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Umbrella Project

Toolbox for Common Forecasting, Risk assessment, and Operational Optimisation in Grid Security Cooperations of Transmission System Operators (TSOs)

Deliverable 1.2 „Interim Report“

Content

1 Overview on and state of the UMBRELLA project

This *Interim Report* is a halfway summary of the FP7 project UMBRELLA. It describes the objectives and the results achieved by the end of the second of four project years. More in-depth scientific details can be found in the public *Deliverables* on the UMBRELLA homepage (ref. to 7 Dissemination). UMBRELLA is also cooperating with the related FP7 project iTesla, i.e. some public workshops are performed commonly, test environments are harmonized and a common proposal on potential development of future TSO rules will be proposed at the end of both projects in 2015.

The general background of the UMBRELLA project lies in the growing shares of electricity generation from intermittent renewable energy sources (RESs) as well as increasing market-based cross border flows and related physical flows that are leading to rising uncertainties in transmission system operation. Due to large installations of renewable energy generation such as wind and photovoltaic, the difference between actual physical flows and the market exchanges can be very substantial in the mainland central Europe synchronous area.

By previous smart grid studies within the 6th European framework program remedial actions were already identified in

- operational risk assessment,
- flow control by phase shifter coordination and
- operational flexibility measures.

But for the coming years, transmission system operators (TSOs) are forced to manage power flows within the capability of existing networks by using available operational measures such as

- network reconfiguration by switching and
- flow control devices.

Thus the zonal structure of the European energy market along with the legal responsibilities of TSOs for different system areas imposes increasingly complex requirements on the system operators concerning quality and accuracy of cooperation. Therefore the system security research and demonstration project UMBRELLA is dedicated to a further development of common grid security tools that are one of the major challenges European TSOs are facing. The UMBRELLA toolbox to be developed will enable TSOs to ensure secure transmission network operation also in future power systems with high penetration of intermittent RESs and with new opportunities for network operation like

- new interconnections and
- an increasing number of load flow control devices.

The UMBRELLA framework also can be used to assess the influence of different operational rules and market rules on the system security. Hence it is also a task of the UMBRELLA project to contribute to progress in the development of such rules.

The three main objectives of the project are:

1. Development of a dedicated innovative toolbox to support the network security approach of TSOs. This toolbox shall include:

a. simulation of uncertainties due to market activities and infeed from renewable energy sources on different time scales from day-ahead to real time
b. optimisation of corrective actions considering uncertainties on different time scales according to total costs and transmission capacities in the whole system
c. development of risk based assessment concepts for anticipated system states with and without corrective actions

2. Demonstration on the enhancement of existing and running procedures by utilisation of the developed toolbox. Therefore after synthesis of the several contributions from research institutes and universities extensive tests are planned where the toolbox is embedded in the current information system and enables acting in the consistent target system based on a decentralized approach.
3. Provision of a scientifically sound basis to support common TSO rules.

At the core of the UMBRELLA research project are three key elements

- Forecasting (work package WP2)
- Optimisation (work package WP3)
- Risk-based assessment concepts (work package WP4)

which in particular are performed by the project partners from universities

In Order to implement the developed academic methodologies into a practically applicable toolbox further research and synthesis is needed. Therefore the different algorithms developed by the universities are integrated during the next step called

- Synthesis and prototyping (work package WP5)

by the research institute and TSOs involved (refer to table 1.1). It will provide a toolbox prototype, suitable for demonstration and tests within a large-scale TSO cooperation of 9 TSOs during the last phases of the project called

- Demonstration and testing (work package WP6)

To foster the cognition of the outcomes from the UMBRELLA project focus is also given to a parallel dissemination of the results to the public and interested stakeholders. This is done by:

- Dissemination (work package WP7)

The overall the project management tasks are bundled in

- Project management (work package WP1)

Table 1.1 List of Participants (TSOs and Research Institutes)

Participant No./Abbrev.		Participant legal name	Country	Organisation type
1	TTG	TenneT TSO GmbH (Coordinator)	Germany	TSO
2		Amprion GmbH	Germany	TSO
3	CEPS	ČEPS, a.s.	Czech Republic	TSO
4	ELES	Elektro-Slovenija, d.o.o	Slovenia	TSO
5	TNG	TransnetBW GmbH	Germany	TSO
6	PSE	PSE S.A.	Poland	TSO
7		swissgrid ag	Switzerland	TSO
8	TTB	TenneT TSO B.V.	Netherlands	TSO
9	APG	Austrian Power Grid AG	Austria	TSO
10	DUT	Delft University of Technology	Netherlands	University
11	ETHZ	ETH Zurich	Switzerland	University
12	TUG	Graz University of Technology	Austria	University
13	RWTH	RWTH Aachen	Germany	University
14	UDE	University of Duisburg-Essen	Germany	University
15	FGH	FGH e.V.	Germany	Research centre

Forecasting (work package WP2)

Information on the current status of the European grid and the expected evolution in the hours to come is already available with current grid management procedures like the Day-Ahead Congestion Forecast (DACF). But the increasing infeed from intermittent RESs as well as short-term trading implies that possible deviations from the expected values become increasingly important to identify critical system states, which endanger system security.

Consequently point forecasts (expected values) only provide limited information on possible security risks. Securing the stable operation of the electricity grid requires not only the consideration of the most likely (or expected) development but also of possible deviations from this scheduled path. Therefore point forecasts will be replaced by forecasts of probabilistic distributions (including but not limited to extreme events).

Besides volatile distributions for renewable infeed and short-term trading, also conventional load forecast errors and power plant outages contribute to the uncertainty in future system state and will be considered.

Optimisation (work package WP3)

The significant changes in energy generation, especially the growing utilization of renewable energy sources and the nuclear phase out in several EU countries lead to a rising number and frequency of congestions in the transmission grid. At the same time, the selection of measures to relieve these congestions is getting more complex due to the increasing number of load flow control devices like phase shifting transformers (PST), FACTS and HVDC connections and due to their interdependencies with topological modifications and required redispatch measures. Therefore the objective of the work package is the development of an expert system that is capable of assisting the transmission system operators in the congestion management process.

