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EXECUTIVE SUMMARY

This deliverable is the first one of the work package 5 of the GARPUR project, focusing on the mid-term period and on asset management. It constitutes the outcome of task 5.1 "Functional workflow of the mid-term decision making process". It will serve as a basis for the next tasks of GARPUR WP5, and also to validate the functional specifications of the GARPUR Quantification Platform (work to be carried out in WP7). It has been written by several partners, five of them being European TSOs, the two other being academic partners with strong links with the local TSO. It is also based on the responses from a questionnaire survey answered by ten TSOs located in Europe. Special attention has been paid by WP leaders 4-5-6 to address every topic in the field of reliability management by the TSOs, so that the overlaps between these 3 work packages are as limited as possible, and so that no important issue has been forgotten in the grey zones at the interfaces between the different time-frames.

The grid components are naturally ageing, especially when operated close to their technical limits, and most of them are subject to hostile external conditions in the open air. Asset management encompasses all the activities undertaken by a TSO to make sure that these devices are efficiently maintained, and thus can have an extended lifespan, or, once they have reached their end of life, are replaced by new ones. Inspection of assets and maintenance actions also aim to act as preventive measures which objective is to decrease the number of (unexpected) failures, therefore resulting in fewer service interruptions and a more efficient management of financial, human, and material resources. In order to carry out some of these operations, it is sometimes compulsory to request the outage of the concerned equipment for a more or less long duration. This raises the other main issue that work package 5 aims to address, i.e. the scheduling of the outages. As such outages will weaken the reliability of the grid, it is therefore an obligation for the TSO to perform early security analyses in order to check that the proposed outages should not jeopardize the network security once it comes to real-time operation. Moreover, the installation of some light and non-strategic new components is also one of the levers which belong to the scope of WP5.

This report offers a comprehensive description of the TSO activities above mentioned, and also suggests some pathways to upgrade the current methods in the future into a probabilistic framework. Wherever relevant, the interactions with external actors (mainly generators and other TSOs) are also mentioned. With respect to the project ambitions, the issues of non-monetary factors such as environmental concerns and human safety have also been inquired.

The report is divided into seven chapters. After an introduction defining the scope of the document and its role inside the whole project, chapter 2 presents the overall view of the activities to be tackled in Work Package 5. The framework is represented under the form of a diagram constituted of 4 main modules, which also displays the main links with the other time-frames. Chapters 3-4-5 and 6 specifically address each of these modules, and provide a more detailed description of the different input/output data, decisions, and sub-activities. Eventually, chapter 7 proposes some suggestions for the upcoming work in WP5 for the practical implementation of new reliability management approaches.

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1 INTRODUCTION

1.1 Background information on the GARPUR project

According to the *GARPUR Description of Work*, the GARPUR project designs, develops, and assesses new probabilistic reliability criteria and evaluates their practical use while maximizing social welfare. In response to the ENERGY call 2013.7.2.1: Advanced concepts for reliability assessment of the pan-European transmission network, GARPUR aims at:

- defining new classes of reliability criteria able to quantify the pan-European electric power system reliability in coherence with its evolution towards and beyond 2020;
- evaluating the relevance of the criteria and compare different reliability management strategies through impact comparison on the resulting global social welfare, thus pinpointing the most favourable evolutions away from the N − 1 criterion in the decades to come.

GARPUR also aims to ensure that the new reliability criteria can be progressively implemented by TSOs at the pan-European level to address new types of system threats while effectively mitigating their consequences on society as a whole. The seven main objectives of the GARPUR project are:

- **O1:** To develop a consistent probabilistic framework for reliability management, covering the definition of reliability, the calculation of reliability criteria, and the formulation of optimization problems expressing the economic costs and the desired target reliability levels at the pan-European level and within each individual control zone.
- **O2:** To develop a consistent methodology for the quantitative evaluation of the economic impact on society of different reliability management strategies both at the pan-European level, and within each control zone.
- **O3**: To develop a quantification platform able to compare different reliability management strategies in terms of their impact on the social welfare.
- **O4**: To ensure the compliance of the developed methodologies with the technical requirements of system development, asset management and power system operation, and to demonstrate the practical exploitability of the new concepts at the pan-European level and in all decision making contexts.
- **O5**: To validate the different reliability criteria with the help of pilot tests.
- **O6**: To ensure the general acceptance of the proposed methods and tools by all stakeholders affected by the reliability management of the pan-European electric power system.
- **O7**: To define an implementation roadmap towards the use of the new reliability management practices.

This report focuses on the first objective, specifically by identifying present reliability management methods and by highlighting where a probabilistic framework could improve the current practices.

1.2 Position of WP5 activities within the whole framework

Within the GARPUR project, the mid-term horizon discussed in WP5 bridges the gap between long-term planning and short-term operation planning. In this context, the options to construct new transmission infrastructures are no longer available, but some lighter interventions, such as replacing conductors, installing reactive power devices, or preparing the protection schemes, remain possible. Although the operational state of the target system cannot be ascertained accurately at this stage and must be evaluated based on records from the previous years, the scope of uncertainties is getting sufficiently narrowed to perform a rough assessment of the future grid reliability, and to take early actions for the threats that have been detected. Most of the analyses relevant for this period of time are strongly

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correlated with the needs for maintenance and replacement operations (for both power plants and grid components). These needs may require putting some of the grid components out of service while the operation is carried out. Such scheduled outages weaken the reliability of the grid, and must be planned in a clever way which will be the least harmful to the network and its end-users. Yet, the benefits from such maintenance will last for several years through an increase of reliability of the said component, which becomes less likely to fail unexpectedly during a critical period. If too little is done in asset management, the TSO will save some direct costs in the mid-term but it may result in important indirect costs at latter stages to avoid undesirable system under-performances. However, it is important not to over-state replacement and maintenance programs as it would result in high direct costs – eventually charged to the end-consumers - not sufficiently compensated by significant reliability improvements.

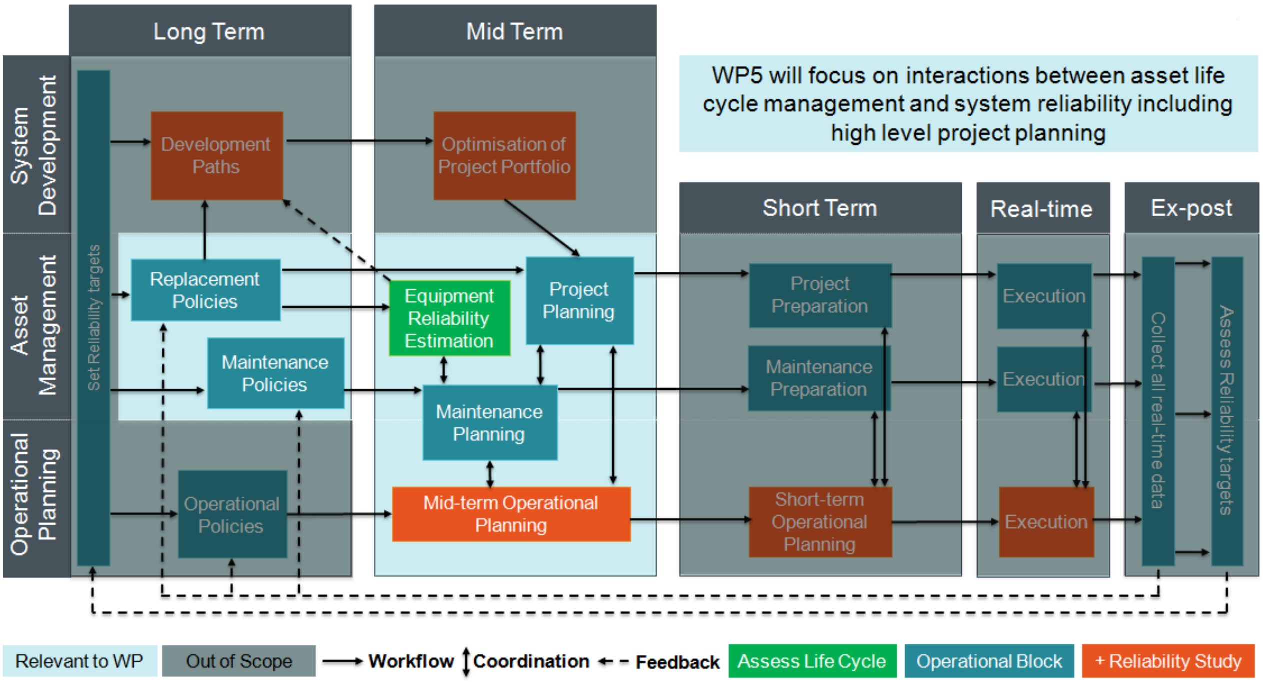

Figure 1-1: Scope of WP5 within the whole reliability management framework

Within the whole reliability framework, WP5 focuses on a period which ranges from roughly 1-2 years to the point when weather forecasts become sufficiently accurate to switch from historical record data to measured data. This point can approximately be settled at one/two months ahead of real-time operation. It assumes the main decisions on grid development, which require a long period of concertation with all involved actors and propose modifications in the connection points and available transmission capacities, have already been addressed within WP4 and are now out of hand. In this deliverable and in the rest of the work package, it is assumed that the structure of the grid is a fixed input data, except for the addition of lighter and less strategic new assets such as capacitor banks. Yet, the decisions taken in the scope of WP5, in particular rehabilitation or replacement of grid infrastructures also have effects on the reliability of the system in the long run. This fact is visible on Figure 1-1 above. On the other hand, the plan drafted in the mid-term horizon can be updated once it comes to short-term operation planning (WP6). In this time-horizon, the different data and forecasts are gaining accuracy, which means in particular that depending on the (now better assessed) reliability level of the system, the operator can adapt the initial maintenance schedule. It can decide to postpone or cancel a planned outage when the operational conditions are critical, and conversely, should these operational conditions be more favourable than expected, bring forward outages that should have happened at a later stage. For convenience, a set of definitions is proposed in annex 3 to summarize the content of each time-frame/Work Package.

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It is somewhat important to remind that the division of work in the GARPUR project between WP4-5-6 and the following diagrams in this report do not intend to reflect the internal organisation of a TSO in terms of departments/units.

Two main concepts are responsible for this division of work. The first one is that the decisions concerning the assets should explicitly address the power system reliability (robustness of the surrounding grid, value of lost load in case of a contingency,...) and not the just individual assets. The second one is that each time frame has its own field of decisions which can be implemented – the further the time-frame, the wider the scope of possible decisions. If for instance the window to undertake the construction of a new transmission line in time has been missed, then it becomes up to the mid-term to propose a back-up solution, but only with the remaining means of action. Sometimes, taking no action and waiting for the conditions to be known more precisely may be the best option, but the decision to postpone an action should be a conscious choice, preceded by a risk estimation based on the current available data.

1.3 TSO challenges regarding these activities in the context of GARPUR

The next sub-sections express some of the core problems of the TSOs with regard to WP5 that the reader should keep in mind throughout the reading of the document. These core problems are also the main identified items that could (or should) be included in the definition of alternative reliability criteria, in the specific context of asset management. The last one is particular and difficult to handle, because operational constraints must be included, while the evaluation of the performances and benefits of a decision should cover several years or even decades. The four core problems are:

- Adapting the maintenance and replacement efforts at the proper time and where they are mostly needed.
- Avoid a latent ageing of a population of assets and smooth the resources distribution.
- Get trustworthy information from scarce data to assess the deterioration process of the components.
- Ensuring a good reliability level during outage periods. Although it is also to a large extent a short-term issue, the outage schedule is prepared during the mid-term period, and a too tough outage schedule could be untractable once in the short-term and therefore jeopardize the whole system.

1.3.1 Determining the optimal replacement and maintenance time

The replacement policies of the TSOs implicitly define a target reliability level. Indeed, an early replacement of the components should reduce the amount of energy not supplied – at least, if no interruption of supply happens during the corresponding outage. But as the component could have lived longer with an acceptable reliability level, it means the cost of such replacement was not optimized from a socio-economic point of view. Thus, TSOs have to arbitrate between different options, e.g. do nothing, apply preventive maintenance, wait for failure then fix, replace, or grid development solutions. These options, particularly their costs and consequences, must be evaluated over a long period of time, which is particularly challenging. Moreover, the criticality of the component to the power system is not equally balanced. The consequences of the failure of a particular device depend on several parameters, such as its location and the robustness of the surrounding grid. It is then not optimal to ensure the same level of maintenance for all the pieces of equipment belonging to the same family. TSOs have been using their own self-made rules and indicators for many years, but a clean framework would be appreciated to assess the criticality of the different components of the grid.

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1.3.2 Avoiding latent ageing of the whole grid

Another extremely important matter is that the continental network experienced a massive construction period decades ago. Many components will reach their end of life at the same time in the years to come, and therefore, if the replacement policies were only based on a myopic approach, TSOs would have to perform all the replacement operations and scheduled outages within a short period of time, which is impossible from the perspective of the power system and because of workforce management. Hence, TSOs have to anticipate the replacement of some fine-working equipments in order to smooth the workload over a longer period of time. Knowing which equipment, and what anticipation rate, is a current issue for them.

1.3.3 Getting trustworthy data from scarce information

The scarcity of failure data for the computation of reliability parameters presents a problem to managing TSO assets. Given many grid components are usually replaced before a major end-of-life failure occurs, minimal data are available to build models to assess their deterioration process. This is particularly true for time-based maintenance, while condition-based or reliability centred maintenance (see §3.2.2) may provide some input on the asset's condition.

Actually, such deterioration models should be complex and incorporate specific parameters for each individual asset: technology provider, sustained stress, environmental conditions (rain, pollution, etc.), and previous maintenance records, among others. In a similar manner, it is difficult to evaluate the benefits of maintenance. In order to gather such information, an experimental approach would consist in maintaining most of the components while not maintaining at all the others, and compare the number of failures. This is obviously something that no TSO would ever try. And yet, being able to determine a relevant probability of failure for each of the components of the grid is a must-have prerequisite for a probabilistic approach in reliability management, for all time-frames, from real-time operation to long-term system development. In practice, it doesn't seem relevant to only rely on such deterioration models, without taking into account human expertise to evaluate the condition/probability of failure of assets.

1.3.4 Outage period and respect of the reliability criteria

Regarding outage management, the N-1 rule as applied today from the mid-term perspective can be unnecessarily constraining, because TSOs mostly base their case studies on worst-case scenarios. In a time when the flows on the grid are getting more and more unpredictable, such worst-case scenarios can be challenging for the outage planner when it combines extreme temperature scenarios (and associated load) with abnormal cross-border exchanges and an unfavourable wind production pattern.

Therefore, it doesn't make sense to commit high preventive costs to anticipate a N-1 threat that would occur only in very particular circumstances, especially when the concerned component is known to be particularly reliable, while a significant N-2 threat can be totally ignored in the current practices. Likewise, it is important for the TSOs to have tools to help them decide if a particular maintenance/replacement action has to be carried out within a short deadline even under hard operational conditions (hence purposefully accepting a higher risk during this period), or if it can be reasonably postponed to a later date. As the N-1 policy is, in its strictest application, ignorant of the probabilities of failure of the components, it doesn't provide any clue to imagine the best decision when reliability has to be assessed over a long period of time. This is typically a case where the "reliability, but not at any cost" philosophy is of interest. One of the practical concerns for TSOs is to have better decision tools to decide whether to resort to costly measures such as night work, helicopter support, or preventive redispatching, to fasten the maintenance work, and thus reduce the overall risk induced by the outage.

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1.3.5 Mathematical needs for the rest of the GARPUR project

In a nutshell, the main stake of the further work in GARPUR WP5 expressed in mathematical terms could look like the following: the probabilities of contingency of the grid components are influenced by the money invested in asset management, and by the criteria used for asset prioritization. The problem that TSOs have to face is to evaluate the proper amount of money that should be spent in asset management, and when/where it should be spent, in order to obtain the optimal reliability level from the socio-economic perspective over a long period of time.

This optimization has to be performed under two hard constraints coupled with the long-term and short-term time-horizons:

- Resources (workforce, money…) are limited, with the consequence that all the required work must be spread over many years instead of being carried out within an optimal short period;
- The schedule of outages for maintenance and replacement operations should be arranged in order to ensure a sufficiently safe network once in real-time operation (understand, in winter the possibilities for planned outages are limited).

1.4 Accuracy of the diagrams and displayed information

The diagrams presented in the rest of this report aim to represent an average description of the activities targeted in GARPUR WP5 which could suit the decision making process of any of the European TSOs. One of the difficulties is to separate what appeared to be “gut-feeling” input data, maybe used only by very few TSOs, from data which should appear in the common description that fits any TSO. They should be used as a reference point for the upcoming tasks in the project.

Besides, for the sake of readability, it is not reasonably possible to display all information on the different diagrams. Some arbitrary choices had to be made about that, so that only the most important aspects are highlighted in the diagrams, while complementary explanation can be found in the text sections to complete what is missing.

The proposed framework is presented under the form of one master diagram, which is itself composed of four main modules belonging to the scope of WP5, and which shows the interactions with the other time-horizons. A more accurate diagram is proposed for each of the modules, based on a zoom principle over the master diagram. Each of these four more detailed diagrams reveals sub-activities and additional input/output data that were deemed too detailed to appear on the master diagram.

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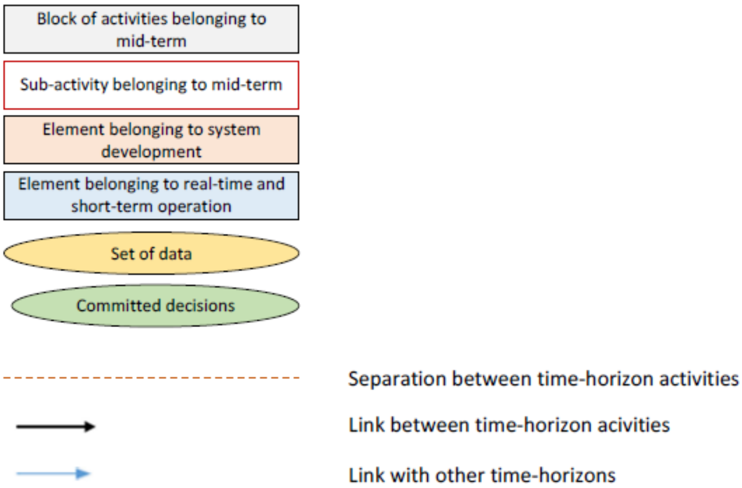

Figure 1-2: Legend used for the workflow diagrams

1.5 Insight into the asset management activities

In order to provide a quick and very practical overview of the asset management activities, the sections below present some of the operations carried out by the TSOs for the most common assets. These sections do not aim to extensively cover all the existing operations, nor to go into too much unnecessary detail.

