations. For INTER-TSO data exchanged, the detailed node-breaker topology is expected in the future but at the moment the bus-branch topology is exchanged. In general the TSOs have the static and compatible dynamical models for the electrical devices present in their network, although sometimes dynamic models of some specific devices are not available. However, most of the TSOs have to run carry out for specific studies including specific devices with a level of detail not supported by the current formats; in order to have a convenient level of modeling, they use models from libraries provided by their tools. Sometimes these tools are flexible enough to allow definition of new models: for example, it is possible to design new regulation models in EUROSTAG. In the case of INTER-TSO the data are limited to the UCTE-DEF format but in the near future additional data (CIM-XML) could be handled.

6.2.2. Expectations in iTesla

The expectation of the iTesla TSOs is that the available description of system should be as detailed as possible. The simulation tools should be adapted to handle these data, or should be able to extract the needed data from the full data set. It is also expected that the possibility exists to merge or extract data of a specific geographical area or voltage level. The results should be shown on a single line diagram as close as possible to the TSOs traditional schemes. The TSOs expect that iTesla makes a contribution to remedy the problem of missing data. The iTesla toolbox could propose default set of parameters, models and regulations to be used for missing data, together with aggregate models for wind and PV generation.

Most TSOs are doing some kind of model validation. The models used for the different equipment are validated during the phases of purchase and connection of the equipment against measures. TSOs are regularly validating the models against major disturbance measurements, mostly for specific project/study/devices. However validations methods may vary from one TSO to another one. The limitation and difficulty is to be able to reproduce the correct load and generation pattern for the given instant of the incident together to have a good representation of the neighboring networks. Most of the TSOs do not validate large scale power systems model. PMU measurement data is used in offline validation when available.

The TSOs expect a model validation/parameterization based on real-time or PMUs measurements. Ideally iTesla would propose a procedure to validate automatically the model based on real-time or PMU based measurement with an indicator of the model quality for each equipment.

6.3. Simulation tools

6.3.1. Available tools

6.3.1.1. Current Status

TSOs are using a variety of simulation tools; some of them are integrated in the SCADA systems. Other tools are external and use data provided by SCADA systems in input.

The following table summarizes the tools listed by the respondents:

Tool/Platform	**Number of different companies using the tool:**	**Functionality specified by respondent**	**Comments**
Convergence Platform	2	• Optimal power Flow • Static Load Flow • Short Circuit Analysis • Slow Dynamic simulation • State Estimation	In-house tool developed by one of the responding TSOs
Eurostag	3	Fast Dynamic Simulation	Developed by RTE and Tractebel
PSA	1		
PAS	1		By Siemens or ABB
ASTRE	1	Slow dynamic simulation	Part of Convergence
COURCIRC	1	Short Circuit Analysis	Part of Convergence
SPIDER EMS/Aristo	1	• Dispatch Power Flow • Security Analysis • Short Circuit Analysis • Terminal Security Analysis • Voltage Collapse Analysis	
ASPEN	1	•	
CAPE	1	•	

In general most of the TSOs have tools developed by external parties or vendors, with the exception of one respondent that develops most of the tools in-house. In General, those TSOs that have external tools have agreements for maintenance and customizations. There was little explicit response on ease of tool evolution. Some TSOs can control this, especially those that have strong agreements or in house development. For certain studies the scenarios / scripts are developed in-house for some TSOs.

Most respondent have listed several limitations of their current tools as well as missing/incomplete functionalities. Prevalent in the responses, is the inability to perform effective dynamic simulations, and risk assessment associated with such dynamic behavior. Other general observations is ineffective or incomplete data required to modeling and analysis, i.e. either data regarding details of neighboring systems or imprecise data from the own system (in the case of modeling for example: nodal level models, while in the case of measurements for used in studies, then imprecise measurements from old devices). Furthermore functionality to import/export data or models in common formats is missing, for example in the case of CIM/XML import.
Other limitations or missing functionalities include unbalanced studies and modeling of specific devices such as HVDC lines or FACTS.

Some interesting concepts that can be translated to requirements can be extracted from respondents, but are open to subjective interpretation. For example respondents have pointed out concepts such as “Robustness of Simulation” or “timeline” in the simulation system. These could also be a valuable input if elaborated.

6.3.1.2. Expectations in iTesla

Fast dynamic assessment is required. iTesla should be interoperable with other fast dynamic simulators, i.e. offer interface to other simulators so that they can be used as modules. Same applies for static load and slow dynamic tools and optimizers.

iTesla should be able to run offline and online optimizations. Finally, it is expected from iTesla to offer a shared optimization runtime.