Algorithms for an enhanced optimal power flow (enhanced OPF, EOPF) considering uncertainties are designed. The goal of the EOPF is to determine optimal topologies as well as set points for load flow control devices in order to minimize redispatch volumes while maximizing possible power transports and avoiding violations of security conditions while taking into account the uncertainty of the system state's development. Remedial measures have to be chosen for some future state yet unknown. Fig. 1.1 shows a simplified outline of this situation.

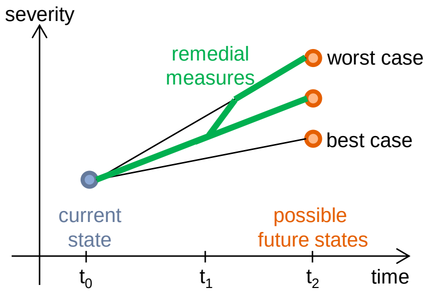


Fig. 1.1 Development of system parameter states

Risk-based assessment concepts (work package WP4)

The topic of work package 4 is risk-based security assessment, which encompasses both the probability and the severity of events. It can be used to optimize transport capacities and thus facilitate market operation without jeopardising system security. A risk-based measure carries more information than the deterministic criterion and allows for a quantitative definition of how secure the system is, as opposed to the binary N-1 criterion which only deems the system secure or insecure. A risk-based criterion allows for a more explicit definition of the trade-off between security and cost, and can lead to a more effective utilization of existing transmission capacity.

Due to the more comprehensive treatment of probabilities, risk-based methods are better suited for incorporation not only of outage probabilities but also of different kinds of forecast uncertainty. Special attention is paid to the influence of fluctuating generation resources on power system operation. Further, the developed methods include concepts that assess how cascading events, state-of-the-art technological measures (e.g. FACTS and PSTs) and how different market designs/cooperation rules between TSOs influence the overall system risk.

Synthesis and prototyping (work package WP5)

The results of the work packages 2 – 4 on Forecasting, Optimization and Risk-based Assessment concepts are the input for developing the prototype toolbox. Therefore the results are reviewed carefully in order to identify those methods most appropriate and promising for a usage in the different time steps of operational planning (starting day-ahead) as well as daily operation of the TSOs. For a successful realisation of the toolbox it is crucial to achieve usability for system operation. For this purpose it is necessary a suitable usage concept is developed in collaboration with the TSOs in order to achieve an applicable tool box and take the full advantages for system security and optimal grid utilisation. The different components of the toolbox are then integrated in the existing processes of network operation.

Demonstration and testing (work package WP6)

Finally the functionality of the developed toolbox is demonstrated using appropriate test cases. To compare results and conclude on necessary rules a harmonized testcase is agreed upon with the related FP7 FP7 project iTesla.

The test results will particularly be used to identify needs for further harmonisation of operational requirements in TSO cooperation rules and to provide possible defence actions and methods to achieve the European-level coordination of defence plans and black start as far it is concerned in the toolbox.

Dissemination (work package WP7)

In the subsequent chapters an overview on the current state of the research activities and results so far is given. The report closes with an illustration on the dissemination activities undertaken during the first half of the UMBRELLA project.

2 Modelling uncertainties relevant for the operation of the European transmission grid

Work Package:	WP2 Forecasting
Working period:	January 2012 – December 2015
Work Package Leader:	University of Duisburg-Essen
Partners involved	RWTH Aachen, FGH e.V., Graz Technical University, ETH Zurich, PSE S.A., Elektro-Slovenija d.o.o, ČEPS, a.s.

2.1 Objectives

Work package 2 aims at developing a set of methods describing the key developments influencing the future state of the European electricity grid. Securing the stable operation of the electricity grid requires not only the consideration of the most likely (or expected) development but also of possible deviations from this scheduled path. These deviations are referred to as uncertainties. Most relevant for a secure grid operation are four sources of uncertainties, namely:

- renewable energy infeed: wind and solar power,
- load,
- power plant outages and
- short-term trading activities.

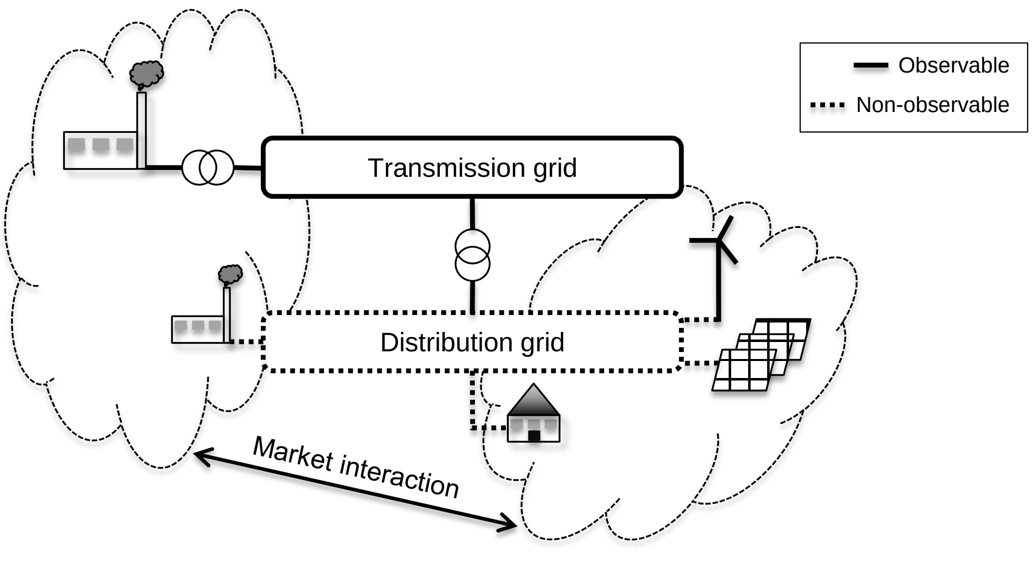


Fig. 2.1 Observable and non-observable influencing factors

Most of the mentioned processes are more or less easy to predict individually. However, TSOs have limited information on the detail of these processes, but can only observe an aggregation of them. This makes the collection of data and its use more difficult. Fig. 2.1 illustrates this situation graphically. In order to predict the possible deviations as good as possible, these processes have to be separated from each other and in a later step aggregated again. How this separation is implemented shows Fig. 2.2. Thereby, tasks 1 to 3 focus on relevant uncertainties. Because the discussed uncertainties cover all relevant uncertainties for a secure gird operation, they can be aggregated to probability distributions of load and infeed at each grid node. Task 4 and 5 condense the additional information to so-called system states in order to forecast them. This will allow TSOs to identify critical system states in advance, which gives them more time to prepare.