1.5.1 Introduction to asset management

The following definition of asset management has been presented by the CIGRE Joint Task Force 23.18 [1]:

"*The asset management of Transmission and Distribution business operating in an electricity market involves the centralization of key decision making in the network business to maximize long-term profits, whilst delivering high service levels, with acceptable and manageable risks*"

Several elements of interest from this definition should already be underlined:
- Asset management reasons on the whole grid, and not on a single component
- The gains in terms of reliability (and implicitly monetary benefits) must be evaluated over a long period of time when considering a decision
- Asset management is a natural risk-based topic, encompassing expenditures on the one side and reliability performances on the other

The asset management operations we will consider can fall into the following categories:
- Inspection of assets
- Routine maintenance (usually, light interventions)
- Scheduled maintenance (time-based and independent of the detection of damages on the component)
- Preventive maintenance (triggered after an inspection revealed damage on a still operational component)
- Corrective maintenance following a component failure
- Scheduled refurbishment

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- Replacement/retrofitting/removal of a component

The natural reliability curve of a component is quite stable for most of its lifetime, and then drops quickly from a certain age to a point when the reliability level is no longer acceptable. The day-to-day maintenance aims at extending the lifespan of the component by performing some light interventions on the asset. The inspection visits, when no intervention on the asset is directly carried out, constitute the opportunity to evaluate the health state of the component and detect any potential damage on the component. In this case, a further fixing operation would be planned within a delay corresponding to the emergency of the degradation, from a level where immediate repair must be undertaken within the next hours, to a few years. The visits can be scheduled or opportunistic, e.g. decided shortly after a violent thunderstorm, or prior to a forecasted heavily loaded day when a failure of the component would be particularly difficult to handle.

Once the components approach their expected end of life, thorough reviews are performed to evaluate if the overall quality of the component is acceptable. Consequently, some parts may be replaced, or the component might experience a long and heavy rehabilitation stage. When the said asset is reckoned to be beyond repair, the remaining options are to replace or retrofit it, or, in coordination with the system development teams, to propose a new grid structure.

However, ageing and natural deterioration are not the only factors motivating the replacement of assets. The functional obsolescence of protection devices, the lack of spare parts for old technology or regulatory enforcements, among other factors (see §3.2.4), can motivate the renewal of the entire existing assets by newer and faster ones. A last aspect to mention is the human threat. It includes the growing problem of theft of metallic parts, and to a lesser extent, of vandalism and sabotage. It also includes accidental human error, such as damage during maintenance, traffic accidents, and erroneous decision making.

1.5.2 Overhead lines

Overhead lines cover a very large outdoor area, and thus are highly exposed to natural hazards, including extreme weather conditions (ice, rain, wind, lightning, etc.), as well as deterioration due to pollution and salt. The wide diversity of climate even across a single country explains how the failure rates of one technology can be very heterogeneous from one line to the other.

<u>Handling the vegetation threat</u>

The natural growth of vegetation is also a threat because of the risk of contact between the line and the tree, which would result in short-circuit and possibly the start of a fire. The regular inspection operations, and the models to assess growth rates, enable the TSO to maintain this particular risk under control. Except in very special cases, the vegetation is sufficiently far from the line so that no outage is required for the operation.

<u>Handling the bird threat</u>

The most sensitive areas where the birds are likely to hit overhead lines are identified by the TSOs. One way to prevent birds from colliding with overhead transmission line is to settle “scarecrows” and other similar devices (visual or audio), which aim at keeping at bay these animals.

Besides, The annual migration of huge birds (typically, storks) lead the TSOs to carry out certain particular operations each year at the nesting period. In addition to the risk of electrocution of the bird, the fall of the nest branches on the conductors can generate power cuts. Hence, during this period, the teams in

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charge of maintaining the lines will remove the threatening nests, and install protected nests on a platform on the top of the tower.

Inspection of overhead lines

The overhead lines are regularly visited in order to check the state of the conductors, joints, insulators, and the proximity of vegetation. Infrared scans for the detection of hot spots may also be performed, although it is a complex and expensive inspection process.

Three different methods exist for the inspection of these assets:

- Ground inspection. They enable the checking of the state of several elements such as insulators, foundation, and painting, which naturally degrade with time and external aggression (environment, vandalism). They also permit the identification of the potential presence of vegetation menace, the presence of any new infrastructure close to the line, and the state of the ground. These foot patrols are slow, but do not require outages.

- Climbing inspections. These operations consist in sending linemen up towers to have a close look at the state of the cables, especially at their weakest points (interfaces). They require the outage of the line, but are usually very efficient.

- Aerial inspections (use of helicopters). Their main utility is the detection of vegetation threats and to detect hotspots through infrared scans. They are fast, expensive, and do not require the outage of the line. Usually, they are undertaken by campaign (on a large group of components) because of the logistic difficulties and in order to optimize the costs.

Maintenance of towers and of their foundations

Metallic towers are regularly painted for protection against corrosion. Other maintenance action could be the reparation of corroded parts with fishplates, or the retightening of bolts. Wooden towers may be equipped with fences for protection against birds such as woodpeckers, and receive treatments against bugs and moss. The concrete basement of the towers are also regularly inspected and repaired to prevent mechanical weaknesses due to cracks. The painting of towers may require the outage of the line.

Maintenance of the conductors, insulators, and other equipments

A power transmission line is composed of different connecting mechanical parts such as:
- the conductors;
- the insulators;
- the suspension clamps;
- the vibration dampers;
- the cable connections.

The conductors are regularly inspected in order to detect cable alterations (observations, infrared scans). Depending on the damage level different reparations will be conducted. The breaking of a few strands will generally be treated with the use of an adapted collared piece in order to limit further degradations and restore the cable integrity. Such action is simple to realize and can be performed under live work, for TSOs using such technics. If the damage is deemed too serious, then the damaged portion will be replaced, which means two collared junctions will be necessary in order to incorporate the new part.

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Cable junctions are sensitive parts due to the mechanical and thermal stress they experience. They will be closely looked at during the line inspections (thermal inspection).

The insulators will be also inspected and cleaned. It is indeed important to clean and grease regularly the insulator elements in order to limit the pollution soilings and preserve the insulator properties.

Suspension clamps and vibration dampers will be also inspected. By experience, those elements are less troublesome regarding maintenance activities.

1.5.3 Underground cables

The inspection and maintenance of underground cables differ from overhead line as:

- They are not subject to natural hazards (except earthquakes);
- Their repair time is much higher;
- Inspection of these assets is harder to perform;
- Their associated costs are generally higher;
- Their repartition is not homogenous but corresponds to different needs or constraints (environmental acceptance, public authorizations ...);
- They are generally built in grounds belonging to local collectivities, in urban areas. This implies that the TSO has to share the ground with other utilities, should withstand certain external evolutions.

Cable technologies

High voltage cables are mainly now synthetic insulated (XLPE...), but for historical reasons TSOs have to cope with less reliable old technologies (Oil Impregnated, Oil-Filled ...). The choice of the technology will mainly depend on the voltage level of the equipment. For cost and environmental reasons it is possible to have equipments mixing two technologies between two substations (even overhead-underground), or of two different ages (partial renovation). An electrical junction is then necessary between the two parts. This one could be tricky to realise and may affect later on the reliability of the whole assembly.

Preventive maintenance

The fixing of a cable on outage could be long and difficult to realize depending on the environment (urban vs. rural areas, access conditions...).

The first preventive maintenance action is observation. It consists in checking whether there has been ground evolution above the cable, for example:

- plantings which can damage later on underground infrastructure with their roots;
- ground evolution (new ground covering) which can affect the cable heat release;
- civil engineering works in the vicinity (new underground network such as gas, water, telecommunication);
- obstruction to existing cable access ways.

Along its path, the cable will encounter a lot of different obstacles such as rivers, roads, railways... Consequently, its burying depth varies. Sometimes it will be possible to dispose of an access to it in order to verify its state (gallery, along a bridge ...). For Oil Filled cables, it is necessary to verify the oil pressure, to inspect Oil ancillary equipment. As for transformers the quality of the oil could be also inspected (dissolved gas) but this method is still to be improved for cables. Even if it is not possible to measure their impact on reliability, those inspection visits are deemed valuable. Indeed, the average fixing time for a cable is about one week, compared to one day for an overhead line.

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Corrective maintenance
The main problem considering cables is the intervening duration which could vary a lot depending on the nature of the problem and the access conditions to the cable. First, it is necessary to detect the problem location. A pre-location is performed by wave propagation, and then the fault location is refined by acoustic detection. In some cases, it will be necessary to inform the local authorities, for example if it involves traffic interruption on a main road. Depending on the cable length, the nature of the end-users, the difficulty to back up the outage, temporally workarounds will be used, as the setting up of a bypass cable.

About reliability
The two main factors permitting to assess the cable reliability are the age of the equipment and the feedback on the previous problems collected on the cables of the same technology. The past stress level of the cable is also suspected to play a role, but no reliability model uses this information in the current practices. Some old cables with poor reliability may be present in the grid. They are generally non-energized, and kept situationally to facilitate outage planning by providing a parallel electrical path. In some cases, the transmission capacity of known unreliable or problematical cables will be limited, temporally or permanently, to limit the risk of unexpected failure.

1.5.4 Substation components and infrastructure

Concerning the maintenance in substations, two specific points are important:

- It encompasses a lot of different equipments, facilities, telecommunication systems, electrical devices (lines, cables, transformers, busbars, protections ....);
- Substations are spread all over the TSO control perimeter. They are then highly exposed to natural hazards, including extreme weather conditions (ice, rain, wind, lightning, etc.), as well as deterioration due to pollution and salt. The wide diversity of climate, even across a single country, explains how the failure rates of one technology can be very heterogeneous from one substation to the other.

TSOs don't need special public authorisations in order to intervene in their own substations. They generally have the proper tools and spare parts in the vicinity of the substations in order to facilitate the more common maintenance actions.

A lot of discrepancies exist between the substations. In adition to the meteorological environment quoted above, there is the facility of access, the available space between equipments, the general state of the substation, the role of the substation in the electrical system, and also the level of technology of the substation (manual vs remote control, classical vs Gas Insulated Substation, platform on stilts, converters substations).

The environmental impacts of substations are also to be considered. This point is specifically addressed in section §3.2.5.

1.5.4.1 Facility maintenance
Facility maintenance includes the maintenance of the buildings, roads and grounds, fences, gutters, pipes, lights, ancillary services... As all these actions are not very relevant considering GARPUR objectives, they will not be further developed in this document.

1.5.4.2 High voltage equipments
Those equipments cover a wide range of devices, e.g. transformers, on-load tap changers, circuit-breakers, busbars, disconnectors, compensators, and smallest ones such as reactances, condensers, lightning or surge protections... Depending on the equipment, different kind of maintenance actions are

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managed by TSOs, ranging from light inspections to in depth maintenance (intervention for several days). The most important operations concern the circuit breakers, over transformers and on-load tap changers. Severe damage may lead to a standard replacement of the equipment.

Maintenance of circuit-breakers
The behaviour of circuit-breakers is of prime importance when addressing the security of the system. They are used to interrupt short-circuit propagation or in order to modify rapidly the topology of the system. Different kinds of circuit breakers exist, the maintenance actions are planned depending on the technology. SF6 circuit breakers are nowadays worldwide used due to their cost and characteristics, and need regular refillment.

Maintenance of transformers and on-load tap changers
The maintenance of transformers varies according to their importance. Light interventions can be oil controls or aero-refrigerant cleanings. In-depth interventions may necessitate the use of hoisting equipments.

Maintenance of disconnectors
Disconnectors are known to be less reliable than circuit-breakers. Consequently, the operators prefer to prepare in advance the setting of the disconnectors in a way that will limit the need to use them in urgent situations. Thus, when the necessity occurs, they just have to action the circuit-breakers, which means they can act more quickly and confidently. By doing so, the reliability of disconnectors is a bit less at stake. The maintenance on disconnectors varies from simple visual controls to in-depth interventions (about one day). Intervention on disconnectors can be coupled with those on circuit-breakers from the same protection cell.

Maintenance of condensers
While the number of condensers is generally limited, intervention on those equipment can be long (up to several days) depending on the technology of the condenser.

1.5.4.3 Low voltage equipments

This category encompasses a lot of different equipments generally regrouped in the same building, such as wirings, control command, alarm, telecommunication devices, protections and automatons.

Wires, control command, alarm and communication devices
Preventive maintenance for those equipments is generally light, visual and contact controls, cleanings. Please refer to section §1.5.5 for more information on the maintenance of ICT devices.

Protections and automatons
The purpose of protections is to detect power-system disturbances and perform control actions in order to protect human beings in the surrounding and equipments. The purpose of automatons is to help the operators by performing actions such as reclosing circuit breakers after short-circuits, or monitoring a circuit-breaker failure. Different kind of protections and automatons exist and can be associated depending on their objectives (over-current, over-voltage, distance, current differential …). Their reliability is very important for the power-system, this is why control, redundancy and overlapping are the rule when designing protections. Periodic maintenance operations are scheduled on those equipments in order to verify their settings and operational efficiency.

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1.5.5 ICT devices

Although not the first family of devices one would think about when addressing TSOs' asset management, the maintenance and replacement of telecommunication equipments and non-physical assets (e.g. software, data-bases) is in many ways similar to the other components of the grid. As the TSOs are always trying to optimize their practices, and rely more and more on complex software decision tools using many different data flows, the quality and availability of the information become of growing importance to assess reliability. The good behaviour of automatons is also one of the key elements to achieve good reliability performances. It is a matter of importance in GARPUR, where corrective actions and their associated probabilities of failure have been identified among the pathways to improve reliability management.

The notions of preventive and corrective maintenance suits ICT (Information and Communication Technology) devices as well. The preventive maintenance operations for such equipments typically are:

- Software/databases upgrading (including security upgrade against cyber-attacks)
- Periodic testing, to make sure for example that an automaton delivers the proper signal

It is of interest that, depending on the existing level of redundancy, a software can have to be out of service during the version upgrade, and that there exist a possibility that the new software version, which has not yet been tested in real-life conditions, introduces new bugs that didn't exist in the previous version. It should also be mentioned, in the case of a TSO software tool which requires data flows from external sources (like for example meteorological data), that any evolution in the format of the external data has to be accounted for in the TSO tool. The penalty would be that the reading process would fail, incapacitating the software to run properly.

One interesting aspect about ICT is that the triggers for replacement are usually different from those for physical assets. Most of the time, the replacement is motivated by:

- The emergence of a more performant technology
- The disappearance of spare parts or the loss of skill to maintain obsolete software and hardware

On a day-to-day basis ICT contingencies are managed without much difficulty by the TSOs. Now, considering their importance for the reliability of the whole electrical system, there is the risk that a "High Impact Low Probability" ICT event could jeopardize the reliability of the whole electrical system (this issue has for example been addressed within the AFTER project [41]). Those can lead to the loss of information, unreliable or out-of-date information, and can alter the behaviour of electrical system protections or remote devices (e.g. load shedding system) or incapacitate a TSO operator to take the good decision at the good time.

Among the most sensitive elements of the ICT system are the SCADA and the communication network. This is why numerous protections and backup solutions have been designed in order to preserve their proper functioning or their service continuity even in degraded mode operation.

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2 FUNCTIONAL WORKFLOW OF THE CURRENT MID-TERM DECISION MAKING PROCESSES

2.1 Introduction

The present chapter introduces a high-level decomposition of the TSOs activities encompassed within the scope defined in section 1.1 and of the main interfaces between the different time horizons. The proposed description is formed of four main modules, the content of each of them being refined in the subsequent chapters of this report. Suggestions for upgrading the current practices are proposed in chapter 7. Additionally it summarizes the existing multi-actor issues in this context.

2.2 Overall description of the relevant activities and master diagram

The proposed decomposition is illustrated on Figure 2-1.

It starts with a module dedicated to the choice of the maintenance and replacement operations that are planned for the next years (module 1). One of the main outputs of this module is the list of components that will need to be out of operation during the next year for either maintenance or replacement. The requested outages and resources from system development projects will also have to be added to that list. The specificity of this module 1 is that it doesn't merely focus a period of time within the mid-term. For example, the replacement policy must have a look on the ageing of the different equipments over the next decades. If this policy only looked at the next few years, it might not notice a peak of simultaneous replacement (and outages), which would be untractable if not properly anticipated. Similarly, for components reaching their end of life, several alternatives are opened: it is possible to replace the old component with a similar one, or to keep the same grid architecture but use an upgraded version of the old one, with improved performance – for example use of a higher-capacity cable. Also, the decision to modify the former grid structure to propose a different one needs to be examined. In order to do so, the information on the expected end of life of the assets is communicated to the long-term planning departments, where the experts understand the evolution of the consumption and generation in the area. Beside, these experts also have the required knowledge on the different technical solutions, and on the acceptability difficulties they should face.

Before assessing the reliability of the network in the range of a few years – few months ahead of time, TSOs must first prepare scenarios for the analyses. Obviously, a fine description of the future meteorological conditions is out of range. Hence, such scenarios are usually defined based on recorded data from the past years, and on refinements brought by the mid-term planner. Among the latter, the most important input data are the maintenance plans of the power plants provided by the electricity producers. The different reliability analyses for the mid-term period are usually performed on worst-case scenarios in the current practices. The preparation of these worst-case scenarios, that we expect to become probabilistic scenarios in the future, is the object of module 2.

The proposal of a consistent reference outage schedule is the main task of module 3. This module aims at verifying that the future network should be sufficiently robust to withstand any significant threat that could occur, and in the case of the detection of a frailty, check that corrective/preventive actions should be available to deal with the aforementioned threat. Some actions specific to the mid-term horizon can be implemented within the range of a few years to a few months, such as the installation of automatons, the installation of capacitor banks, or in the most tense situations, negotiation with energy suppliers so that they postpone their own maintenance to a period more favourable to the system. These measures require a quite long implementation delay, and therefore cannot be evoked once in the short-term horizon. Yet, they are faster than the many years unavoidable for the building of new heavy equipment and prior concertation with local authorities.

The last module developed in this framework concerns the storage of data and the learning from recorded events. The lessons learnt and feedback experiences have been reckoned as a particularly promising path for improvement of the current practices in WP5. In particular, it should permit to gather all the data needed to perform a more accurate assessment of the individual reliability level of all the different components of the grid. It is also in this module that the forecasting errors are assessed, and that the tuning of the different forecasting models should be performed.