From the responses, iTesla is expected to be a platform which is open so that extensions can be developed and experiences can be shared. The issue related to maintenance of openness of modules developed during and after iTesla prototype was made explicit by one respondent. Basically that modules developed during the iTesla project will be open to everybody.

6.3.1.3. Expectations beyond the iTesla prototype:

Sharing modules after iTesla should be optional for those that will be privately developed.

6.3.2. Supported remedial actions

6.3.2.1. Current Status

In general all respondents have some sort of remedial or contingency lists, some of which are automatically taken into account other which are taken into account manually by operators based on experience. Events are usually mostly sorted by severity.

Common remedial actions that respondents have outlined:

- Post Fault actions
- N-K actions
  - On generation
  - On line
  - On substation level
- OLTC, phaseshifter, SVCs, HVDC
- Manual actions not in tools e.g.
  - Topology actions
  - Redispatching measures

6.3.2.2. Expectations in iTesla

Risk based approach should be a feature provided by iTesla, furthermore iTesla should also consider remedial actions automatically.

6.3.3. Data compatibility between the different tools

6.3.3.1. Current Status

In general respondents have indicated that real time data compatibility is usually one way: data from the real time system can be imported in the offline external system; but offline EMS calculation tools outputs cannot be transferred back to the real time system. This is the general case for tools such as PSA/Eurostag/PSS-E tools. In some particular cases this is not possible, for example one respondent pointed out that they could not transfer a real time situation of the grid to external tools such as PSS/E and

Aristo. For example compatibility problems even exist on the mapping between the EMS/SCADA and PSS/E, due to line numbering limitations.
Other respondents have a common mapping between some of their tools, either by using mapping tables or by using the same interface for communication with their common object model interface.

6.3.3.2. Expectations in iTesla

Based on the fact that compatibility problems do exist, one expectation from iTesla is that it makes it easier to manage compatibility issues. Specifically for example mapping data formats between tools should be easier with reasonable maintenance efforts. The use of universal identifiers (i.e. ids/keys/ permanent links) for data sources/ devices/ is recommended. Modules developed in iTesla should have to conform to a common standard for exchange and modeling. iTesla should provide conversions for common main formats required by TSOs.

6.3.3.3. Expectations beyond the iTesla project:

A full resolution of compatibility issues would be a plus, but it induces a huge amount of work.

6.3.4. Observability of neighboring TSOs:

6.3.4.1. Current Status

TSO's observability of neighboring systems varies. In two cases, there is limited observability of neighboring systems. In one case, it is restricted to DC link operation; while in the other case there is poor observability and little real time measurements from neighboring systems. For two other cases, observability is sufficient. For some TSOs, it is the border substation of neighbours that they can observe, but one believe this cannot be further improved with more inputs due to the simplified models they have utilized to represent them. For one TSO, each external element that can significantly (above a threshold) influence internal flows when lost (mainly the two first substations and related lines as well as main parallel international path, i.e. the France-Germany interconnection) are monitored in real-time.
Two TSOs use TASE 2 protocol for exchange of information with other control centers (it is possible that other TSOs do the same but they have not mentioned it). Coreso's observability depends on its stakeholders: they regularly receive D2CF, DACF and snapshots from their stakeholders; they also have viewer functionality in stakeholders' SCADAs (through the TASE 2 exchange mentioned). What to observe in the stakeholders' systems is based on experience rather than on a sensitivity analysis. This is in contrast with another TSO that determined neighbor's observability requirements based on a sensitivity analysis.

All respondents agree on a general need for increased shared monitoring, basically because neighboring grids could have a great impact on home grids. Other TSOs have specifically indicated that increased monitoring is needed mostly for the coordination level, or to some end such as emergency assistance needs via DC links.
Most respondents agree that there should be more shared monitoring, and most have some sort of initiative to increase shared monitoring, Coreso has initiative with other TSC and ENSTO-E to collaborate. One TSO also has some initiative with neighboring TSOs to import complete CIM based neighboring systems into theirs. Two TSOs see no need for shared monitoring on a national level. One TSO believes that increased shared monitoring may decrease overall system performance of the SCADA/EMS, and prefers the use of DACF.
From collected answers, it seems there are different interpretations to "Shared Monitoring", most have assumed neighbor observability but some have assumed share monitoring on national level. This concept of monitoring needs to be clearly defined in the next steps of this project.

6.3.4.2. Expectations in iTesla

Respondents expect from iTesla to facilitate observability; some respondents expect neighboring systems to be observable through the iTesla toolbox. One TSO pointed out an interesting functionality that could be useful for iTesla: based on a sensitivity analysis, the iTesla toolbox could automatically define the needed observability area and the needed level of modeling.