Subsequently, each task with its main objective is described more detailed.

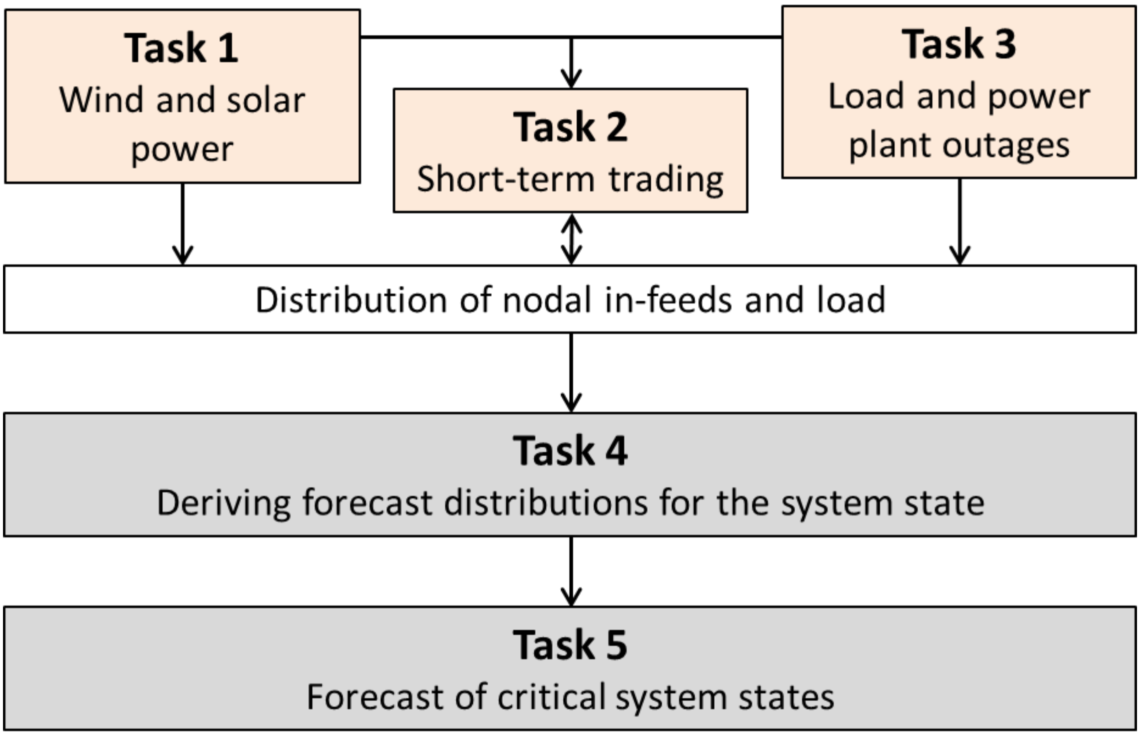


Fig. 2.2 Overview of work package 2

<u>Integrating uncertainty in renewable power forecasts (Task 1)</u>

So far most TSOs receive and use deterministic forecasts for wind power infeed in their control region. This serves then as basis for the corresponding infeed schedules. The focus of this task is to identify appropriate possibilities for describing the corresponding uncertainties in a way that grid operators can make use of the information most efficiently. Data for the analysis including RES infeeds are provided by TSO project partners at an appropriate level of detail.

One of the main project objectives is to address problems across borders in the early phase of the project. In a first step a test case for one country will be implemented in MATLAB. In parallel data for all countries are collected and harmonised to be able to meet the requirements of a European approach.

In a second step these data are used in the test system, which is extended to six countries. This test system should especially be capable of providing estimates of renewable power infeeds including bandwidths of uncertainty to go beyond the current practice within TSOs. In a final step, data for the whole relevant system is considered and the corresponding forecast tool built up.

Integrating uncertainty in short-term trading (Task 2)

Trades among power producers, traders and consumers, as far as they include physical delivery, are reflected in the generation and consumption schedules submitted to the TSOs. However with increasing market integration also short-term trades gain in importance. These intraday trades are often submitted to the TSOs rather late and an anticipation of the trades would be highly welcome in order to assess in advance possible impacts on system security. In this field, little research has been carried out so far – given that intraday volumes have been limited in the past and information was only scarcely available. Therefore this task will involve a detailed analysis of intraday renominations and a subsequent proposal for statistical description. Data on day-ahead schedules and physical delivery as basis of the analysis are provided by TSOs.

Integrating uncertainty in load forecasts and power plant outages (Task 3)

Analyses of load forecast errors and power plant outages have a long tradition in utilities and academia. Therefore this task will focus on the identification of suitable descriptions of the associated uncertainties in view of providing a consistent overall system state description. One point that will be specifically considered in this task is the use of information on the current forecast error to improve predictions for the close future.

Deriving forecast distributions for the system state (Task 4)

In this task methods will be developed to derive information about future system states and their occurrence probability based on previously discussed forecast distributions. The main objective is to provide information about the system state to system dispatch. Therefore appropriate system state parameters (SP) have to be developed which characterise crucial information about the whole system in a feasible way for operational work. In this context it is important to provide algorithms and results in a way that regional and temporal specifications are fulfilled. Necessarily, the system state parameters (SP) have to be defined in close collaboration with the TSOs.