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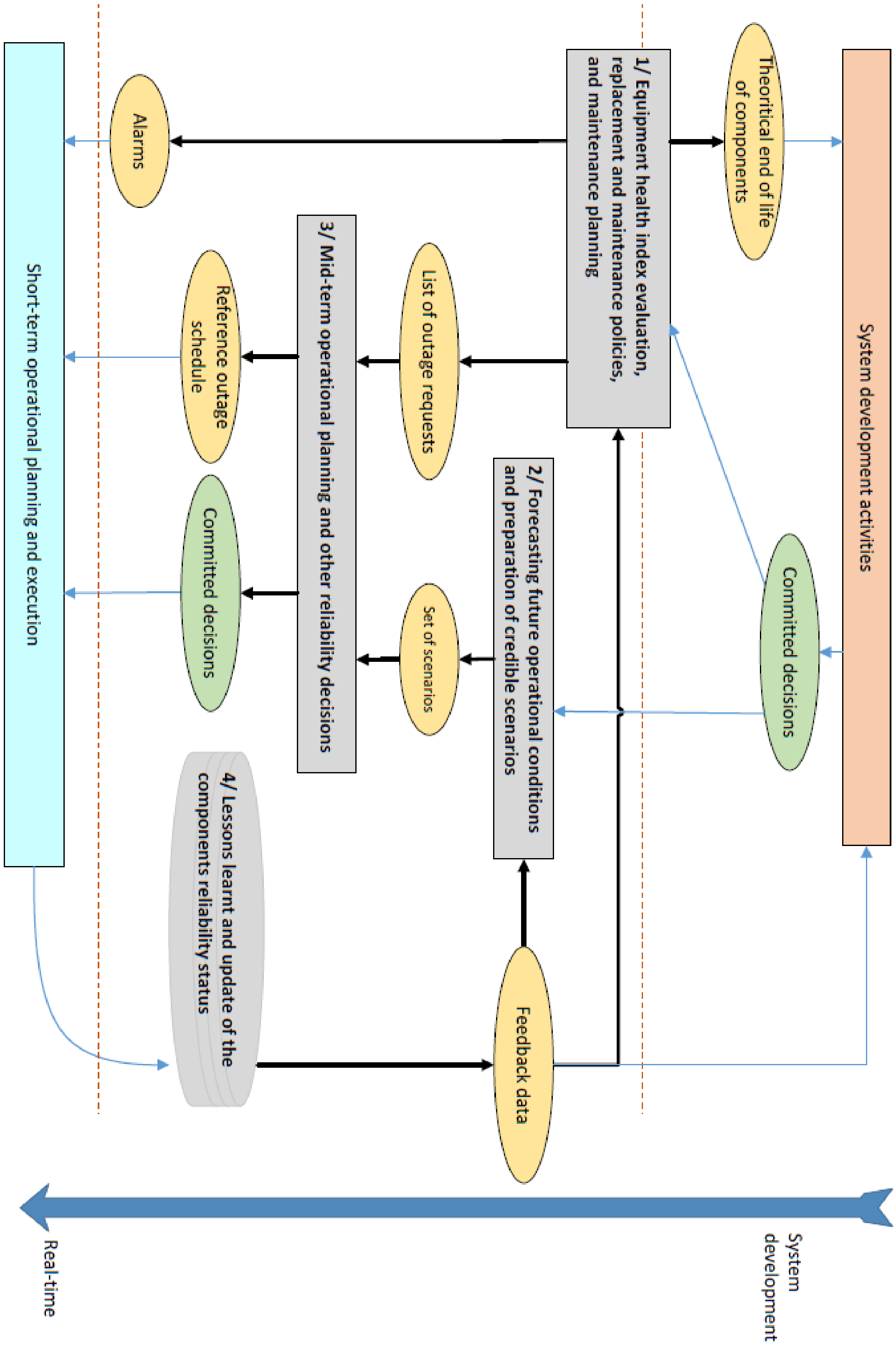

Figure 2-1: Master diagram for activities encompassed within WP5

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2.3 The reality of the iterative process

A reader having a first look at Figure 2-1 should be aware that the reliability assessment of a target network at some date cannot be properly represented within the form of a flowchart, because this reliability assessment, and the associated decisions, are regularly updated with the latest data available.

In order to simplify the iterative nature of the decision making process, all the case-by-case adjustments that occur are not represented in the diagrams. For instance, the replacement of an asset can be initially proposed for year 2015, then be postponed to year 2016 so that it happens in parallel with another planned outage. Then, in year 2016, the initial time-window can be modified in the month-ahead horizon because of an unexpected delay in another prioritary work. Eventually, the replacement operation can be postponed or cancelled the very day it was supposed to start because of an unexpected cold spell that leads to tense operational conditions. More information on short-term constraints can be found in GARPUR D6.1.

2.4 Links and data-exchanges with the other time-frames

The purpose of this section is to enumerate and explain the links and data-exchanges between asset management activities and the other time-frames, i.e. system development activities (§2.4.1) and operation activities (§2.4.2).

2.4.1 Asset Management and System Development activities

The data exchanges between asset management and system development activities mainly concern the expected end of life of network components. For each component the following informations are generally given by Asset Management:

- Date of expected decommissionning or replacement
- Costs and characteristics of the replacement solution

The asset management policies define the strategies concerning the refurbishment of each class of components. If a replacement solution is proposed, the characteristics of the new component can be slightly different than the old one due to technology evolutions.

Considering the future transmission network needs and the costs of the replacement solution, the opportunity to upgrade the component or to propose instead alternative development solutions is examined in a System Development context.

Depending on the chosen solution, the asset management will be in charge of the component replacement/upgrade/removal or of the implementation of the development solution. The expected date of replacement can be subject to different considerations, such as observed unreliability or the necessity to rapidly eliminate a technology (regulation enforcement, safety or environmental considerations, obsolescence, etc.). To be effective, the removal of a component also needs the approval of operation. Some components no more useful in a day-to-day utilization can be kept off-line most of the time, and in case of need (maintenance work on another component) be put in operation to improve the network reliability during the short critical period of time.

Finally, the purpose of development activities is to anticipate the future operational needs. Thus, a lot of present operation difficulties have generally been identified, and a certain number of them will find a solution in the years to come. Owing to societal reasons, it is generally easier to upgrade an existing

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electrical path rather than to build a new one. Therefore, a part of the existing concerned lines will be replaced before they reach their theoretical end of life.

2.4.2 Asset Management and Operational activities

A lot of information concerning asset management is in fact collected during the different exchanges with operational activities. In particular, this information helps to understand how maintenance is conducted in order to minimize its potential effect on operation. Secondly, it feeds the "Lessons Learnt" files.

The exchange of the reference outage/development schedule between Asset Management and Operation generally begins several years before operation and follows a precise sequence at the yearly/monthly/weekly horizons.

Yearly basis

Several years before operation (generally up to five), the Asset Management provides a list of the main forecasted maintenance activities and of the replacement projects. Those projects are generally classified depending on their importance and on the required resources.

This first schedule targets different objectives:

- A draft allocation of the financial and human resources
- A first exchange with operation, notably concerning the key and sensitive projects
- If necessary, the confirmation or anticipation of worksites authorizations with public authorities (in particular for underground cables in urban areas)

On an annual basis different information is exchanged between the Asset Management and System Operation contexts.

System Operation informs Asset Management of:

- The strategic components or areas (important for the balancing or the stability of the system)
- The sensitive components or areas
- Potential difficulties to schedule an outage (necessity of a short return on operation, necessity to modify or disable protections, necessity to coordinate with a third party, risk of financial penalties …)

This information is important for Asset Management in order to rank the different maintenance operations according to their importance, their risks (system, human), the resources to allocate, and the duration of the interventions.

A tentative schedule is elaborated and communicated at the end of this process. It includes the different maintenance and development projects, the allocation of resources (material, human, special equipments), the technical requirements (outage necessary, live work, etc.), and the additional allocation of resources for inspection/testing and emergency works.

Monthly/Weekly basis

This tentative schedule will be updated and discussed with operation on a monthly and weekly basis. Some new maintenance works will be included to the previous yearly schedule (opportunistic, emergencies), while some others may be advanced, cancelled or postponed due to unfavourable load conditions or adverse weather conditions.

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Daily basis
In real time, the operators have to cope with contingencies and any kind of unexpected events, which can impact outage management.

2.5 Coordination with the different actors

Asset management activities involve a lot of coordination with other actors that we can separate into the three following categories:

- Actors in charge of another interconnected network (neighbouring TSOs, DSOs, special customers such as railways),
- Actors directly connected to the TSO network (Energy Suppliers, industrial Consumers),
- Non Electrical Actors which can affect the scheduling of operations (Public Authorities, External Maintenance or Rental companies ...).

The balancing of energy which is done by operation during the Mid-Term and Short-Term time-frames can also affect the TSOs' maintenance activities.

2.5.1 Coordination with connected networks (TSOs and DSOs)

The coordination with neighbouring TSOs is essential for interconnected countries. This can be done via many means including bilateral exchanges between two neighbouring countries, and participation in inter-disciplinary groups or cooperation organizations such as ENTSO-E or the BRELL ring. The basis of international cooperation is described in the Entso-E Operation Handbook [40] and is put into practice in the Multi Lateral Agreements signed by each TSO.

On an annual basis the TSOs build and share their Winter and Summer outlook reports which assess the adequacy of the power system as well as the potential electricity issues which may be faced with during the coming seasonal periods. Forecasted maintenance of generation power plants and of the transmission system (especially the tie lines) are taken into account in order to identify the system balancing and bottlenecks under normal and severe conditions. The reports consider both the national level and the interconnected network level to evaluate the risk of supply outage. Moreover operational regional coordination initiatives such as CORESO or TSC have been conducted in order to facilitate the exchanges of information and countermeasures between the TSO's.

Cross-TSO and cross-DSO coordination is also required for outage management. See §5.2.4 for additional explanations.

2.5.2 Coordination with generators and industrial customers

TSOs and generators exchange schedule information for maintenance operations on an annual/monthly/weekly/daily basis. Generally the TSOs are able to carry out their maintenance operations during the period of unavailability of the generation installation for its own maintenance, thus granting the generation units an optimal grid access service. Depending on the authority the TSO may have on the generators, some contractual obligations may be settled between the TSO and the generators (see §5.2.4 for further explanations).
In the same manner, TSOs and Industrial Customers exchange schedule information for maintenance operations in order to allow the TSO to carry out necessary maintenance operation during the periods of unavailability of the main Customer (e.g. railway network or factories), or at least during the least constraining period.

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2.5.3 Coordination with Non Electrical Actors

Depending on the maintenance operation, coordination can be mandatory or necessary with non electrical actors such as Public Authorities or external maintenance/rental companies. This will lead to binding time-table constraints in the elaboration of the maintenance schedule.

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3 EQUIPMENT HEALTH INDEX EVALUATION, REPLACEMENT AND MAINTENANCE POLICIES, AND MAINTENANCE PLANNING

The main goal of this chapter is to provide a focus on the module 1 of the master diagram with a more accurate description of the concerned data and activities. This more detailed version is presented in Figure 3-1 and the different submodules will be further explained in the chapter. In particular, the following elements will be introduced:

- the indicators used for the health index evaluation
- the triggers currently used to decide a maintenance/replacement operation
- the parameters taken into account in the asset management policies
- the environmental concerns and some other topics which seemed relevant in the context of WP5

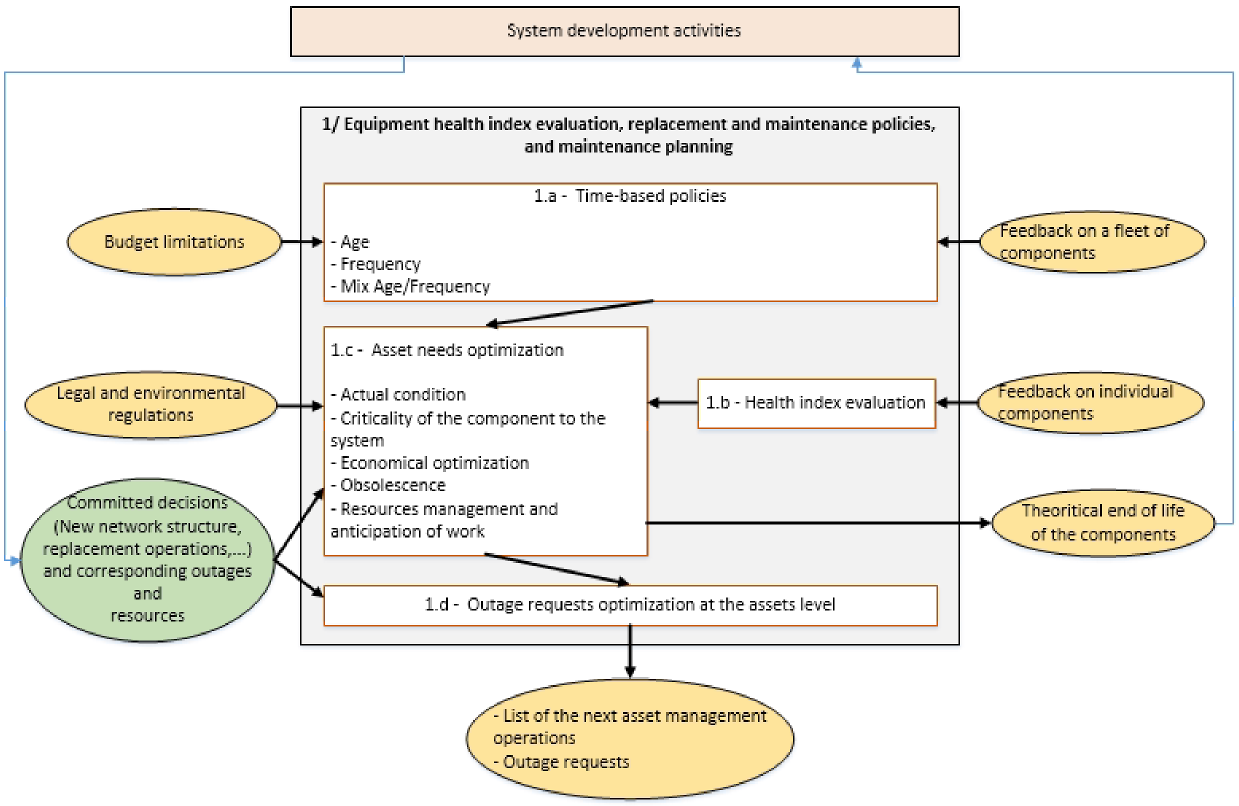

Figure 3-1: Diagram for the module "Selection of the required inspection/maintenance actions and detection of the replacement needs"

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3.1 Health index evaluation

The health index is one method of representing the condition of each component of the grid. It is a normalised value that represents the risk of the component failure and also the relative time to its end of life. The health index should be computed with consideration to several aspects of the component condition, as a weighted average or as the maximum of them. Those particular indices are usually selected from the list below:

- **Age index** – Age is the first attribute which is observed. In general it is expected that the failure rate and service cost increase with age.
- **Sustained stress index** – Aging of same components or their parts is strongly correlated with loads or switching cycles. This index represents the stress level endured by the components through its life.
- **Degradation by the environment index** – There are many environmental factors that have influence on component condition. This index represents component degradation by corrosion caused by pollution or salt deposit as well as damage by strong wind and lightning and also risk of short circuit caused by growing vegetation.
- **Actual condition index** – This index represents the condition of the component that was estimated at last maintenance or periodic inspection or online diagnostic – e.g. oil and SF6 leaks, analysis of oil quality and transition state analysis.
- **History of technological model index** – TSOs usually operate groups of components of same type and similar age. This index represents the average failure rate and maintenance cost for a component group.
- **Model sustainability and reparability index** – Sometimes components work well and reliably, but in case of failure, the repair can be difficult. This is due to the inability to buy new spare parts and depleted stocks. The second reason is that the time needed to repair is too long. This is included in this index. Although not a direct "health" indicator, this index must be taken into consideration.

If we observe the indices in time, we find that most of them slowly rise. After some component maintenance operation, some indexes get significantly reduced, meaning the life of the component has been extended.

3.2 Asset management strategies

3.2.1 General considerations

Every replacement and maintenance policy has two aspects – timing and task (What to do? When to do it?). These aspects are linked and must be determined together or interactively. Several approaches are currently used by the different TSOs, which can be ranked from the simplest to the smartest. Of course, the most sophisticated methods require input data and evaluation methods which may be challenging to estimate and put in place.

The core problem for the asset managers and equipment experts lie in balancing the different options at hand over a long period of time:

- Doing nothing vs. corrective maintenance vs. preventive maintenance vs. replacement
- Including in the analyses the forecasted grid development projects, anticipating some work to smooth the resources, and including environmental and other non-monetary factors in the definition of the policies

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3.2.2 Possible strategies for asset management policies

All the following strategies are representative of the current practices of the responding TSOs.

Corrective Maintenance (CM)

The simplest strategy is to do nothing until the component failure. The bright side is that no money is spent on unnecessary preventive maintenance. However this is not a winning approach, because the overall gain of preventive maintenance on a fleet of components exceeds by far the expense incurred. Moreover, because of the high number of unplanned contingencies due to this strategy, a low reliability level of the network and random resources needs can be expected. This method is usable (and used) for unmaintainable noncritical components. It is also used in combination with preventive maintenance strategies, whenever a component fails (and in spite of preventive maintenance, any component may still fail).

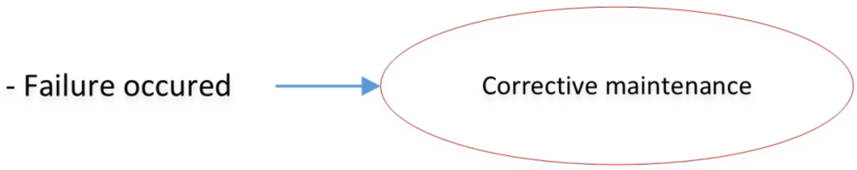

Figure 3-2: Input parameters for CM

Time-Based Maintenance (TBM)

In order to circumvent the lacks of pure corrective maintenance, the reliability can be controlled by the introduction of preventive maintenance in addition to the post-failure fixing operations. The first step is a time-based approach (age/frequency/mix). The time between failures or time to degradation of subparts (e.g. oil degradation or leaks) is seen as a random value. The time interval for preventive maintenance or inspection should be set as quantile of this value with probability that is determined by target grid reliability and by component impact on the grid. This quantile can be estimated from life curves, or by recommendations from the technology provider. Also the time intervals can be set from the analysis of historical data reliability. After the implementation of time-based policies, the different time intervals may be adjusted from experience. If the observed reliability is low, the time intervals should be shortened, or the performed maintenance can be heavier. On the other hand, if the reliability is high, then it is possible to assume the current policies are over-dimensioned, and consequently the time intervals could be extended. In other words, shorter intervals provide higher reliability but also usually higher maintenance costs.

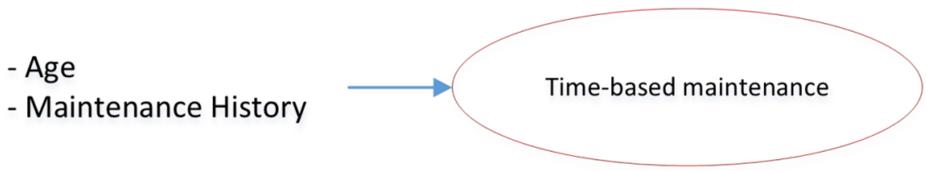

Figure 3-3: Input parameters for TBM

Condition-Based Maintenance (CBM)

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Time-based maintenance can be refined by incorporating in the equation the fact that all components are subject to different conditions (different loading, different pollution exposure....) and therefore do not degrade at the same pace. Consequently, the time-intervals abovementioned should be adjusted in order to put more efforts on the infrastructures subject to hostile conditions and heavy loading rather than on those which are in a more favourable environment.