One TSO mentions that if iTesla considers all network of ENTSO-e for security evaluation this can solve the problem of observability of the neighbor TSO for security evaluation.

7. DEFENSE PLAN AND RESTORATION

7.1. Definition

7.1.1. Framework for defense plan development

7.1.1.1. Current situation

Each TSO develops his own defense plan in line with the existing national regulatory framework. Policy 5 of ENSTO-e is also used during the development of the defense plan.

7.1.1.2. Contingencies taken into account

Each of the TSOs take under frequency collapse, loss of synchronism and voltage collapse into account during the development of their defense plan. Also multiple contingencies are sometimes taken into account, but these are often not listed. These combinations of contingencies are per definition worse than those taken into account in any system analysis. During the development of a protection scheme for this combination of contingencies usually an ad hoc method is used. The reason is that usually the cases are very case specific as well as their consequences.
Other (specific) contingencies that are often taken into account are loss of an important corridor to the grid of a neighboring TSO, a fault combined with an out of service (OOS) of a tie line and overloading.

7.1.1.3. Expectations in iTesla

A common European framework containing development of defense plans would be desirable. Also a feature to simulate the defense plan on the complete ENTSO-e network, instead of on the own grid and a limited external zone of the neighboring TSO, could give a new insight to the impact of the defense plan on the degrading system.

7.1.2. Phenomenon and control schemes

For specific phenomena that can occur on the grid different control schemes have been designed. Some of these schemes are triggered by the event itself (event based) and others are triggered by the systems response on the event (non event based). Both types of triggers are used for the system protection schemes in the relevant grids. Some control measures are not being automated and are started manually. This can be the case for slow evolving phenomena where the dispatcher interacts (e.g. adjustment of the voltage set point). Also OLTC blocking is mainly activated manually.

7.1.2.1. Loss of synchronism

In the case of loss of synchronism, ring opening and grid separation are the solutions that are usually considered.

7.1.2.2. Frequency collapse

In order to stop a frequency collapse, load shedding is generally used by all TSOs. When comparing the different load shedding schemes, it should be noted that each TSO uses different set points. For example one TSO has his under frequency load shedding trigger set to 49Hz, while a neighboring TSO has his trigger set to 48.5Hz. Also the number of load shedding steps, the delays and the amount of load shed in each step are often set to a different value.

7.1.2.3. Voltage collapse

In the case of potential voltage instability, usually the first thing that is being done is injecting more reactive power. This can be done by adjusting the set point of the active generators and by switching on all capacitor banks. Generation re-scheduling could also be made in cases where main generation production is away from main load centers. The use of OLTCs (On Load Tap Changers) is also common. Blocking the OLTCs in an appropriate context could also prevent from voltage collapses.

In the case that these control strategies did not succeed in stabilizing the voltage, regional shedding of load is applied automatically or not.

7.1.2.4. Overload

When an overhead line is overloaded, special control schemes using generation redispatching to relieve overload are used. Loading beyond the circuit ratings is also allowed for a short duration, this gives the opportunity to shift generation. In case of severe overload, tripping of load and/or generation is also applied.

7.1.2.5. Slow phenomena

In case of slow phenomena and the beginning of voltage collapse, the voltage set point can be lowered to minus 5% nominal voltage set point. The next step is the blocking of the OLTCs to stop the decay of the backbone of the grid. The final step that is considered to stabilize the system is load shedding.

7.1.2.6. Expectations iTesla

iTesla should provide a tool to coordinate the design of system protection schemes between different TSOs. Also recommendations on the use of renewables in defense plans should be determined. So the renewable generation will displace conventional controllable generation to the minimum which is required to ensure the system security. Renewables can have a positive effect in case of over and under frequency situations, but further research is required. A final expectation is the use of PMU's (Phasor Measuring Units) in defense plans. PMU's can give a wide area view on the electricity grid in contrast to the local measurements used today. Based on the data collected by the PMU's methods should be developed that give early warnings to system operators when critical conditions arise. Based on this data also new protection scheme methodologies should be developed that will reduce the effect of the contingency taking place.

7.1.3. Validation of the defense plan

Each TSO simulates all the contingencies considered in the defense plan in off line mode. The complete defense plan is being verified during dispatch training.

7.2. Data

7.2.1. Data used in simulations

7.2.1.1. Current situation

During the simulations to validate the defense plans the TSO uses real time data of his own grid. The neighboring grid is taken into account by modeling the external system based on external data (from the neighboring TSO). The models being used during off line and on line simulation are different but the input data remains the same.