Forecast of Critical System States (Task 5)

This task combines the results of tasks 1 through 4. Given the distribution functions of the relevant uncertainties, the goal is to quantify the probability of occurrence for specific combinations of uncertain events that cause critical system states. It is important to find out which critical system states have a high probability to occur and which critical system states would have a major impact on system security even if their probability of occurrence is rather low. For a selection of predicted system states judged to be relevant according to the product (or, more general, combination) of their probability of occurrence and their impact on system security, the behaviour to be chosen, i.e. the remedial measures to be applied, in those events can thus be planned in advance (ref. to WP3).

2.2 Progress and results

The methodology development for modelling the uncertainties in task 1 to 3 is completed. The methods are described more detailed in the individual parts below. During the kick-off phase of the project, it has been found that the only sufficient level of detail is the grid node level. Thus, necessary inputs for the developed methods must be provided on a very detailed level. This level of detail assures that the methods developed in subsequent work packages can provide an additional benefit for TSOs.

The second step comprises data gathering in order to evaluate the developed methods and to lay a foundation for testing the toolbox. Unfortunately, the collection and treatment of data has turned out to be much more time-consuming than originally expected. During the specification process it became clear that the methods under development required a level of detail for the data which exceeded the level of detail available at the TSOs. Hence data at an adequate level of detail could not be provided by all project partners. In order to cope with this issue, it has been decided to generate a data set that is realistic enough and, at the same time, can be provided within an acceptable timeframe to keep the overall time line of the project. At the moment, the completion of a test case, which contains uncertainty data for all participating countries, is about to be finalized.

Integrating uncertainty in renewable power forecasts (Task 1)

Exemplary results on the estimation are given in Fig. 2.3, Fig. 2.4 and Fig. 2.5. Fig. 2.3 shows the forecast intervals for a selected grid node with high wind infeed in Northern Germany (about 196 MW installed wind power capacity). The quantiles of the forecast distribution are plotted over the prediction horizon. Against first intuition, the uncertainty bandwidth does not increase with increasing forecast horizon in that particular case. The reason is that for the more distant time steps the expected infeed is lower and therefore the downwards deviations are limited. A further reason is that forecast deviations in wind speed do not translate into as high deviations in wind power since the non-linear power curve of the wind turbines has a lower slope at these wind speed levels.

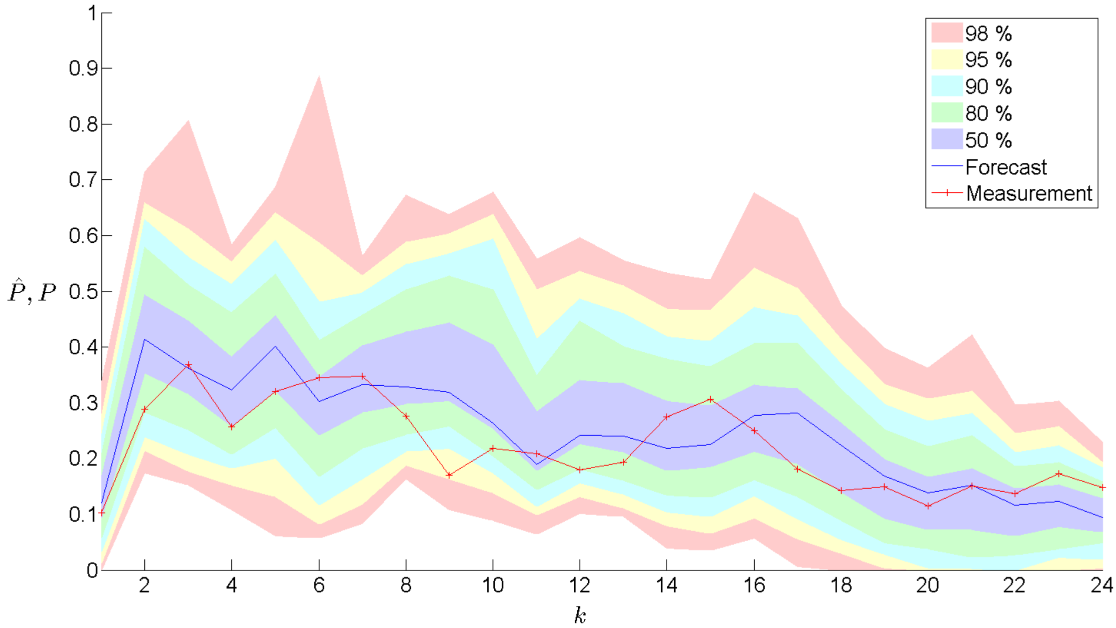


Fig. 2.3 Exemplary results of wind power forecast distributions for a selected grid node as a function of the forecast interval

Fig. 2.4 and Fig. 2.5 show the corresponding correlation between the computed forecast errors in the 29 grid nodes for two different look-ahead times of a case study. More precisely it is the resulting correlation matrix after the Gaussian copula (used to model spatial interdependences)

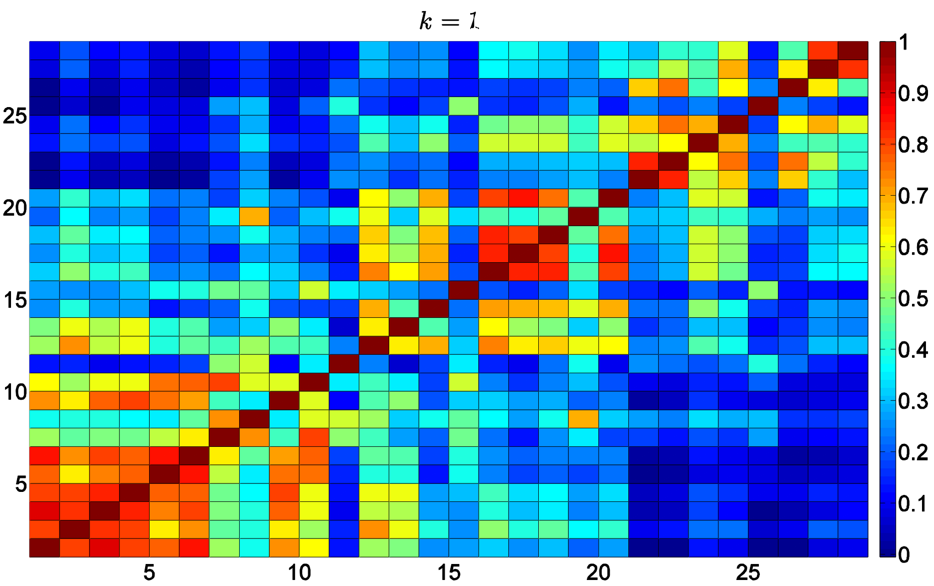


Fig. 2.4 Exemplary results on correlation matrix between different grid nodes for look-ahead time 1h