This is possible by introducing measures such as online monitoring, diagnostics, periodic inspection and statistical modelling which provide clues enabling to differentiate the components that really need maintenance from the others. Condition can be simply represented by a health index.

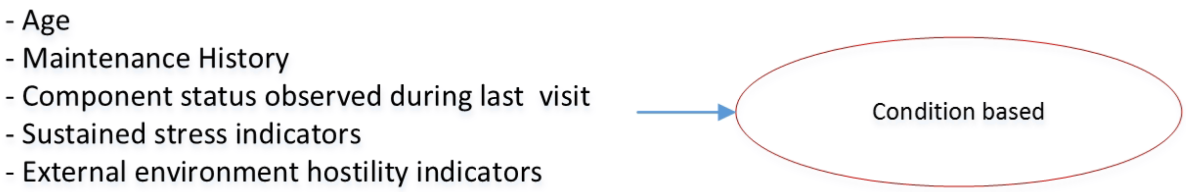

Figure 3-4: Input parameters for CBM

Reliability Centred Maintenance (RCM)

The most complex strategy used by TSOs seems to be the one called reliability centred maintenance (often abbreviated RCM), which is a combination of condition-based maintenance with additional indicators as safety and the importance of the component on the performances at the network level. Therefore, the assets that are the most critical to the grid (for instance those for which a contingency would result in high non-distributed energy) will have a higher maintenance effort than those for which a failure would have less consequences for the end-users. This approach is risk-based and includes extensive FMECA (Failure Mode, Effects, and Criticality Analysis) evaluations of all possible failures and failure modes for an asset and its sub-components. RCM is time and resource consuming, something that usually discourages companies that want to apply it in a clear framework rather than empirically.

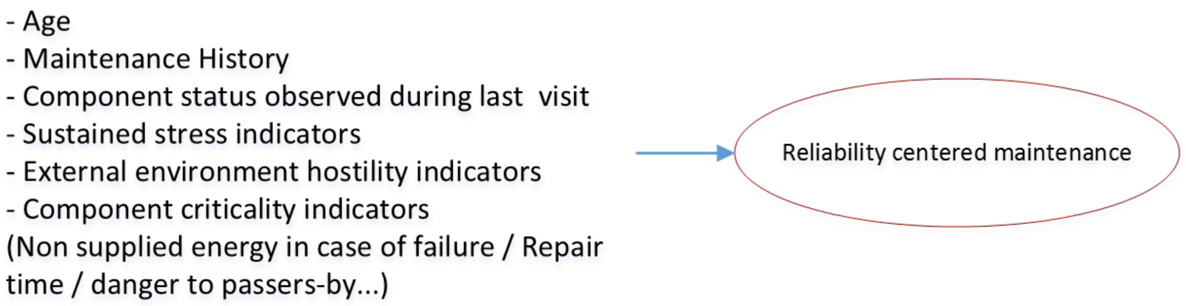

Figure 3-5: Input parameters for RCM

3.2.3 Budget considerations

The budget for asset management can be differentiated into three categories:

(i) Planed preventive maintenance and repair;
(ii) Unexpected repairs after component failures or of components that are close to failure;
(iii) Development, replacement and refurbishment projects.

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Categories (i) and (ii) are considered to belong to operational expenditures (OPEX), while (iii) is seen as capital expenditures (CAPEX). Obviously, the budget devoted to emergency repair after components fail cannot be anticipated precisely, and must be forecasted based on experience from previous years. Traditionally, OPEX and CAPEX have their budget defined several years in advance, and these budget allocations can be adapted depending on the foreseen requirements (in particular for the foreseen replacement needs). In practice, the yearly asset management workload is mostly defined by the allocated budget resources. These buget allocations are fairly consistent from one year to the next.

The yearly budgets are distributed by families of equipment (overhead lines, transformers, circuit-breakers...). Depending on the forecasted needs, it is possible to revise those budgets to grant more funds to a specific family that requires it, at the detriment of another family of components.

3.2.4 End of life management

End of life refers to the point when a component is subject to one of the following conditions:

- The component has known a major failure and is from this point beyond repair;
- It is no longer economically viable to maintain the component compared to the replacement cost (economic obsolescence);
- A new technology, more efficient or capable of new functions, has emerged and justifies the need for replacement (technological obsolescence). Components for which finding spare parts is difficult, or for which the competences to manage these old assets are fading, also fall into this category;
- New regulations have come into force and compel the replacement of the components (regulatory obsolescence).

Further explanations of these end-of-life triggers can be found in [36]. As explained in §2.4.1, when a component is reaching its end of life, concertation with system development becomes necessary.

For most of the components, the replacement of the old component is performed prior to the final failure. Yet, another option in use for the most expensive assets like transformers consists in buying spare parts in advance, store them in the substation, and wait for the failure to occur before replacing the transformer by the new one. This method enables to use at its maximum the lifetime of the component, while mitigating the consequences incurred by the failure.

3.2.5 Environmental concerns

This section deals with non-monetary issues which are associated with asset management activities, and how they can influence the asset management policies. Some of them could be deemed relevant to be included in the future criteria proposed in GARPUR. These elements are currently in the mind of the people who have to take the decisions, but TSOs lack the proper tools to quantitatively assess the impact of their decisions on these parameters and also to intercompare these impacts which cannot really be translated into monetary costs.

Non-monetary impacts can be divided into the following three categories:

(iv) Environmental concerns.
(v) Human safety.
(vi) Image, legal and regulatory.

3.2.5.1 Environmental issues

All TSOs are concerned with different environmental aspects related to their activities, which may include carbon footprint, biodiversity, fires, pollution and waste reprocessing, among others. In the following

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sections, the subjects in relation with the context of mid-term and asset management (described in §1.1) are addressed. Issues such as EMF (electromagnetic fields) are left aside because they are completely out of scope of the reliability management process, and issues such as the visual impact of the building of new lines is regarded as specific to system development, and hence should be further developed in WP4.

Carbon footprint

Among the main factors responsible for carbon emissions due to TSOs activities, the top four ranked are:

- grid losses
- SF_6 (sulfur hexafluoride) emissions
- purchases of electrical equipments
- worksites emissions (wastes)

The minimization of losses is a subject which is relevant to all TSOs time-frames. In most electrical networks, the generation fleet includes non renewable energy sources, and diminishing the losses means diminishing the amount of coal and nuclear fuel burnt to produce energy. Consequently, the monetary cost related to losses buying could be also adjusted with an ecological parameter. Concerning WP5, scheduled outages generally have a negative impact on the losses because the equivalent resistance of the network increasess due to having a component out of operation. In some cases, it is possible to interrupt maintenance and reconnect a line overnight in order to reduce losses during the required outage. Yet, this decision rather falls into the scope of short-term operational planning. The preparatory work performed in the mid-term horizon can nonetheless propose plans to reduce the restitution delay of the lines (or of the concerned equipment) so that this possibility appears reasonable once in the short-term.

SF_6 leaks are also one of the main environmental concerns for the greenhouse gas footprint of the TSOs. SF_6 is a gas used as insulator for circuit-breakers and also in gas insulated substations (GIS), for which there is no known substitute. The issue with SF_6 is that it is approximately 20 000 times more potent than CO_2 in terms of global warming potential. For the proper behaviour of circuit breakers, the impermeability of the SF_6 container has to be checked regularly. When leakages are observed, the circuit-breakers have to be refilled with new SF_6, and the leak fixed. The ideal solution to avoid the environmental damage caused by SF_6 is to find a substitute, but in the meantime it is necessary to adapt the rate of maintenance on circuit-breakers and GIS to limit the leaks.

Finally, replacing old components too early before their expected end of life by new ones induces the fabrication of electrical material in an unoptimized way. Also, the heavy logistic required to transport the new components from the factory to the substations or anywhere they are expected is also accounted for in the TSO carbon footprint.

Biodiversity

TSOs implement different kinds of actions in order to preserve fauna and flora biodiversity when constructing or maintaining grid assets. These actions are generally limited to sensitive areas like natural protected areas. The protection of the avifauna is one of the complex challenges TSOs have to cope with. They have to limit for example bird collisions with overhead lines by installing avifauna devices to repel them or by creating special nesting areas for migratory birds (see §1.5.2). Similarly, rodents can eat telecommunication wires, and should be repelled. In some cases, TSOs may have to postpone maintenance operations during nesting period of protected species.

Noise

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The noise caused by electricity flows on overhead lines or transformers can be disturbing for inhabitants and wild life. Performing some maintenance operations, such as cleaning transformer's fan, can reduce that noise.

Risk of fire, water pollution, and waste reprocessing
Contact of vegetation with a transmission line can lead to a short-circuit, which may result in a fire, with difficult to measure consequences on the surrounding environment. Hence, TSO assets are regularly inspected to make sure the vegetation growth has not become a threat, and when adequate, trimming of trees is undertaken. Wooded areas crossed by overhead lines are particularly exposed to this risk.

Oil leakage from transformers and underground cables is also a threat to the environment, because of water and ground contamination. Similar to the problem of SF_6 leakages, asset inspections provide an opportunity to monitor that there is no oil leak, or when one has been spotted, to fix it as soon as possible. Overall, the presence of collecting pits greatly reduces the potential for oil leaks to damage the surrounding environment, and this risk can be deemed limited and under control.

Although it is not directly connected to the reliability management decisions, waste reprocessing is also an important objective for the TSOs that has to be mentioned. Indeed, worksite maintenance can generate different kind of waste (ground, metal, oil, asbestos …). According to the nature of the waste specific reprocessing actions are taken.

3.2.6 Human safety

A special attention is given to human safety by the TSO. It concerns the safety of worksite workers performing the maintenance, as well as third party such as civilians, suppliers and firemen. For instance, the unexpected fall of a conductor on a wanderer or on a road is an unlikely event, which yet has to be accounted for when deciding the maintenance/replacement policies. The severity of a workplace accident may range from slight injury to heavy handicap or even to several deaths in the worst cases. Risks to human safety are mitigated by employing all the necessary measures and training is undertaken to avoid the risks of electrocution. When planning outages and comparing candidate decisions (See §5.5), the risk to human safety must be considered in combination with the technical reliability of the electrical system.

3.2.7 Image, legal and regulations

TSOs do not have much experience with image, legal or regulatory consequences. Most of the indicators used to measure these impacts rely on text analyses, and are therefore hard to quantify. For instance, when considering the image impact, an indicator could be the number of newspapers articles. But some papers are critical against TSOs, some are not.

3.2.8 Accounting for non-monetary indicators in the asset management strategy

In their current practices, TSOs do not only focus on direct monetary costs to define their asset management policies, they also consider other indicators, such as the potential consequences on the environment or the risk to the security of people. For illustrative purpose, the frequency rate of maintenance of overhead lines crossing highways will be higher than for others, due to the risk of having the conductors falling on the road.

These other non-monetary dimensions cannot be omitted, and the question of how to integrate them in the equation has always been a tricky one. One option would be to translate them into pseudo-monetary values that could be melted with all other variables, and allowing for direct comparison. Yet, these kinds of comparisons can be argued. Therefore it is possible to work with a set of indicators (called business

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values), and provide several ranges of consequences measured through relevant Key Performance Indicators. A common representation used for that purpose is a Business Values Matrix, as the one presented in Figure 3-6. This method has the advantage that it postpones the comparison stage at the very end of the process when it is not easy to melt everything in a single pseudo-monetary unit value.

Business Value	Gravity level			
	Moderate	Serious	Severe	Catastrophic
Financial	< 100 k€	100 k€ à 1 M€	1 M€ à 10 M€	> 10 M€
Quality	< 100 kmin	0.1 – 1 Mmin	1 - 10 Mmin	> 10 Mmin
Safety	Longlasting absenteism	1 disabled	1 death/heavy handicap	Several deaths
Legal	Condemnation	Heavy fine	Imprisonment	Loss of licence
Environment	< 100 k€	100 k€ to 1 M€	1 M€ to 10 M€	> 10 M€
Image	Regional article, complaint in newspapers	TV program, national article, week regional	Week national, month regional	> 1 month national
Regulator	< 10 corrections	Dozens of corrections	Single conflict	Structural clashes

Figure 3-6: Example of a business value matrix

The thresholds in the matrix above are likely to be different from one TSO to the other. Among other parameters, it should depend on the size of the responsibility area of the TSO.

3.3 Maintenance planning

This section deals with maintenance planning. There are two different cases – preventive and corrective (emergency). In the case of preventive maintenance, the tasks are planned in advance and human, financial and special part resources are well known. On the other hand, a TSO should be prepared for forced outages which means to be able to restore the grid as soon as possible. For this reason, TSOs must keep capacity of human workforce and stock sparse parts/components. These resources are usually shared with preventive maintenance.

3.3.1 Preventive maintenance planning and outage pooling

The first list of required inspections, preventive maintenances and repair actions is elaborated several years before operation. The list is created based on the replacement and maintenance policies. This

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activity is coordinated with grid development. Human workforce, spare parts needed, time and price are estimated for each activity. These actions are scheduled to draft a first plan. The long horizon allows optimal use of resources capacity and pool the activities with same outage request. Additional requirements can be added in next year(s) due to condition based maintenance.

3.3.2 Emergency repair

Even in cases where preventive maintenance is implemented, components can fail suddenly or can have to be turned-off if a recent diagnostic raises an alarm. Forced outages of multiple components are also possible (e.g. multiple component damage by fire in a station, cascade failure by overloading after contingency or damage of several power lines by hurricane etc). It could cause partial grid or total grid blackout in the worst cases. These events cannot be completely eliminated. Forced outages may interrupt predictive maintenance because they cannot be done due to grid constraints or resources should be needed for emergency repair.

Emergency repair involves the following steps:

- Estimation of the degree of grid damage;
- Restoration of power supply;
- Restoration of grid robustness level;
- Analysis of the cause of the failure and adaptation of the preventive maintenance.

3.3.3 Workforce issues

Among the topics related to the asset management policies, the following workforce aspects should not be forgotten, although they probably will not be the main concern for the rest of the GARPUR project:

- The workforce for the asset management operations is often a mix between internal people and specialized third-parties;
- This worforce is shared between development projects, inspection/maintenance/replacement projects, and the fixing of unexpected failures;
- The question of training and necessary skill to carry out the most difficult interventions is relevant to asset management.

3.3.4 Determination of the intervention characteristics

For each of the outage requests, the following informations are determined:

- Earliest date to start the work;
- Latest date to start the work;
- Duration;
- Restitution delay;
- Operatory process;
- Workforce needs;
- Logistic needs;
- Possibilities for live work or any other special action;
- Known incompatibilities with other outages.

3.4 Component procurement and logistics

In a basic sense, the process of procurement and shipping a spare part can be summarised by the process diagram shown in Figure 3-7. The individual aspects of the procurement and logistics workflow are discussed in the relevant sub-sections below.

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In general, the procurement and logistics problem would be solved on a case by case basis. This is due to the choice of manufacturer and logistics depends entirely upon the economy, as well as the capacity of individual firms to manufacture or transport the goods at the time of request. This case by case problem can be considered as part of a larger macro-problem, which aims to optimise the quantity and location of stored materials. Ideally, the logistics problem would only be required when spares are used and need to be placed, or when new components are required. An additional macro-problem could be considered, in which parts are not replaced by identical components, but instead all ‚similar‘ components are migrated to identical models in order to reduce the quantity of spares required at some point in the future (i.e. two unique transformers require two spares, whilst two identical transformers may need only one spare).

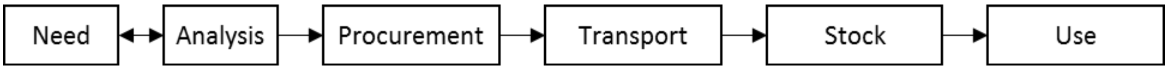

Figure 3-7: Part procurement and shipping workflow

The procurement and logistic workflow is initiated by some identified need to procure a new component (either as a spare part or as a part intended for immediate use). This need may be generated within an Asset Management or a System Development context. The cause of the need is not within the scope of the procurement and logistics problem.

3.4.1 Analysis

Once a need for a new component has arisen, it is analysed to determine:

- If the part can be replaced by a different component (i.e. a more modern component, a model that is identical to a nearby component to allow for ‚component pooling‘, etc.)
- If the need is valid (i.e. cost of spare is greater than its benefit)
- What quantity of the component is required

In general the analysis process must occur in coordination with the engineer responsible for initiating the procurement process, in order to assess the feasibility of alternate components or solutions. Similarly the analysis may result in the need being determined as superfluous, such as in the case of the stock of the component being enough to guarantee system reliability. In general terms, the analysis step aims at optimising the procurement of goods in terms of reducing costs whilst maintaining the required stock of spare parts and required part quality.

3.4.2 Procurement and transport

The procurement task then aims to minimize the cost of manufacture and logistics, as well as the time required for the order to be received. The main risks associated with the procurement and transportation tasks can be seen as:

- Time lost due to delays in manufacturing
- Time lost due to delays in transport (i.e. a ship visiting intermediate harbours in order to fill its carrying capacity, or a ship running aground)
- Damage to goods in transportation (i.e. movement of sensitive parts during shipping or lifting by cranes)
- Loss of goods in transportation (i.e. goods falling off of ships, or being lost/stolen during change of transport methodology)

In general the manufacturing goes through an initial tendering process. Upon acceptance the transportation may go through a tendering process. Both processes are subject to a risk assessment, to

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manage the risks listed above. The costs of manufacturing and transport (before tender) are somewhat predictable, normally within a margin of 10%, based on historical quote data. Generally the process is to assume that the cost has increased slightly since the previous quote, such that all cost estimates are pessimistic. The cost predictions however may be significantly wrong when significant macro-economic changes occur, such as the busting of the cable cartel by the EU in 2009 which resulted in cable costs reducing by approximately 30-40% [42].

The total manufacturing and transport time depends upon the component type being manufactured. For non-unique or small parts, the total time from order to arrival ranges between 2-4 months, depending on the location of the manufacturer and the complexity of the component. Circuit breakers take approximately 6 months. Transformers may take anywhere from 8 to 12 months. Generally electrical components take the longest due to their technical complexity, and their unique design parameters (i.e. not off the shelf). Specifically regarding transport, the time required for a manufactured good to reach storage is subject to:

- The manufacturing location
- The transportation methods used (trains, ships, planes)
- The number of changes of transportation methods (requires time consuming logistics to move an item from a train to a ship)
- The season (i.e. shipping in the North Sea is normally avoided in winter months, and the weather affects shipping times)
- The capacity of the transport, and its likelihood of making additional stops to maximise its capacity use
- Cost constraints on the transportation (i.e. slower transportation in order to reduce cost of low importance items)

Large and heavy spare parts restrict the potential paths for transportation between the manufacturer and the storage point. This also restricts the number of logistics companies that are capable or willing to transport the good. As a result, the transportation costs increase significantly for larger/heavier parts as it may restrict road routes, require police escort, require stronger carriages, and restrict ports based on crane sizes, among other considerations.