Forecasted data (market and meteorology) are provided in a wide variety of formats (xls, ascii, Oracle, MySql...)

7.2.1.2. Expectation iTesla

Tools developed in iTesla should support all relevant data formats to input data models and forecast data. In general, a pooling of data and more real-time measurements from neighboring TSOs are preferable.

7.2.2. Data Models in Simulations

7.2.2.1. Current situation:

The data models used in simulation may be different, using different data formats. In general different models are used for on-line and for off-line simulations, but the data (extracted from real time) may be the same.

7.2.2.2. Expectations for iTesla

The support for a wide range of relevant formats is also expected in this context.

7.2.3. Historic data

7.2.3.1. Current situation

Some TSOs use historic data of SCADA measurements to validate their defense plans during offline simulation, others do not. It usually depends on the availability of such data. If a TSO encountered any major disturbances in the past, he usually includes these in his simulations.

7.2.3.2. Expectations for iTesla

All of the TSOs consider that simulations based on historic data can have an added value, as they can give new insight and diminish the impact of the same event. Therefore it would be useful that there would be a feature that could record dynamic disturbances and to input this historic data to simulate these events. This data concerning historic events should also be more easily accessible.

7.3. Coordination

Coordination between neighboring TSO's is detected as a general need, and several coordination initiatives are already established on a regular basis and/or under way.

7.3.1. Coordination between TSOs during execution of defense and restoration plan

7.3.1.1. Current situation

Some TSOs already have significant coordination during defense and restoration plan execution.
Others are considering better cooperation. Usually common action is agreed by using the usual communication links and the congestions and security management procedures.

7.3.1.2. Expectation for iTesla

Some input on agreed coordinated actions obtained as output of the Defense Plans and Restoration Work package.

7.3.2. Common training with other TSOs

7.3.2.1. Current situation

Some neighboring TSOs have common training (for example on yearly basis) and undertake exercises regularly to ensure familiarity with emergency procedures in conjunction with other involved companies. Others have almost none. In some cases these meetings are used to validate common Defense and Restoration plans.
For most of them there is no formal and regular training with neighboring TSOs. Though some have had or are organizing training sessions in cooperation with a neighboring TSO.

7.3.2.2. Expectation for iTesla

More regular training sessions with more TSOs is preferable. ITesla tools should provide a preferred framework and a common platform for such training sessions. This should facilitate decision making on the European level.

8. CONCLUSION

In this synthesis, TSOs express some key requirements for security assessment.

8.1. Working at a European level

More coordination at a European level is necessary. iTesla should propose a common ground for pan-European studies, through merged data provided by TSOs and stored in a common database.
As a consequence, the study of specific constraints related to crossboarder lines and their associated actions should be possible, so as cascading effects impacting several TSOs. iTesla should also facilitate the study of new devices such as DC lines and integration of massive amounts of renewables. Coordinated remedial or preventive actions could then be elaborated using the iTesla toolbox. It should allow having a common European framework containing development of defense plans.

8.2. An open platform

In order to be used by a large number of users, partners should be able to easily import the data to be assessed. iTesla should adapt as much as possible to the existing exchange formats. TSOs agree that the CIM format should play a major role in the definition of static data. iTesla should be flexible enough to accept input data not contained in the CIM format. A common conversion module should then be developed to do so.
The platform is also expected to accept “user defined” models in an open format in order to allow the modeling of specific and new devices. Design, validation and improvement of common models could then be facilitated.
The partners also expect openness to plug in their own modules. Clear interfaces need to be defined to be able to launch private computation modules.
It is also expected to have easy access to the platform’s outputs; results should be clear and easily understandable.

8.3. Risk assessment and probabilistic approach

iTesla should be able to deal with probabilities associated to contingencies defined by users in input. Probabilities of failure of curative actions should also be taken into account for an appropriate evaluation of risks. The concepts of impact, severity scales and security rules have to be defined and used properly for a consistent assessment of the risk in security analysis.

8.4. Dynamic security analysis

Up to now, TSOs are able to deal with dynamic issues but only a few are able to do it close to real time. For those able to do so, tools used in planning and close to real time operation are generally not compatible leading to additional issues. Continuous dynamic security analysis with a common tool should definitely be a plus to all partners. TSOs expect in output some help on curative and preventive actions, in accordance with the different time frames of studies (D, D-1 and D-2).
Accurate dynamic simulations are expected in particular for grids involving new power system devices such as DC lines, renewable generation, SVCs…

END