has been applied. The results are given in the upper part for the forecast horizon of one hour, in the lower part for the forecast horizon of six hours. It becomes obvious that the dependence structure changes with the forecast horizon, what motivates different copulas for different look-ahead times. The nodes are sorted by increasing distance from a reference node. Obviously the correlation between the forecast errors in the close vicinity of the reference node is very high, whereas the correlation to more distant grid nodes declines rapidly. This is true almost independently of the forecast horizon.

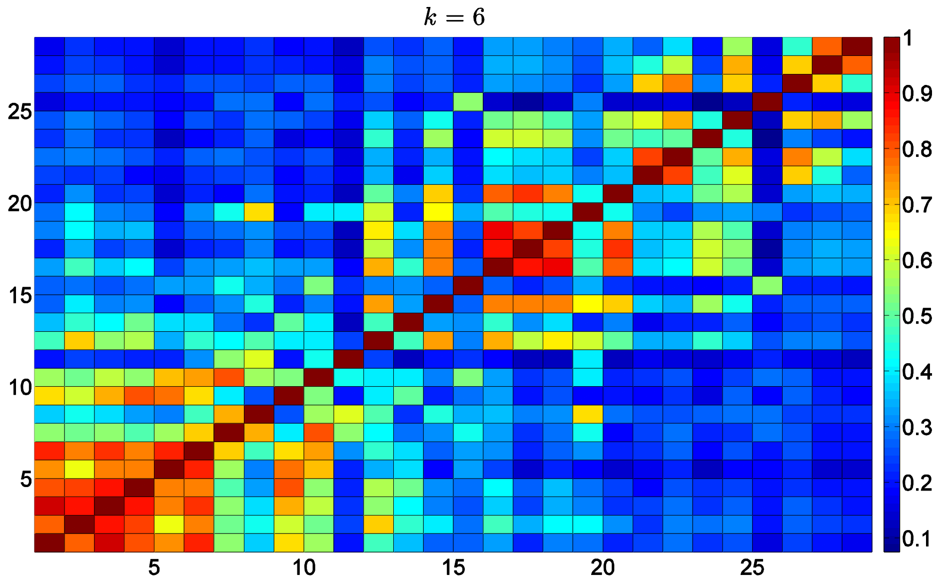


Fig. 2.5 Exemplary results on correlation matrix between different grid nodes for look-ahead time 6h

<u>Integrating uncertainty in short-term trading (Task 2)</u>

After a detailed analysis of processes in the intraday market, it has been decided to explain deviations from the generation schedule with a fundamental approach. The basic idea is to aggregate the factors that influence the intersection between demand and supply in order to foresee which power plant would adjust its output given the technical limits of such adjustments. When this is implemented for all possible deviations from the deterministic forecasts, the entire range of generation adjustments can be estimated. This procedure is illustrated in Fig. 2.6. A detailed evaluation of this method will be implemented after all necessary input distributions are fully compiled.

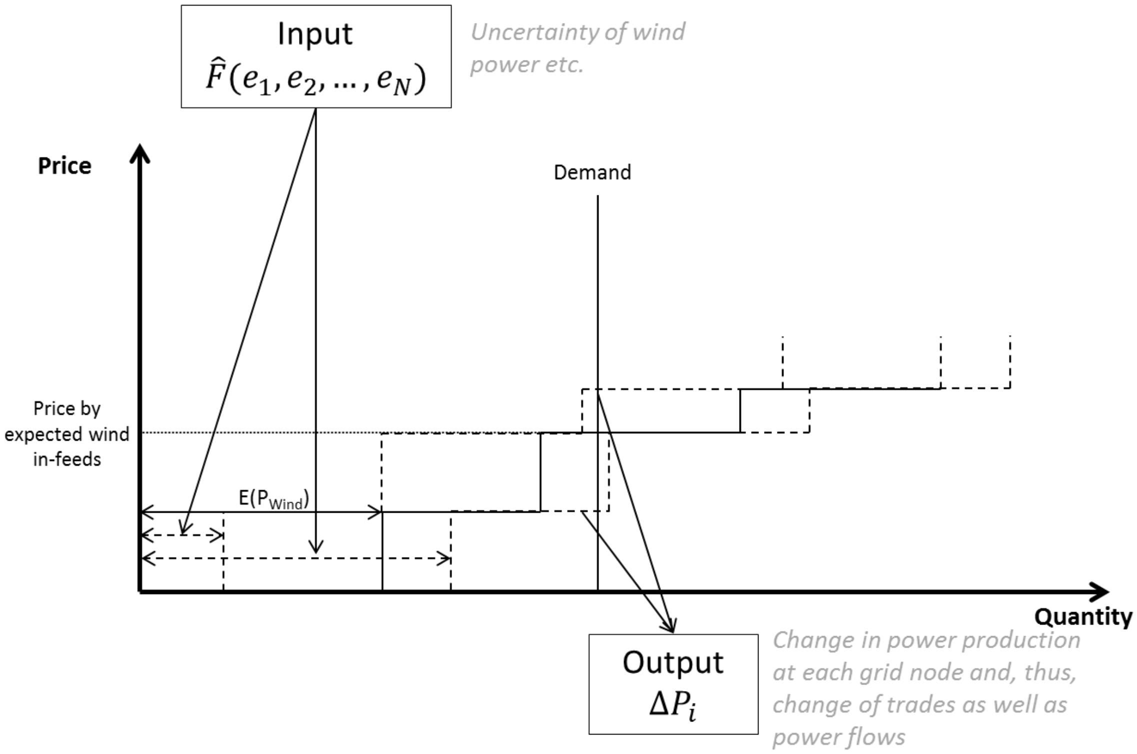


Fig. 2.6 Basic merit-order model to analyse the impact of intraday trading

<u>Integrating uncertainty in load forecasts and power plant outages (Task 3)</u>