3.4.3 Stock

The stocking of goods task can be described as the optimisation of where a particular part should be stored, how it is stored, and how it is tracked with internal systems. The internal tracking systems are presently seen as a point for future improvement. That is, the location, quantity and quality of spare parts should be known in a central system. Such a central tracking system would allow for quicker response times in the case of a failure (rather than relying on intuitive knowledge of the location of spares) and also allow for greater analysis of system-wide spare optimisation (quantity & location). Finally, the use of a component depends upon how well the component is tracked (do maintenance teams know where it is? That it exists?), its location, and the location of other spares.

Substation specific parts are kept in substations, whilst spare parts for lines, towers and other parts are kept in one of three large storage locations (yards and warehouses). The quantity is determined such that critical components have spares immediately available, whilst other parts are stored on the basis of a risk assessment regarding whether their failure can be worked around (i.e. replacing a steel tower with a temporary wood tower) or whether their parts can be pooled for similar components (i.e. 10 of the same component may only need 2 spares to be considered reliable). The quantity of parts required is considered as a separate problem to the procurement/logistic problem.

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3.4.4 Use

The use of a component, after the procurement and logistics workflow does not define a task, but rather the endpoint of the workflow. The time of use does not directly affect the procurement and logistics workflow, but may be used to define inefficient timing of the entire workflow. That is, the frequency of use should determine the quantity of stock required. It is not ideal to have stock that is stored for a long period of time (especially outdoors), just as it is not ideal to have stock that is used too rapidly to accumulate to the required levels.

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4 FORECASTING FUTURE OPERATIONAL CONDITIONS AND PREPARATION OF CREDIBLE SCENARIOS

4.1 Introduction

This chapter presents the input data and models currently used by TSOs to prepare the scenarios that will be analysed for the purpose of reliability assessment. In the time-range of WP5, the overall grid structure is a well known input data, while the availability of the existing assets will be the question mark. The future meteorological conditions are estimated according to the records of the previous years, as it is the case for the expected load and renewable production. Information from generators and industrial customers, which are external players from a TSO point of view, on their expected availability for the target period are shared. It seems possible to distinguish different kinds of forecasts/scenarios used by TSOs within the mid-term horizon. For adequacy or system development purposes[1], probabilistic models may be used, resulting in Monte-Carlo simulations. For congestion management during particular outages, outage planners will mostly base their decisions on power-flow studies using only a very limited set of scenarios similar to the cases of the few previous years (for regular conditions and severe conditions).

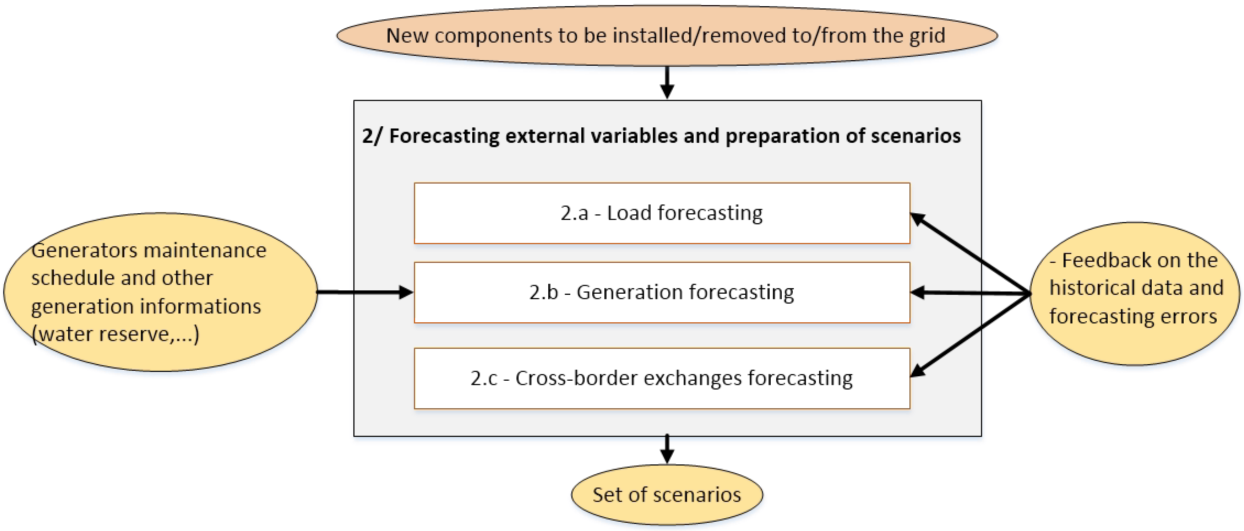

Figure 4-1: Diagram for the module "Forecasting future operational conditions and preparation of credible scenarios"

4.2 Changes in the grid structure

The structure of the grid is supposed to be a well known input data in this time-horizon. The new transmission lines, substations, industrial loads and generation units that are going to be built or removed should have a scheduled date proposed, and the potential delays should remain limited at this stage.

[1] It is important to remind that in WP5, only "quick wins" system development decisions are concerned, such as the installation of capacitor banks or automatons. The building of new transmission lines or other heavy strategic investments belong to the scope of WP4, and the reader should refer to the sibling deliverable GARPUR D4.1.

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As it will be further explained in §5.4, the mid-term horizon allows some light addition of electrical components into the grid, such as capacitor banks or phase-shifter transformers (the latter is usually analysed in a system development context rather than an emergency possibility implementable within the mid-term). The big difference with heavier structure modifications as proposed in system development is that these components are installed inside the existing TSOs' premises, and so do not require a long period of concertation and negotiation with local authorities to obtain development approval.

4.3 Load forecast

4.3.1 "Quick wins" system development purposes

Two types of load forecast can be distinguished:
- individual peak for each substation, called asynchronous peak;
- load of each substation at the moment of the national peak, called the synchronous peak.

In each case, the load must be gathered in MVA (measures of active and reactive power or measures of active power with the cos phi).
Knowledge of the asynchronous peak is important to size grid components. TSOs can determine the asynchronous peak by analysing the measures for each substation. Once the peak of a substation is known the values of all individual loads are extracted. In order to have forecasts it is necessary to interact with DSO's and direct customers to:
- verify or correct the peak value if not representative;
- collect growth factors and punctual changes.

With this information the asynchronous peak forecasts can be computed for mid and long term, which can indicate investment need for grid components. Knowledge of the synchronous peak is useful to size the transmission grid. TSOs can determine the synchronous peak by measuring the total load and extracting all individual loads at the moment of the national peak. In order to avoid distortions, it is important to include some quality checks in the extraction. For each load a bulking factor is computed as the ratio between the value of the load at the synchronous peak and the asynchronous peak. By knowing the asynchronous peak forecasts and bulking factors for each load asynchronous peak forecast can be calculated : $Sychronous\ peak\ forecast = bulking\ factor * asynchronous\ peak\ forecast$. This is called the "micro" approach.

In general, the sum of all the individual "synchronous" loads doesn't fit with economic and energy growth prospects. A last correction must be made by taking into account the growth prospects for the entire country and for the various economic sectors (residential, transport, industry etc.). This is called the "macro" approach. The synchronous process is described for the national peak moment, but can also be applied to any other moment (for example at the moment of the summer dale). Another approach to deduct other moments throughout the year is to apply different load profiles to the synchronous peak. This approach lowers the level of detail, but is time-efficient. Figure 4-2 below gives an overview of the load forecast process.

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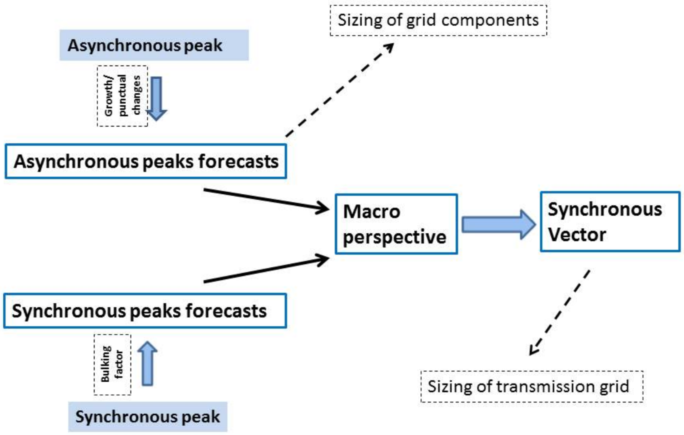

Figure 4-2: Shows the process of sizing the grid and its components given Peak data

The described methodology for load forecasting is relevant from one year ahead and beyond.

4.3.2 Adequacy purposes and grid constraints identification purposes

Load forecasting in a shorter time horizon, typically for the testing of scheduled outages, can also be computed by analyzing historical data from previous years for the same period. The seasonal variations of the load can be easily explained by the seasonal differences of day-light duration, temperatures, and of economical activities. Different conditions and scenarios can be computed, for example:

- Normal versus severe weather conditions; severe conditions should be understood as temperatures around 7°C below reference temperatures in winter, or 7°C above reference temperatures in summer. Temperature have a very significant impact on the load forecasts due to electrical heating or air-conditioning devices;
- Differences in load profiles and peak periods (e.g. morning and evening peaks in winter, night and 11pm peaks in summer)

Some case-by-case adjustments can be proposed by the mid-term expert planners depending on their knowledge of the recent changes in the load profiles (significant evolution of the consumption of a city, unfavourable economic climate leading to a reduced consumption from industrial customers,…).

4.4 Generation forecast

4.4.1 "Quick wins" system development purposes

In many cases TSOs know the maintenance schedule of all type of power plants (nuclear, pumped storage, gas turbine...) sufficiently in advance. They participate often in the planning process in order to avoid maintenance of a generator on an unadvisable moment (for example high demand in winter period). In order to plan generation outages TSO gather all the outages requests between 3 and 6 months in advance the year Y-1. First they plan the outages. Then they verify that the grid is safe and that no congestion occurs by computing Load Flow calculations with usual N-1 criterion. Loads are forecasted by using historical data. In case the maintenance schedule is not known, historical data can be used to calculate the expected planned outage rate (EPOR) for each type of power plants.

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On top of planned maintenance, unplanned outages can occur. An expected forced outage rate (EFOR) can be calculated based on historical data for each type of power plants. In case no historical data are available to calculate the planned and forced outage rates, general data for each type of power plants can be found in various sources in literature. For the mid-term, TSOs normally have a clear view on the decommissioning of generating units due to aging or other reasons (for example economical reasons). However, for the longer time horizon more uncertainty can arise on the set of generating units that are available.

On top of the dispatchable generation the generation mix is characterised by a growing amount of non-dispatchable generation units (wind, solar, CHP, etc.). These generation units are often taken into account by using profiles. When using profiles it is very important to respect the spatial correlation of the output of renewable energy sources (within a country, but also between different countries). Historical profiles are often used, adapted by the growing amount of installed capacities. For the estimation of the installed capacities different sources are used:

- databases collected by the TSOs or regulators based on information from DSOs, direct clients, developers...;
- national policies to reach certain targets;
- national studies which calculate potentials for the country;
- predictions based on historical growth rates.

The forecasts of the dispatchable and non-dispatchable generation units are used as input for market models. The unit commitment model estimates the optimal schedule of the dispatchable power plants to meet the electricity demand, taking into account non-dispatchable generation units and the operational constraints of the power system. When running the market model it is advised to run Monte Carlo simulations over several years in order to include:

- different drawing on EFOR (and EPOR in case the maintenance schedule is not yet known);
- different profiles for non-dispatchable generation units;
- uncertainties in fuel prices.

An outcome of the market model is a full generation forecast of dispatchable and non-dispatchable generation units. The following figure gives an overview of the input and outputs for the market tool:

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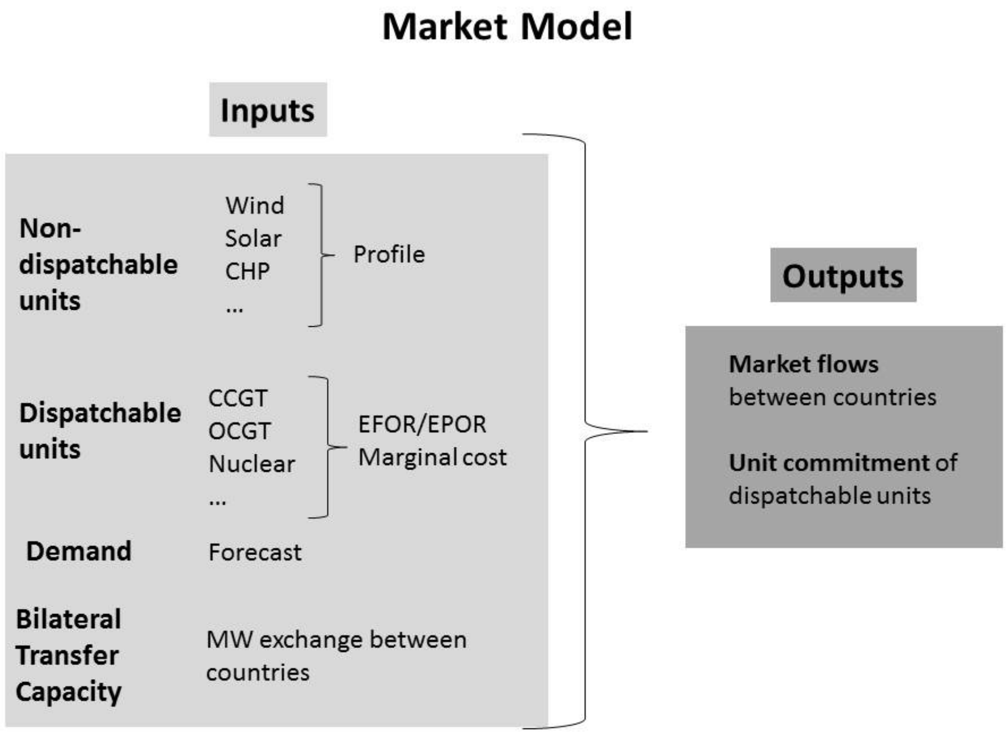

Figure 4-2: Market model diagram

4.4.2 Adequacy purposes and grid constraints identification purposes

In this context, the unavailability schedules transmitted by the generators are used for the different analyses:

- For outage scheduling and subsequent reliability analyses;
- For weekly adequacy analyses;

The renewable energy production, photovoltaic in particular, is becoming a topic of interest especially for summer off-peak periods, as the question of the evacuation of the surpluses has arisen due to the growth of this kind of electricity production. For adequacy studies, water reservoir levels may be predicted under a probabilistic form, taking into account the records of water stocks (which depends on the precipitation level and periods of snow melting).

4.5 Cross-border exchange forecast

4.5.1 "Quick wins" system development purposes

The flows given by the market model are not physical flows but market flows. In order to get physical flows, load flow calculation can be made on the basis of load and generation forecast obtained through the market tool or by applying power transfer distribution factors (PTDF). The first method is more accurate, but more time consuming. In order to calculate the market flows between the countries, an important input is the bilateral transfer capacity. The bilaterally agreed transfer capabilities between market nodes (BTC) should specify the expected capacity available for the market on an interconnection between two areas. In the future the impact of flow based market coupling should be evaluated. This will probably have an impact on how to come up with a cross-border exchange forecast.

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4.5.2 Adequacy purposes

In adequacy analyses, the cross-border exchange capacities are actually an output of the analyses. Depending on the forecasted consumption and generation units availability, the import/export maximum values that are deemed acceptable are computed.

4.5.3 Outage scheduling and grid constraints identification purposes

A few realistic values from the previous years are used.

4.6 Other relevant variables needed for the elaboration of scenarios

In addition to the MW supply/absorption variables and known grid structure modifications described above, several other parameters must be taken into account in order to elaborate scenarios that will be used to in the grid constraints analyses.

The following parameters are usually picked from a former similar case, used as a reference case. They are variables under the TSO control, hence they can be adjusted by the maintenance planner based on its own expertise:

- Topology;
- Voltage plan: the base voltage plan can be adjusted based on the expert planner's expertise, for example to fill a value for a generation unit that was on outage in the former case but will be in operation for the network under study;
- Transformers (including Phase Shifter Transformers) taps;
- HVDC set points;
- Loading limits on transmission lines; the thresholds depend on the component characteristics and on the season (i.e. on the expected weather condtions);
- Status connected/out of service of reactive devices

Besides, another relevant input that could appear in the preparation of scenarios, but which cannot be classified as current practice by the TSOs, would be the assessment of the probabilities of failure of the components taking into account per-season values, instead of values averaged on the year. See §7.1 and Annex 1 for a complementary description. To a lesser extent, the possible delays in generator maintenance, building or replacement of transmission lines, could be included in a future detailed probabilistic framework.

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5 ELABORATION OF A REFERENCE OUTAGE SCHEDULE, NETWORK RELIABILITY ASSESSMENT, AND RISK ASSESSMENT OF THE SUPPLY/DEMAND BALANCE

5.1 Introduction

This chapter mainly presents how TSOs transition from a list of outage requests as defined in chapter 3 to a reference outage schedule. Indeed, the output of the module 1 of the master diagram (Figure 2-1) as described in chapter 3 was mostly established without consideration to the network power flows, voltages, and security constraints. The point of the module 3 described in the present chapter is to show how TSOs incorporate all these parameters while preparing the outage schedules, hence permitting to operate the future network within an acceptable risk once in the outage period.

Some other reliability analyses (mainly adequacy) are also performed within the mid-term time-frame, in particular for the specific winter and summer seasons. The ENTSO-E summer and winter outlooks[2], which can be found online, provide each year an overview at the regional and European levels of the highlighted risks regarding the security of supply for these periods. Moreover, and independently of outage management, some actions specific to the mid-term, such as the installation of automatons or of capacitor banks, are also listed. These latter actions require a quite long implementation delay, and therefore cannot be evoked once in the short-term horizon. Yet, they are faster than the many years unavoidable for the building of new heavy equipments and requested prior concertation with local authorities.