The main obstacle when forecasting load and its uncertainty in the context of TSO operation is that only the vertical grid load is observable as shown in Fig. 2.1. What makes the vertical grid node forecasting difficult is that it consists of several factors, namely renewable energy infeed, infeed from conventional power plants in subordinate grids and, of course, the actual load, which is consumed by power consumers. The expected infeed from renewable energy sources and its related uncertainty is known from foregone tasks. The production of conventional power plants in subordinate grids, however, is not known, but it is also less intermittent and not present in all grid areas.

Within the project we will model infeed from conventional power plants in subordinate grids as noise until further information becomes available. Hence, the remaining uncertainty is the uncertainty of the actual load. The actual load becomes observable when the TSO has perfect knowledge about infeed from renewable energy infeed. Unfortunately, this is not the case or only while making many assumptions. Thus, it was decided to model the uncertainty of load with a parametric approach based on grid nodes where the other factors are negligible and, in a second step, transfer the distributions to other grid nodes. It is important to understand that this procedure will only be applied until more information on renewables becomes available. Thereby, TSOs have to make an effort, if the regulatory framework does not influence the flow of information advantageously for TSOs. When this information is available, the load uncertainty at each grid node can be modelled separately with the proper parametric approach. How a simple standard normal distribution fits to actual data is shown in Fig. 2.7 for an anonymized TSO.

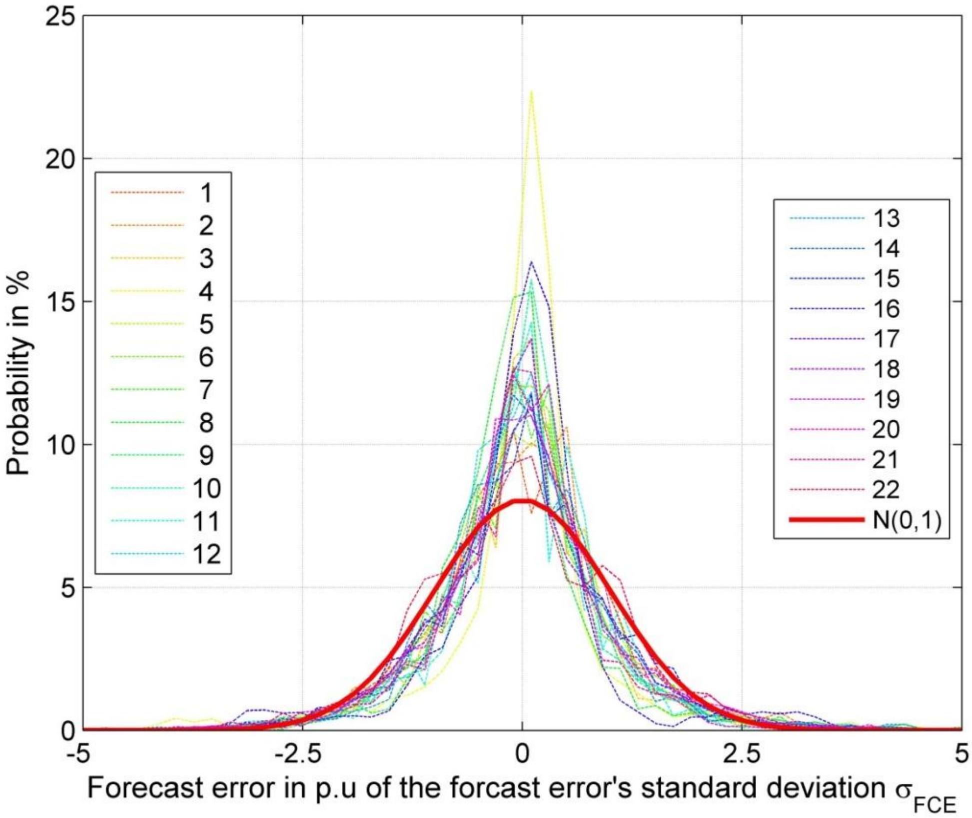


Fig. 2.7: Histogram of nodal forecast errors normalised with the error's standard deviation

<u>Deriving forecast distributions for the system state (Task 4)</u>

This task is concerned with finding a suitable description of the aforementioned uncertainties in terms of integrating them into the operational process of TSOs and providing a consistent overall system state description. In other words, a suitable interface between the uncertainties and system states has to be identified. As mentioned earlier, the uncertainties can be aggregated in order to derive distributions for load and infeed at each grid node. The uncertainties covering all intermittent production changes and demand side uncertainties are utilized in order to estimate the intraday changes as outlined earlier and, thus, changes on the conventional generation side. Thereby, a few particularities, e.g. run-of-the-river hydro power plants, have to be incorporated. Moreover, changes in the generation schedule and on the demand side lead to a change of grid losses, which is also taken into account. Subsequently, this can be used as an input for a load flow calculation.

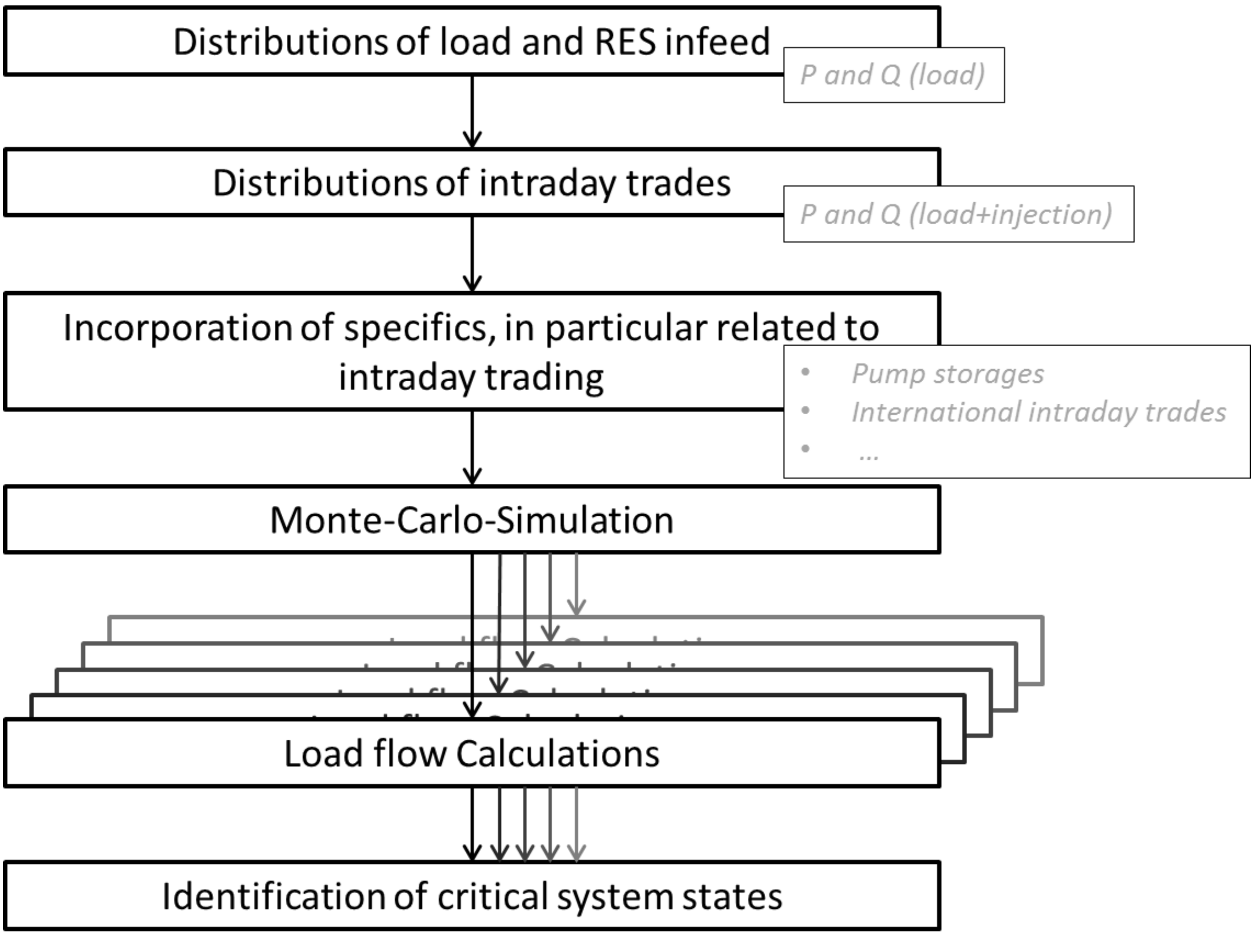


Fig. 2.7 Combination of uncertainties and provision of system states

Forecast of Critical System States (Task 5)

By drawing uniform random numbers for the joint distributions of the uncertain processes repeatedly and using the respective marginal distributions in combination with the point forecast, the load and infeed distributions can be simulated (Monte-Carlo simulation). An additional load flow calculation provides TSOs with comprehensible system states such as voltage and line loading. This process is depicted in Fig. 2.7.

In practice, an extensive simulation for all possible combinations and the appendant load flow calculation are too time-consuming to be practical. Thus, a more sophisticated process has to be developed than the time consuming “classical” Monte-Carlo method. This approach should consider and make use of additional information which is not used for the determination of the uncertainties. The outcome of the afore-going tasks has to be finalized until this problem can be approached.

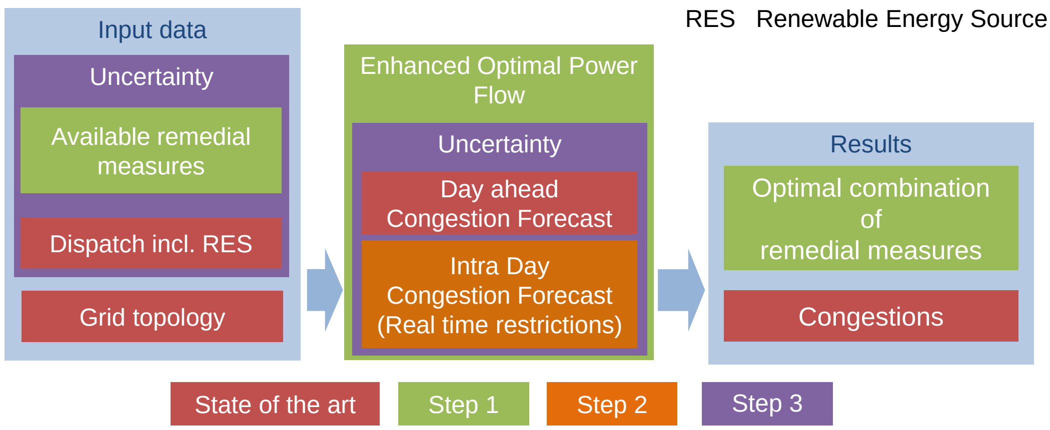
For the interested reader, our work is documented in one report [1] and two publications [2, 3, 4].

3 Optimization algorithms for transmission system operation

Work package WP3:	Optimisation
Working period:	January 2012 – September 2015
Work package leader:	RWTH Aachen
Partners involved	Amprion, ČEPS, a.s., Elektro-Slovenija, d.o.o, PSE S.A., swissgrid ag, TenneT TSO B.V, Delft University of Technology, ETH Zurich, University of Duisburg-Essen, FGH e.V.