[2] https://www.entsoe.eu/

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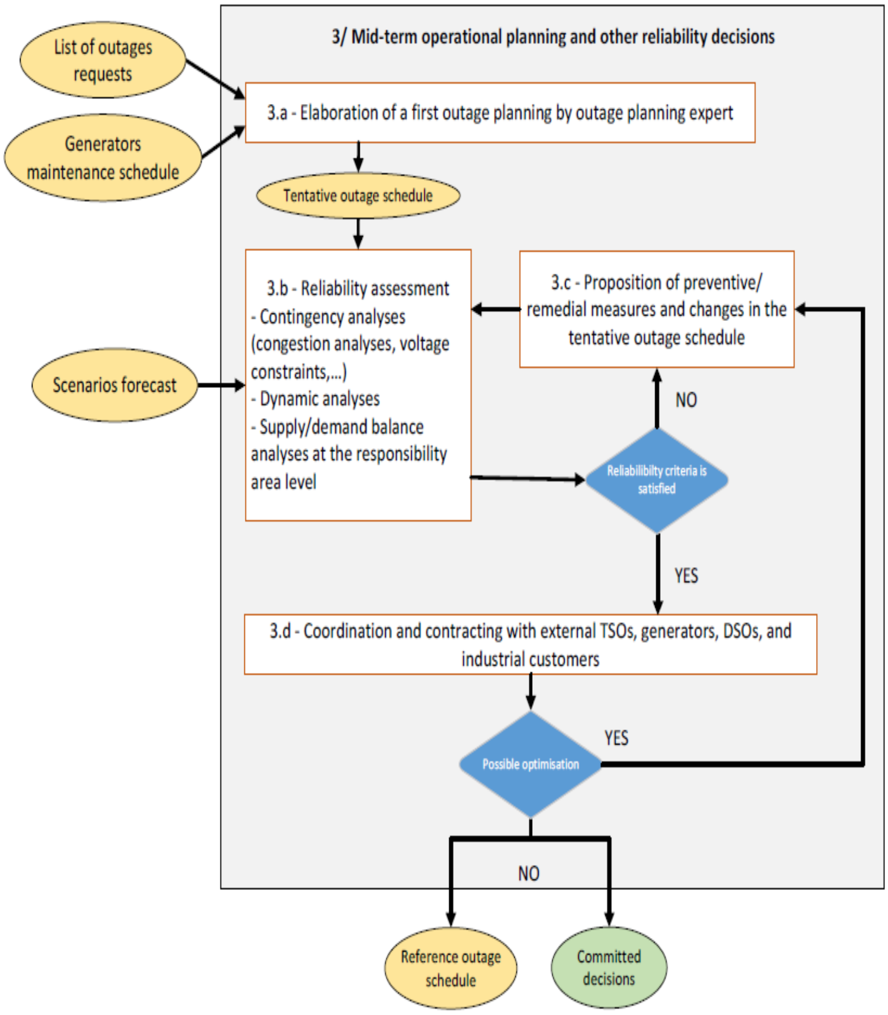

Figure 5-1: Diagram for the module "Elaboration of a reference outage schedule, network reliability assessment, and risk assessment of the supply/demand balance”

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5.2 Elaboration of a reference outage schedule

The preparation of the outage schedule is an iterative process, which usually starts several months or one year ahead. This schedule is continuously updated depending on the latest information received, such as a delay in a power plant's maintenance.

5.2.1 Initial Outage Plan

Most European TSOs tend to have a long-term maintenance plan of periodic activities that extend 5 or more years into the future. This long-term plan consists largely of policies which dictate how often certain components must be inspected, serviced or replaced. It is then common for this plan to be elaborated into an annual maintenance plan, which also includes the outages required by DSOs and connected generators. The annual maintenance plans are typically created in winter or just before, and commence shortly after. Outages that occur in the same region or are related to similar components (See §3.3.1 on outage pooling) are pooled at this stage of the outage planning process.

In general the initial outage plan is created with security of supply in mind, as well as other TSO specific criteria such as avoiding outages that restrict hydropower generation when their reservoirs are likely to be full. The creation of the annual plan is also largely based on knowledge of which outages cannot occur simultaneously, and knowledge of the expected loads and constraints at different periods through the year. As additional outage requests arise during the course of the year, the initial outage plan is constantly revised. The initial outage plan must also satisfy a reliability assessment, as discussed in §5.3.

5.2.2 Medium-term Outage Schedules

The annual outage plans are generally elaborated into smaller periodic maintenance schedules that cover the requirements and timing of the tasks in more detail. The length of these shorter schedules generally range from 2 weeks to 2 months for European TSOs. The outage schedule generally covers a subset of the outages in the outage plan, but with a more detailed reliability assessment given the better accuracy of short-term forecasts (rather than using general worst-case scenarios) for balance and weather. This reliability assessment is a detailed iterative process in refining the schedule given the present circumstance of the grid. Common reasons for maintenance proposals being rejected are:

- Some elements are not allowed to be out of operation during some load or weather conditions
- Many elements are only allowed to be maintained separately of each other
- To avoid unnecessary risks (such as an N-0 situation during a period of high load)
- To avoid unnecessary limitations to the cross border capacities given to the power market
- Short-term workforce limitations
- Short-term resource availability limitations

5.2.3 Reliability analyses

The most constraining outages are tested on a few deterministic cases (usually stressed situations) to ensure that the proposed outage should be robust to any credible contingency. At the moment, these analyses are performed using AC power flow software.

Should a difficult situation be detected, the outage planner would check whether it is possible to adjust the first schedule in a better way. This may occur for example due to several close components being on outage simultaneously.

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5.2.4 Optimization of the outage schedule in coordination with the other actors

Coordination with generators and industrial customers

The availability of the main power plants is a particularly important factor for the assessment of the reliability of the network, in particular when scheduling outages. A change in the electricity supplier maintenance program can lead to changes in the TSO's outage schedule. Likewise, TSOs try to adjust their outage schedule in a way that is most convenient to the industrial clients, e.g. during reduced activity periods (summer holidays) or during their own maintenance.

For most of the European TSOs, the outage schedule of the generators is an external – and non-binding - input, and these TSOs have to adjust their own outage schedule accordingly. They may nevertheless have some possibilities for early contracting with the generators, subject to their regional regulations or against financial compensation, to:

- render the presence of a specific power plant binding during a particular period when it is needed for security reasons
- impose limitations on the power output of a power plant during a particular period
- render the declared outage of a power plant for maintenance binding during a particular period of time. It enables the TSO to carry out a particular network outage while the power plant is unavailable, thus limiting the disturbance to this generation unit

Some other TSOs have more freedom with the electricity producers. They then plan both outages (on the generation and network sides) in close cooperation with the producers.

Cross-border capacity optimisation and coordination with DSOs

Neighbouring TSOs coordinate their outages close to the boarders, both for security reasons, and also to maximize the cross-border capacities. TSOs also have to coordinate and possibly adjust their outage schedule with the DSOs' outage schedules.

Special events

In some particular circumstances, some outages may be postponed because of particular mediatic events, during which an electricity shortage would be highly unwelcome. Such event could be for instance the organisation of a sport event (the Olympic Games), or of a special political meeting. Besides, when a TSO is informed about an unusual cessation of activity at a factory (due to a strike or internal failure for example), it may anticipate some of its work and outages accordingly. In a nutshell, the reference outage schedule evolves with time, unexpected constraints and opportunities, and shouldn't be regarded as carved in stone.

5.3 Reliability assessment

After the elaboration of an initial reference outage schedule, the viability of the schedule must be checked by performing a reliability assessment. This section explains the general procedures associated with this reliability assessment. It should be noted that the reliability assessment is first run for an initial schedule elaborated by an expert. The reliability assessment results then in adjustments to the maintenance schedule, which must then have their reliability reassessed in an iterative process. There also exists some specific levers not linked to outages, which are not long-term development decisions but will not be available once in the short-term, and that consequently fall into the mid-term horizon.

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5.3.1 Supply/demand balance analyses and cross-border capacities

The creation of viable supply-demand balance scenarios and cross-border capacities were discussed previously in chapter 4. The market, physical and cross-border constraints result in some credible scenarios to test the maintenance schedules against. The maintenance schedules are tested by assessing the viability of all scenarios given all the expected grid topology configurations that are scheduled to occur. This also includes the outages of connected generators, DSOs and connections to other TSOs. Specifically, this initial assessment is concerned with testing that supply and demand are in balance for all scheduled outages, and that no cross-border capacities are violated. Should a difficult situation be identified, the situation is re-evaluated accounting for the possible importation from neighbouring TSOs. In case the help from other TSO might be insufficient, the public authorities would be alerted.

5.3.2 Short-circuit analyses

Short-circuit analyses are not applied in the mid term planning of all TSOs. Dynamic simulations are applied to define the operational limits as well as the requirements of power plants in order to secure the needed short-circuit current in the various nodes of the electrical network. Minimum requirements are found using worst-case scenarios. These minimum requirements are then applied as a standard, strict requirement.

5.3.3 Static power flow and contingency analyses

In addition to the power balance and cross-border capacities discussed in §5.3.1, there is also a need to test a potential reference schedule for N-1 security, also known as N-1-1 security. It is of primary interest to identify outages which are not N-1-1 secure, or rather, maintenance outages which cause the system to unavoidably enter an N-0 state. In general maintenance schedules are revised where possible to minimize the occurrence of outages that result in an N-0 state. Where this is not possible, a risk assessment is required to determine the appropriate costly solution or preventative/remedial actions to prepare for the specific outage. The available risk mitigation options are discussed in §5.4.

5.3.4 Dynamic analyses

Dynamic simulations are used for several purposes. One purpose is to define the operational limits during normal network operation. Another is to determine the minimum requirements found during testing of the worst-case scenarios. These minimum requirements act as additional strict constraints on the power flow and contingency analyses to determine whether a particular maintenance schedule is acceptable.

5.4 Possible candidate decisions

As mentioned in §5.3.3, it is sometimes impossible to avoid the need to perform an outage task which puts the system at risk (i.e. into an N-0 state). As such, costly candidate decisions must be made in order to allow the work to go ahead without significantly affecting the system reliability. This section discusses the candidate decisions available in the mid-term timeframe, mainly to mitigate the risks associated with difficult outages (network elements and generation units), but also to mitigate the threats that have been detected between the long term and the short-term.

5.4.1 Adaptation of the outage schedule

The cheapest solution to a difficult or costly outage is to postpone the outage, or modify the outage schedule, to maintain the required level of system security. If the outage is high risk but not immediately critical, it may also be delayed in hope of an opportunistic maintenance window, such as when a

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connected generator has an extended unplanned outage. Essentially this candidate decision is the first option to be exhausted, and the remaining candidate decisions are only considered if reasonable delays are impossible.

5.4.2 Installation of reactive power devices and phase-shifter transformers

Reactive power devices (e.g. capacitor banks) may be installed within the mid-term time frame to supply reactive power to some electrical nodes, hence preventing a potential voltage drop. It is the same about phase-shifter transformers, which aims at offering the TSOs some control over the active power flows of a transmission line.

This decision, to a large extent, can be considered as a system development decision. Yet, given these equipments are installed in existing substations, inside the TSO premises, and thus do not require a long period of concertation beforehand, the installation of these devices is much faster than for transmission lines and than the building of new substations. Moreover, these decisions have as objective to increase the network security, whereas the buildings of new corridors, which increase the network capacities for decades, are more long-term strategic decisions.

5.4.3 Postponing power plants' maintenance program

In specific circumstances, it may be possible to reduce the risk to the system during a difficult network outage by postponing planned maintenance of a connected generator. This is often a costly procedure, and is therefore seldom used.

5.4.4 Night work, live work and helicopter assistance

In some cases the most cost-efficient method of managing the risk of difficult outages is to perform night work, live work, or use helicopter assistance.

Night work is more costly, but the loading of the system during the night may be less critical than during the day, and the economic consequences of lost load may be relatively acceptable. In the same manner, when the restitution delays are sufficiently short, it is possible to interrupt the work prior to a critical period, and restart this work afterwards. It should also be mentioned that sometimes, a TSO might chose to work during the day-time, and give back to the network the component on outage on the evening, thus reducing the losses during the night before restarting the outage the next morning. Sometimes, these practices can be economically profitable.

Live work (work under voltage) comes with added operational risks, but allows the component under maintenance to continue to function during the outage. Live work is only useful for specific maintenance tasks, and is not considered as an option by all European TSOs. It also implies a particular training of the workforce involved. Another method to avoid having a line out of service for the duration of the asset management action consists in setting a temporary parallel line while the work (for example replacement of a tower) is being carried out.

Finally, helicopter assistance may be used to drastically reduce the duration of the outage at increased cost. This does not reduce the instantaneous impact of the outage on the system reliability, but it reduces the consequences by restricting the period within which consequences can occur. This is useful in situations where lost load is unavoidable and the use of a helicopter would significantly reduce outage duration.

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5.4.5 Demand-side contracts

Demand-side contracts may specify some degree of flexibility of demand called a Demand Side Response (DSR). This generally specifies some capacity for the demand of particular users (generally heavy industry) to be shed at some cost to the TSO, when required. Load shedding may be quite costly, but it may also reduce the potential for less-flexible load to be lost during the difficult outage. Given that the proportion of fluctuating production is likely to increase in the near future, it is likely that the proportion of DSR available to TSOs will also rise. Similarly some TSOs make grid connection agreements with specific users that stipulate a limited access to electricity in the case of severe outage situations, which may be used during difficult outages.

5.4.6 Load-shedding automaton

The installation of new automatons, in particular load-shedding automatons, can be made within a few years delay, which corresponds to the time needed for software development and to perform the reliability analyses.

5.4.7 Dynamic line rating devices installation

Dynamic line rating consists in adjusting the authorized intensity thresholds of an overhead transmission line with the ambient conditions, mainly wind, temperature, and solar radiation. Therefore, the link between the heating due to the flow of electricity through the line and the subsequent conductor sag is better estimated, which permits in real-time to accept intensity flows above the standard thresholds when the conditions are favourable.

The setting of the sensors and telecommunication system to enable dynamic line rating belongs to the mid-term horizon.

5.4.8 Setting the protection schemes

Coordinated change of protection relay settings is applied for bypassing reactive compensation devices in some areas. Even coordinated relays system parameter settings for interconnectors is applied between the involved TSOs.

5.4.9 Candidate decision selection

All TSOs have different sets of candidate decisions available to them, based on either policy (i.e. no live work) or due to the structure of the system (i.e. system in which additional reactive power devices would be ineffective due to generation units being locate close to consumers). Similarly TSOs also have unique methods or tools that they use to determine which candidate decision should be made in order to deal with a difficult outage. For example, some TSOs treat it as a financial minimisation problem, in which they minimise the sum of enacting the candidate decision and the expected cost of ENS during the outage. Others use a risk matrix that covers both financial as well as safety, environmental, security and other metrics. Some TSOs in the GARPUR reference group also stated that candidate decisions aren't necessary, or that the decision is made based on expert judgement.

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6 LESSONS LEARNT AND UPDATE OF THE COMPONENTS RELIABILITY STATUS

6.1 Introduction

This chapter aims at introducing the lessons learnt and current practices for data collection and warehousing practiced in TSOs. It also emphasizes on various tools used in data management and the use of historical data in maintenance scheduling. The topic of data collection and management is one of the main features addressed in the next task of WP5 (i.e., task 5.2) of the GARPUR project. This task will tackle the interpretation of the stored data and needs for future practices. In the present chapter, the purpose is to show the position of the feedback loop and warehousing management within the whole framework.

Data collection and lessons learnt are obviously a topic of interest to all time-horizons. In WP5, the main concern is the collection of the data having a link with the assets reliability status. It encompasses all the reports from the field teams following any inspection of the assets, which provide valuable information on their health state and then enable to prioritize the needs in terms of further asset management operation. The consequences of contingencies are also analysed (financial, duration of service interruption, impact on the environment, etc.), thus highlighting the most critical parts of the network and potentially motivating changes in the different maintenance and replacement policies. The record of these data over the years is also invaluable when it comes to fine-tuning the degradation models, reaching a better understanding of the most significant threats, and subsequently the causes behind the threats. This process is represented in Figure 6-1, while an example of a data management system is shown in Figure 6-2. The data management system illustrates one of the many possible architectures. The vital components in the architecture being data collection, communication, processing and storage. Data collectors in the form of PMUs collect data and send it to data acquisition sub-system or SCADA. Similarly, weather data are collected in 'LOG.' The data generated by grid and weather are sent for processing and storage from data collection centers via high speed communication links. The processed data are then saved into a database, which are further refined using various data-mining techniques (discussed later in this chapter.) Sometimes the preprocessed data are used instantly for real-time decision making processes and in some cases, it is stored in database for future decision making processes.

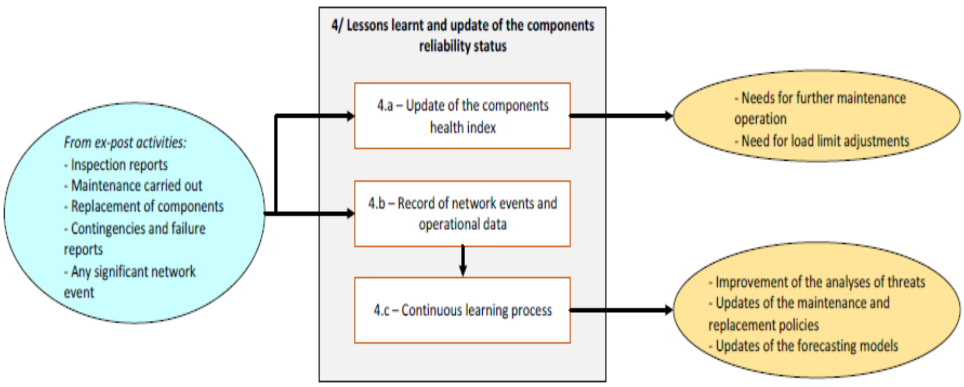

Figure 6-1: Diagram for the module "Lessons learnt, database management, and update of the components reliability status"

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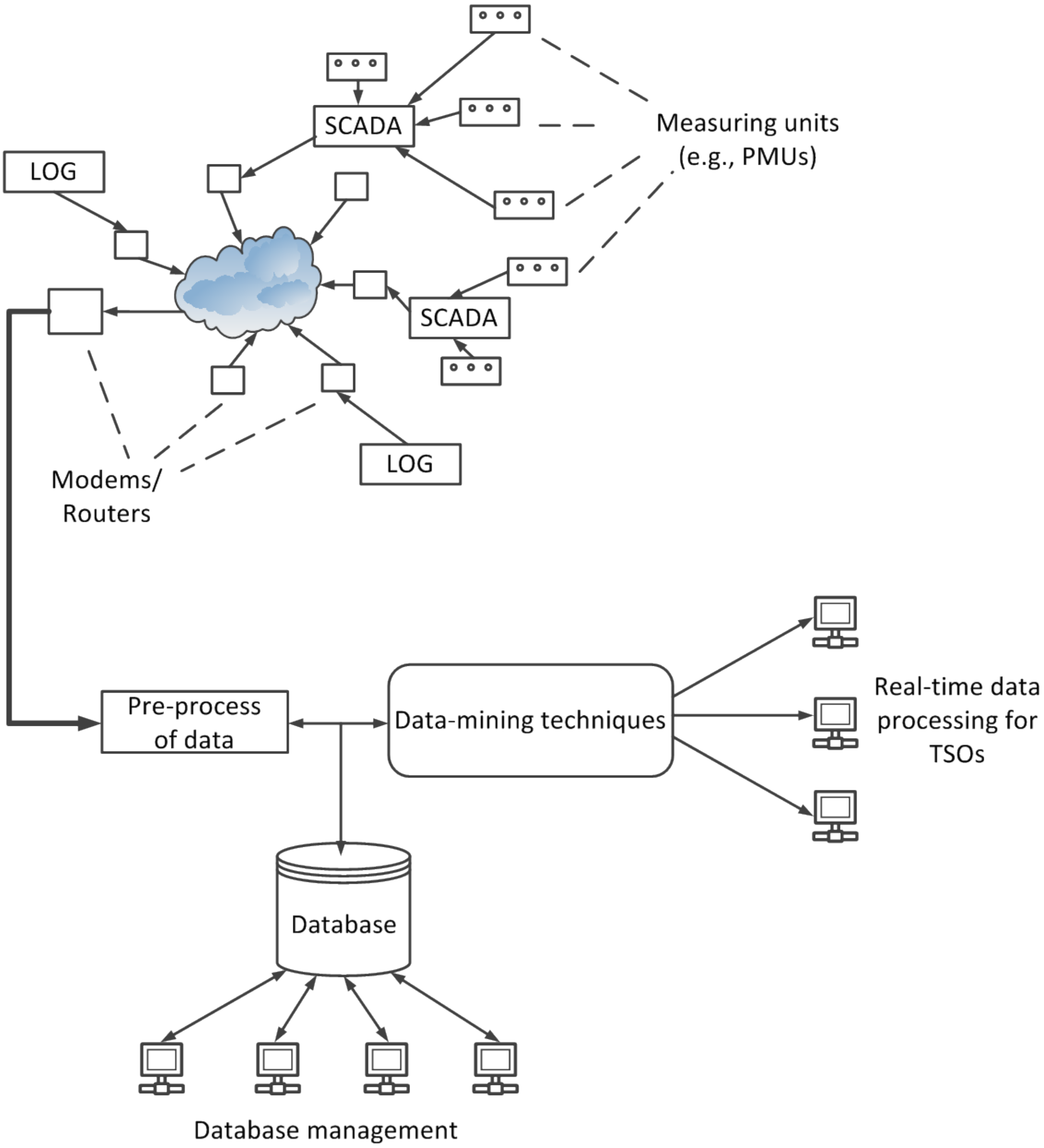

Figure 6-2: An example data management system

6.2 Current TSO practices for data management and modelling

The future European electric power grid is expected to have a significantly large amount of data and resource management, which is driven by the large number of data collecting sources and applications that store, process and share data. The large amount of data will be collected from various field devices like Intelligent Electronic Devices (IEDs), measuring units like Phase Measurement Units (PMUs), and SCADA/EMS devices that collect and pre-process data. The amount of data will increase both in terms of size and frequency of measurement as high-resolution data sources are integrated into the system. The high-resolution data come from grid-, environmental-, and market-conditions and proper utilization of this data can be highly beneficial in terms of optimal grid planning and operation.

To determine the future practices, it is important to learn the current practices of the participating TSOs regarding the collection and use of historical data. Processing historical, off-line, and real-time data helps

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in realizing key factors like anomalies in grid behaviour, likelihood of imminent disturbances and models for demand forecasting. Inputs in this chapter have been gathered from workshops in the GARPUR project and responses of questionnaire from 10 TSOs (northern and central Europe) that are either a part of the GARPUR consortium or a member of the GARPUR reference group.

6.2.1 Software used by TSOs

The TSOs were asked about the software tools they use for asset management, i.e., either internal/in-house developed or external/commercially available. Nine out of ten TSOs responded. Three of the TSOs use their in-house developed software while six of the TSOs use external software like Power System Analysis (PSA) toolbox, PowerFactory, ARISTO, PSS/e and GEN eBase. PSA toolboxes refer to various analysis and simulation based software commercially available, and used widely across the globe. Starting from power-flow, load-flow and calculating short-circuit currents, the toolboxes available also perform system stability and reliability analysis, protection and coordination, contingency analysis, economic modelling, etc. Some examples are PSS/e, DIgSILENT, ETAP, PowerWorld, etc. PowerFactory is an advanced and interactive computer aided engineering tool by DigSILENT [37], used primarily for planning and operation optimization. ARISTO stands for Advanced Real-Time Interactive Simulator for Training and Operation [38]. The simulator has the capability to simulate power system dynamics operation in real-time, both small and large systems. Gen eBase is a multi-functional time series management, data management forecasting and analysis tool developed by GEN [39].

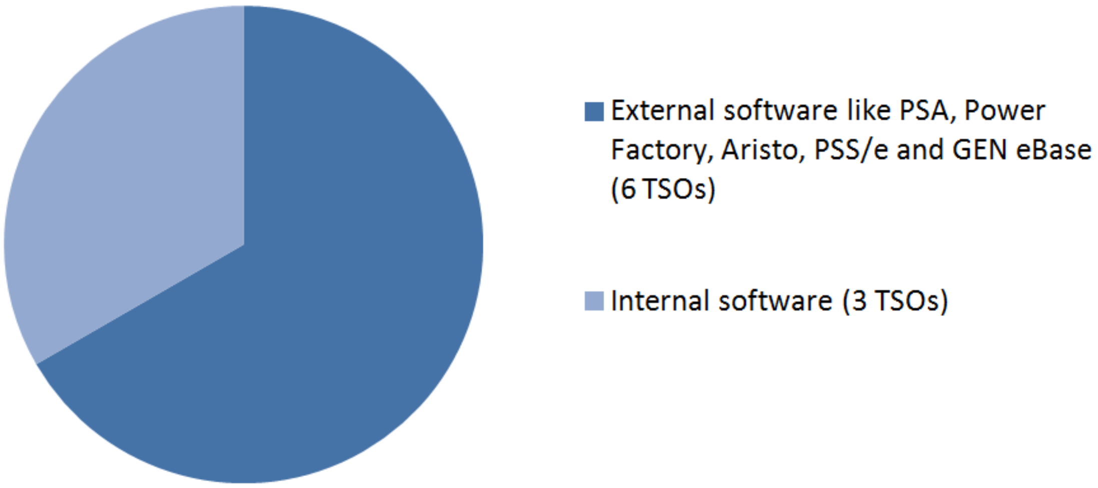

Figure 6-3: Answers to question on software tools used for asset management

6.2.2 Data collection and warehouse

Data collection and warehousing form an integral part of data management and modelling.

Components being the vital part of asset management, it is important to learn what the current practices are in data collection on component's faults, outage times, or failure causes. Nine of the ten TSOs collect these three types of data to correct or improve the system behaviour. One of the TSOs collects more intensive fault data, like, energy not supplied (ENS), cost of ENS (CENS) and protection equipment response during outages.

Continuing with the previous question, TSOs were asked how they use the collected data in asset management. The response is shown in Figure 6-4. Nine of the ten TSOs responded to the question. And, out of the nine TSOs, seven use the data for asset management. The replacement policy is the primary

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outcome of fault data collection. Apart from that, data are also used to evaluate HILP (High Impact Low Probability) events, the evaluation of low performance components and maintenance planning to estimate outage duration. Eight of the nine TSOs further process the data to calculate failure frequency, three of the TSOs process them to calculate repair times and five TSOs process the data to check long-term unavailability.

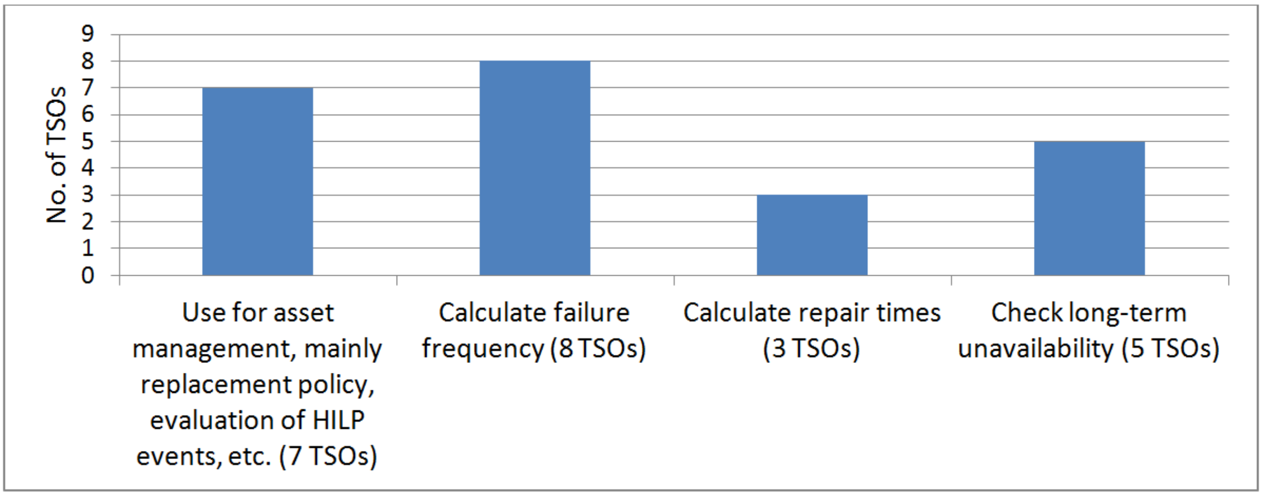

Figure 6-4: Answers to question on usefulness of data collection for components

Human error in data collection is also an important criterion for evaluation. The human error here refers to human-being working at a substation or at a line. All nine TSOs answered they collect data related to human error, and may perform a detailed analysis on human errors, i.e., cause, lessons learnt and ways of improvement.

6.2.3 Database management

A high-performance and extensible computational platform is required to extract relevant information from the large amount of data. Another requirement would be that the platform has the capability to handle high amount of data and process them efficiently.

Conventional database management systems like excel packages, spreadsheets and other statistical software only aim at storing large amount of data, and not focussing on large scale parallel and distributed data processing. However, in recent time, this has been overcome by advent of software packages like MapReduce [1], S4 [2] and FPGA-based data warehousing software [3].

6.3 Analyses of threats and failures

Components in transmission and distribution systems are power transformers, overhead lines and circuit breakers, to name a few. Power transformer represents approximately 60% of the overall cost of the network, and is ranked as one of the most important and expensive components in the electricity sector [4]. Study reveals about substantial study on power transformers in various literatures about health monitoring, ageing, and oil-indicators [5]-[10]. Similarly, studies have been carried out for overhead lines [10]-[13], underground cables [10] [14] [15] and circuit breakers [10] [16]-[17].

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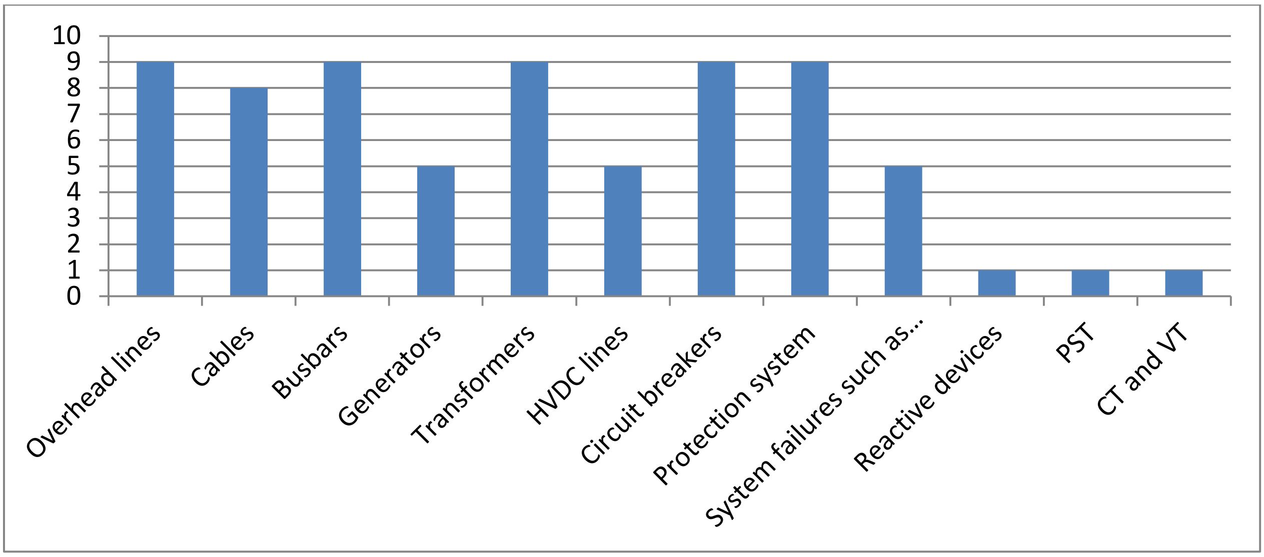

Figure 6-5: Answers to question on components considered under asset management

Components being vital part of asset management, a questionnaire on various components considered under asset management was asked to the participating TSOs. Nine of the ten TSOs responded to the questionnaire, and their response is shown inFigure 6-5. As seen from the figure, overhead lines, busbars, transformers, circuit breakers, and protection systems are considered under asset management by nine TSOs. Cables are considered by eight TSOs, and then it comes down to generators, HVDC lines, and system failures such as under-frequency situation, islanding etc. by five TSOs. Reactive devices, PST and current transformers (CT) & voltage transformers (VT) are considered by one of the TSOs respectively.

6.4 Overview of data mining techniques in TSOs

Data mining in electric power systems has evolved in the last decade because of the growth of available data in the electric power industry. The available data comes from varied fields like measurement devices and helps in performing event detection, and diagnostics. Literature survey shows that data mining has been a matter of interest in the last decade, and the interest involves modelling data sensitivities in identifying relationship, data-enhanced estimation of network models, event identification from oscillation monitoring data, and dealing with the challenges of real-world data and data equality.

With the advent of computational tools and information technology (IT) in the last decade, Kostic [20][21] made studies on application of IT in asset management. [21] focuses on the aspect of integrating IT in asset management by utilizing process data (e.g., SCADA, EMS/DMS) in back-end tools such as ERP, GIS, CMMS and other analysis tools. A decision support system discussed in the same paper based on Human Computer Interaction (HMI) is shown in Figure 6-6. Leaving aside IT and HMI in asset management, various computational models and optimization techniques have been developed for maintenance, refurbishment, ageing and monitoring techniques in asset management, like state diagrams [22], fuzzy techniques [23]-[25], neural networks [26], PSO [27], linear programming [28] [29], branch and bound techniques [30] and other optimization techniques [31]-[33].

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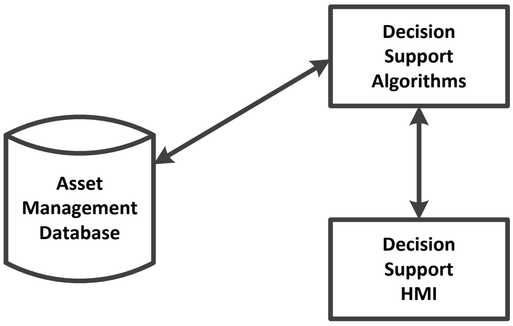

Figure 6-6: An example decision support system discussed in [21]

Learning from the current practices in data management and upgrading them is an important task in the GARPUR project. Data amount has significantly increased in recent times because of various data collection sources like SCADA systems, disturbance monitoring equipments, and other log devices, i.e., weather and outage log devices. Hence, data mining or knowledge discovery in databases will become important activities for a better understanding of the grid, and making correct decisions.

The participating TSOs were asked if they were currently using any data mining techniques in their activities. Nine of the ten TSOs responded to the question, and a majority of the TSOs haven't started using data mining techniques. For one of the nine TSOs, data storage and processing is taken care by external agency. But they don't use any data mining techniques. Similarly, seven other TSOs don't use any data mining techniques. The ninth TSO, however, has plans for implementing data mining technique in near future. In a nutshell, data-mining techniques are seen as promising for the (near) future, but are not used at the moment for operational activities. A first step toward this evolution is the identification of the required data to store (e.g. load history). Thus, TSOs should start collecting them as soon as possible for future analyses.

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7 NEEDS AND OPPORTUNITIES FOR PRACTICAL INTEGRATION OF NEW RELIABILITY MANAGEMENT APPROACHES

7.1 Improvement of the estimation of the probabilities of failure

7.1.1 Calculating differentiated probabilities of failure

A prerequisite for any risk-based reliability assessment of the electrical network, no matter the time-frame, is the evaluation of the probabilities of (unexpected) failure and of the restoration times for all the system components. As introduced in §1.3.3, proposing realistic failure rates for any component is challenging, given very few failures actually occur for most of the components. Yet, in order to bring a real added value to the risk analyses, it is important to propose distinctive probabilities for each asset, and not values that have been averaged out on the whole equipment family.

Asset specific failure probabilities are influenced by many parameters, including:

- Technology
- Age
- Size/length
- Maintenance history
- Failure history (some components in exposed area know very atypical failure rates)
- Sustained stress
- Working environment (pollution, vegetation...)

The complexity of the probability of failure model should not be limited to the previous factors. As a transmission line, which is seen as a single component from the network operator point of view, is actually composed of several subsystems (conductors, insulators, towers, etc.), a method should be proposed to melt information on the subsystems into a single data for the whole component which would be useable for future risk analyses.

Moreover, in short-term operation the probabilities of failure of the assets should be refined depending on the meteorological conditions and seasonalities. Quantifying the delta on the probabilities of failure between normal conditions and adverse weather conditions is once again a very difficult topic. A first step toward this level of detail would be to account for seasonal factors having an influence on the rates of failure, such as bird migration in spring, higher probability of lightning strike in summer, or ice/snow threats in winter only. Inspecting overhead lines in spring during the nesting period makes sense before performing a risk analysis.

Finally, one should be aware that no matter how well an asset is monitored and maintained, there is always a small chance that the component might fail due to an imponderable event, such as a destruction of an underground cable caused by a mechanical digger working on the water network nearby. The possibility of an unnoticed vulnerability can also be included in that category. High impact low probabilities events (such as particularly violent storms) can also cause damages leading to contingencies, no matter how well the components are maintained.

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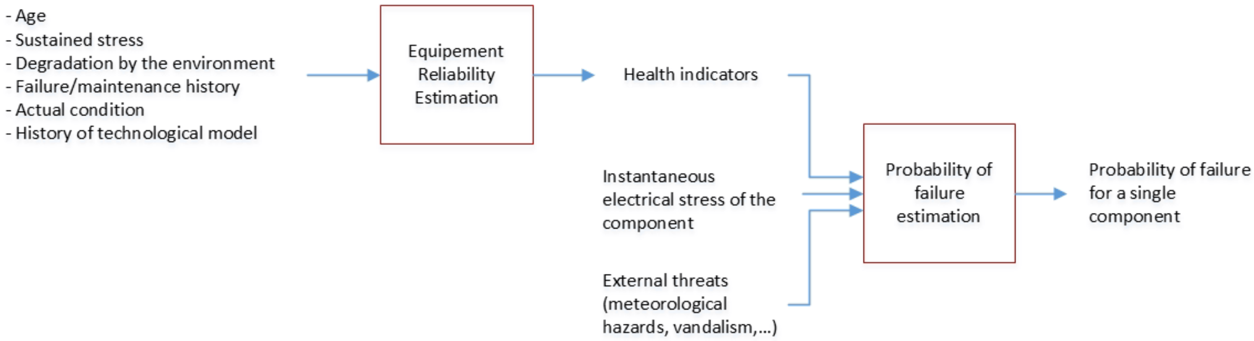

Figure 7-1: Assessing the probabilities of failure of a single component

Several approaches exist to propose models for risk of failure estimation:

- Ageing tests in a laboratory environment
- Statistical analysis of recorded failures
- Mathematical models based on influencing factors (the most famous being the Weibull model, which might be too simple to be valuable for the TSO analyses)

This topic will be further addressed in task GARPUR 5.2. The partners will keep in mind the danger of proposing over-specific and untractable models. The issue of data availability – or current data unavailability versus needs for the future - will also be of high interest. The possibility of sharing experience and pooling data among the European TSOs, although difficult because of confidentiality issues, would be an avenue to overcome the scarcity of failure data.

7.1.2 Assessing the benefit from maintenance on the probabilities of failure

The purpose of maintenance, from routine interventions to heavy refurbishment, is to extend the lifespan of the assets while avoiding unexpected failure. The benefit of maintenance on the failure rates is undisputable, now the question is to estimate quantitatively to what extend such interventions are efficient. The question is difficult, given the TSOs cannot afford to verify experimentally the consequences of not maintaining their assets and compare the failure rates to maintained assets. It is meaningless to propose a probabilistic asset management framework when there is no way of measuring the improvement on reliability brought by the maintenance intervention.

7.1.3 Monitoring the assets

Another promising path of improvement that would enable to improve the assessment of the probabilities of failures lies in new monitoring tools, such as drones and robots. Further investigation on this topic lies out of the scope of GARPUR, but should be mentioned for future research. The key point here is the confidence that we have in the probabilities of failure used for the risk analyses. Provided there exist methods to calculate failure rates consistent with the content of §7.1, such values would be based on non-observed information. The trust that could be granted to such values would be significantly higher if they were confirmed (or contradicted) by field data. Thanks to such inspection devices and monitoring tools, TSOs could have a better confidence in their risk analysis, and also could propose better condition-based maintenance.

Gathering information from such devices would reveal unsuspected vulnerabilities of the assets and raise the proper alarms to the operators. Consequently, urgent maintenance could be triggered to fix the component and make it go back to an acceptable reliability level, or particular preventive or corrective measures would be adopted to limit the critical of the aforementioned unreliable component. Typically,

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the load on such a component would be reduced as long as the asset is deemed to be weaker than expected. Similarly, another gain achieved thanks to this kind of devices would be that once the inspection has confirmed the good health of a critical component, it would become reasonable in a risk analyses to ignore its failure probability with a good confidence. A practical consequence would be that outage planning would become less constrained, or at least would focus on the more realistic threats.

7.1.4 Data quality and learning process

The various challenges in asset management can be summed up as a set of candidate problems related to operation, maintenance, and planning of the assets for which the asset managers are responsible. The responsibilities include identifying alternatives and for each asset, assessing the costs, benefits, and risks. Quality of resulting decisions depends on quality of data used in the assessments and how that data are processed. As discussed in this chapter, data can be characterizing the health, or condition, of the assets. Data collection techniques such as sensing, communication, and database technology have evolved to the point where it is feasible for asset managers to access operating histories and asset-specific real-time monitoring data. Creative use of this data, via processing, mining, assessment, and decision algorithms can significantly enhance the quality of the final actions taken by asset managers. Hence, it may result in a more economic and a more reliable system performance.

7.2 Estimation of the consequences of a failure

Along with the need to have good estimations of the probabilities of failure, a risk-based methodology for asset management requires to be able to evaluate the consequences in case a contingency occurs. This is important for a Reliability Centred Maintenance strategy (cf. §3.2.2), as well as for any network analysis no matter the time-frame. In addition to the criticality of the impacted customers, the duration of the time to restore the failing component to its initial working conditions is one of the main elements that needs to be accounted for in the evaluation of the non-supplied energy.

7.3 Use of risk-based approach for asset management and outage planning

7.3.1 General description of the need

This section echoes the description of TSOs’ challenges described in 1.3. In order to determine the optimal asset management policy, there is a need for a model that ideally, would calculate the optimized maintenance/replacement actions which would offer the best trade-off between grid reliability and costs of intervention. The complexity of this ideal model is immense, given it should compute a global – spatial and temporal – optimum, under hard constraints which are

- The reliability of the network in operation must be ensured at all time, despite the necessary outages
- The resources (mainly financial and workforce) have to be smoothed over a long period of time

7.3.2 Uncertain knowledge on the future state of the network

In order to determine whether or not an outage could be positioned during a particular time-window without jeopardizing the system, a detailed risk analysis should consider the following parameters:

- the probabilities of failure of the different components
- the impacts in case of contingency (including efficiency of corrective actions)
- the duration of the risk exposure

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- the probabilities of existence of preventive or corrective actions to mitigate the threat, and their associated costs
- probabilistic distributions for the injections (load, renewable generation, conventional generation)

The main challenge here would be the translation of all the previous variables in a tractable way usable by the mid-term planner.

7.3.3 Including specific options in the model

In order to be consistent with the actual practices, the different possibilities of live work, night work, or early agreement with generators (see §5.4.4) should be included in the model. Ideally, the people safety issues and other non-monetary parameters should also appear in the formulation. Going for this level of detail might nevertheless be quite challenging.

7.3.4 Uncertain existence of mitigation measures and post-contingency actions

From the mid-term planner perspective, it is difficult to sweep the wide range of possible future situations to ensure that in any case there should be a topological scheme or a re-dispatch strategy that would allow the system to be operated at a satisfactory reliability level. Moreover, most reliability analyses today are only based on such pre-contingency means of action, and leave post-fault mitigation measures aside. Therefore, the actual reliability level once in real-time operation should be higher than the one studied weeks/months in advance. This way of working is reasonable as long as the operational policy relies on preventive control rather than on corrective actions.

Now, in a detailed probabilistic approach, the existence of corrective measures should be quantified in the whole reliability assessment. This assessment is extremely hard to perform long ahead of real-time, as there are many precise requirements for the application of a single particular corrective action. Such requirements could depend on generation units availability, current network topology, load pattern, time required to implement the corrective action, and so on. Consequently, the possibility to apply known possible corrective actions once in real-time, and the efficiency of those, is extremely difficult to evaluate prior to the very short-term operation.

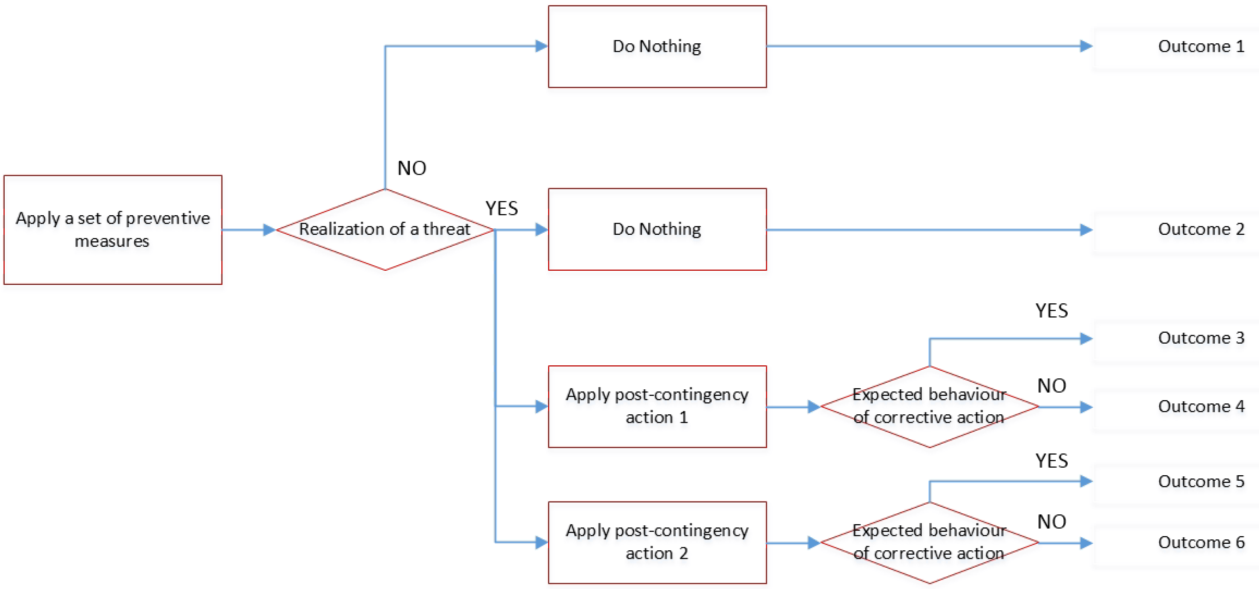

Figure 7-2: Preventive/curative decisions and related outcomes

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The next level to elaborate a bit more the previous description would be to include the potential probability of failure of these post-fault actions, such as circuit-breaker opening failure, and subsequent possible behaviours of the network. The evaluation of such probability of failure of the protection systems is something that could be enquired within WP5.

7.3.5 Defining an acceptable reliability threshold

The last topic that needs to be mentioned here, assuming a framework has been designed for reliability management for the mid-term and asset management activities, is that the acceptable parameters for the optimization framework are still to be settled. For instance there are at least two different kinds of parameters that should be filled while using the framework:

- Where do we put the cursor in the trade-off between the reliability level and the monetary costs?
- Will we accept a decision which is supposed to be optimal from a probabilistic point of view, but which is highly uncertain? Or will we prefer a less optimal decision that is more trustable?

7.4 Transmission of information to the other time-frames

The most important data exchange from the mid-term as described in §1.2 to the other time-frames, namely short-term operation and system development, should be the differentiated probabilities of failure for each component and the associated restoration time:

- For system development, it would provide a more accurate view on the weak parts of the grid
- For short-term operation, it would enable to perform credible risk analyses

Another topic of interest concerning the transmission of information between system development and asset management concerns outage management. Today, the strategy in system development analyses basically consists in ensuring the network should be robust to any N-1 contingency, and then leave it to the mid-term planners to find a favourable time-window to position the required outages. Therefore, it is assumed that there should exist time-windows permitting to have a network robust to the concerned outage and any other N-1 contingency, which is not a conservative approach.

Ideally, TSOs should account for the necessary future outages from the early system development stage, and thus avoid building a grid which would be robust to the loss of any single component but would be jeopardized during a planned outage period.

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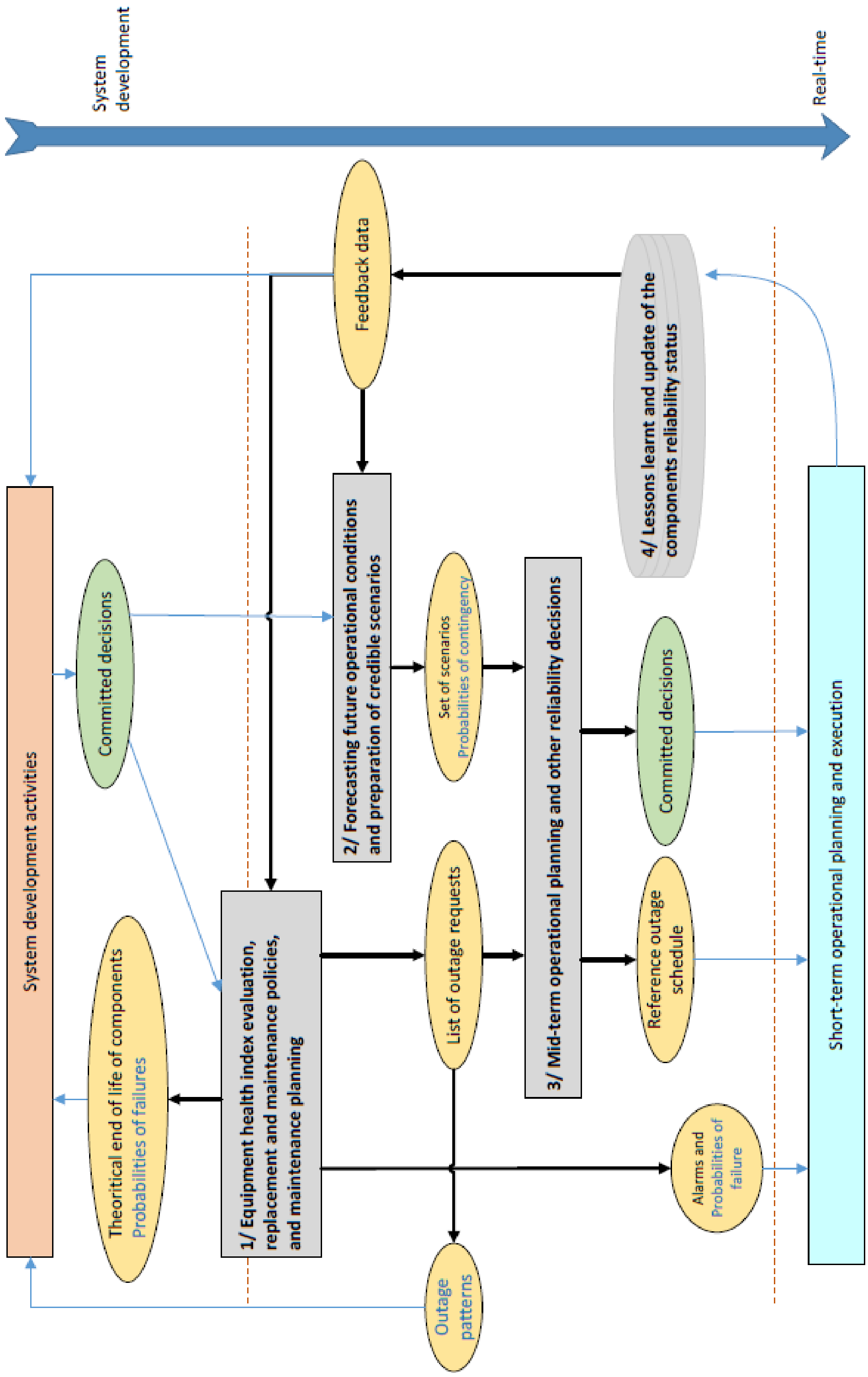
ANNEX 1: MASTER DIAGRAM FOR THE SUGGESTED FUTURE PRACTICES



Master diagram for the suggested future practices

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New features

- Probabilities of contingency are transmitted from the health index evaluation module to all the decisions module, including those in long-term and short-term. In the short-term, the base values will have to be updated in coherence with the latest information available, e.g. meteorological conditions.
- Information on outage patterns consistent with network constraints are proposed for further use in system development analyses. Consequently, these studies can propose grid modifications robust toward future scheduled outages.

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ANNEX 2: SUMMARY OF THE TRIGGERS FOR AN ASSET MANAGEMENT ACTION

It is possible to distinguish several categories of strategies for asset management as described in §3.2.2:

- Corrective (after a contingency)
- Time-based (age or frequency)
- Condition-based (the maintenance/refurbishment/replacement is triggered following a prior inspection)
- Reliability centred (the most critical components are prioritized)

On the whole, TSOs have a quite good understanding of the relevant parameters that should be looked at when deciding to undertake or prioritize a maintenance operation. The main difficulty they face is the weighting of their importance.

Most of the time-based maintenance actions depend on the technology of the component and have been fine-tuned from experience. The flat frequencies can be adjusted case-by-case depending on the following parameters to provide a smart asset management strategy:

- Age (old components are inspected more often than young ones)
- Hostility of the surrounding environment (salt pollution…)
- Criticality of the component to the electric system
- Risk to the environment or to the people (see §3.2.5)
- Repair time

TSOs also take advantage of some scheduled maintenance operation to anticipate other work on the some equipment, thus limiting the total duration of the required outages. Likewise, they might stop maintenance on a device that will be definitively removed from operation in the coming years.

Unscheduled repair actions can also be undertaken following a contingency or a report from an inspection visit or after any other maintenance action took place. In that case, a level of gravity is determined by the field team, which will determine how fast the repair should take place. In the same manner, unscheduled inspection of assets can be launched following a violent meteorological event (storm).

In some particular cases, when a particular grid element is expected to be critical to the safety of the grid in the next days/weeks, a preventive but unscheduled inspection can be undertaken to ensure that it is in good health and unlikely to fail during the difficult time-window.

The final replacement of an old component can be undertaken:

- At a decided given time based on the age of a component. The reason is normally that the expected maintenance cost is higher than the replacement cost, but sometimes a fine-working equipment is replaced in advance to smooth the workload over a large period of time
- Following an in-depth health evaluation operation
- Following a major end-of-life failure. This concerns the most expensive assets, for which it is economically interesting to have the longest possible service life. Spare transformers, which are heavy devices, should be present in the substation to anticipate the failure and enable a fast return in operation
- Because of external regulations
- Because of the obsolescence of a technology (or loss of skill to carry out the operation)

In some rare cases, it is possible to remove a component and dismantle it in order to re-use the spare parts to repair other components. This process is called cannibalization.

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ANNEX 3: DEFINITIONS FOR THE DIFFERENT TIME-HORIZONS IN GARPUR

Long-term horizon

Long-term planning covers activities in the long-term time horizon, i.e. from a few years ahead to 10 years or more ahead of real-time. Activities covered in that horizon include system development, planning of asset replacement and setting of asset policy, e.g. maintenance policy and standard equipment specifications. Asset replacement planning and maintenance policy may be regarded as aspects of asset management. It is to be recalled that WP4 of GARPUR is concerned with system development and WP5 is concerned with asset management. Both activities are performed in the long-term horizon as well as in the mid-term horizon. Furthermore, it may be noted that, in respect of many TSOs' business processes, the activities of system development and asset management interact, e.g. where the particular option adopted for enhancement of system capability is informed by the need to replace certain assets.

Mid-term horizon

Mid-term planning is planning in the time horizon ranging from 1-2 of months to a few years ahead of time. It includes asset management activities such as planning of maintenance and asset replacement; the enhancement of the system's power transfer capability through the installation of new facilities with relatively short specification, procurement, construction and commissioning timescales. i.e. system development; and operational planning. It is to be recalled that WP4 of GARPUR is concerned with system development and WP5 is concerned with asset management. Both activities are performed in the mid-term horizon as well as in the long-term horizon.

In the context of asset management, the scheduling of tasks (maintenance, replacement and/or enhancement) should take into account the predicted impact on the system reliability, as seen from the mid-term perspective.

Short-term to real time horizon

The short-term horizon is considered to start from 1-2 months ahead of-real time and last throughout the real-time moment of system operation. It includes short term part of operational planning as well as the field-oriented aspects of asset management. It is to be recalled that WP5 is concerned with asset management and that WP6 is concerned with the real-time operation and its preparation. However, field-oriented aspects of the asset management (project preparation and maintenance preparation) are out of the focus of this project.

Therefore, in the context of GARPUR, most of the activities considered in the short-term are dealt with in WP6. In the short-term horizon, the main focus is on securing a reliable grid which delivers electricity that fulfils quality measures in real-time operation. The emphasis is on the secure execution of all planned tasks in the system. Therefore, scheduled tasks (maintenance, replacement and/or enhancement) proposed by the mid-term asset management, could if needed, be rescheduled to ensure system reliability.. The short-term horizon includes the rescheduling of maintenance work but also any preventive or corrective actions applied pre- or post to fault.

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