3.1 Objectives

The significant changes in energy generation, especially the growing utilization of renewable energy sources and the nuclear phase-out in several EU countries lead to a rising number and frequency of congestions in the transmission grid. At the same time, the selection of measures to relieve these congestions is getting more complex due to the increasing number of load flow control devices like phase-shifting transformers (PST) and HVDC connections and their interdependencies with topological modifications and required redispatch measures.



- Step 1: Optimization algorithms supporting operational planning process
- Step 2: Short term optimization methods for realtime grid operation
- Step 3: Optimized uncertainty accounting in operational planning

Fig. 3.1 Overview on objectives of WP 3

Therefore the objective of this work package is the development of an expert system that is capable of assisting the transmission system operators in the congestion management process. The achievement of this overall goal is divided in three steps as depicted in Fig. 3.1. In a first step, an algorithm for the day to day operational planning process is developed. This algorithm has to consider the available information about the grid and the expected infeed situation, perform a contingency analysis and use an enhanced optimal power flow (EOPF) to derive an optimal set of remedial measures to relieve the congestions. The second step of the algorithm development takes into consideration the applicability for real time operation. As outages and deviations of RES infeeds (ref. to WP2) will frequently lead to a deviation from the expected load flow situation, it becomes crucial to perform an assessment of optimal remedial measures in real time. This real time assessment is made possible by a modification and speedup of the EOPF. In the last step, the existing algorithms have to be extended to cope with the growing uncertainties in transmission grid operation. Within this extension, the uncertainty modelling developed in work package 2 is used to estimate the expected load flow situations and the risk based security assessment methods developed in work package 4 provide the opportunity to look beyond deterministic security criteria.

3.2 Progress and results

In order to achieve the abovementioned objectives a detailed analysis on current and future challenges in transmission system operation in terms of congestion management has been carried out. This analysis involves a literature review as well as the evaluation of a questionnaire answered by TSOs and providing an accurate assessment of typical congestion types and relevant remedial measures.

Based on this evaluation models for all relevant remedial actions and operational degrees of freedom have been developed and aligned with specialists from the TSOs. These models regarding remedial measures include topology switching, transformer tap changing, tapping of shunt elements, setting of FACTS set points, control of HVDC lines and redispatch. As operational constraints current and voltage limits have been considered important as well as inter-temporal constraints, separate operational limits for contingencies and phase angle difference constraints.

The main challenges for optimization algorithms in the context of transmission grid operation are the system size of the transmission grid with its several thousand lines and nodes, the consideration of contingencies and the integer variables representing i.e. the discrete options of topology switching. To realize an optimization algorithm that is capable of providing a good result within finite time for this complex problem, it is crucial to decompose the overall optimization into several algorithms providing solutions for smaller sub problems and introduce an appropriate coordination between the algorithms. The selected decomposition of this work package is shown in Fig. 3.2.

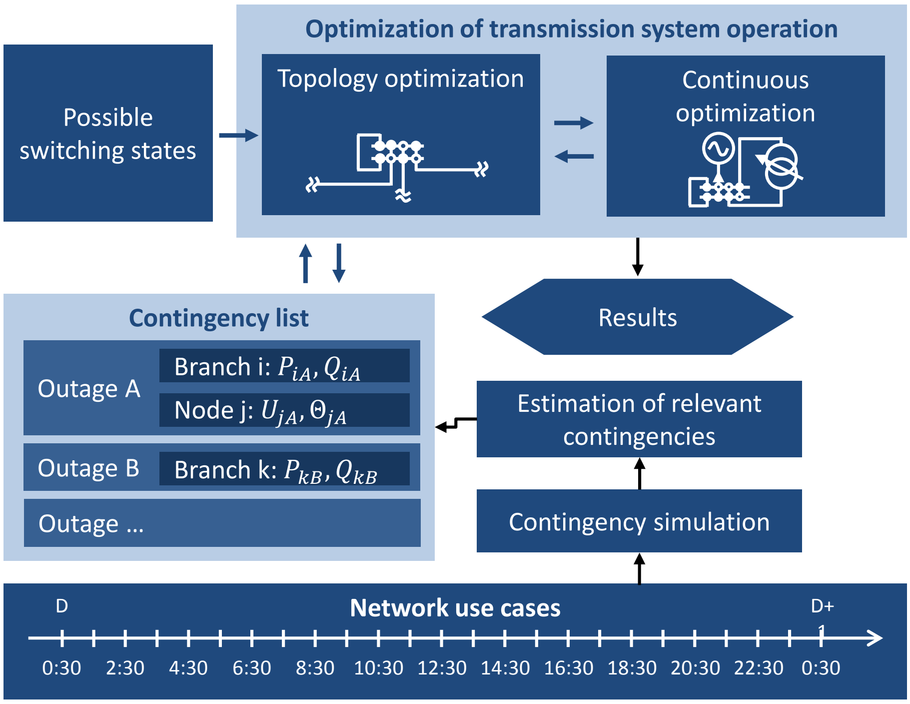


Fig. 3.2 Optimization algorithm structure

Prior to the optimization, a contingency analysis is carried out. This contingency analysis allows for the identification of relevant operational limits in the predicted loadflow situations. This enables the neglecting of most mathematically existing but physically irrelevant constraints in the optimization formulation. Based on the relevant congestions, an identification of beneficial topologies and switching measures is performed using a heuristic topology optimization algorithm. This topology optimization algorithm (ref. Fig. 3.2) is directly interfacing a continuous optimization block that is capable of assessing the impact of PST, FACTS, HVDC connections and redispatch measures.

For real time applicability, the continuous optimization algorithm is adjusted to provide an appropriate weighing of computational accuracy and computational time. Together with the algorithm design that provides best conditions for parallelization, the developed algorithm is capable of providing real time optimization results on a multi country transmission grid model.

Beside the considerations in terms of mathematical and physical modelling work, the implementation of an EOPF provides huge potential in the area of information technology. It is therefore essential for the development of an optimization algorithm to consider data handling issues as well as scalability and maintainability already in a very early phase of the algorithm design. The developed optimization algorithm was designed to meet these criteria and therefore addresses a very uncommon scope of OPF development that provides enormous potential for the performance of the overall algorithm.

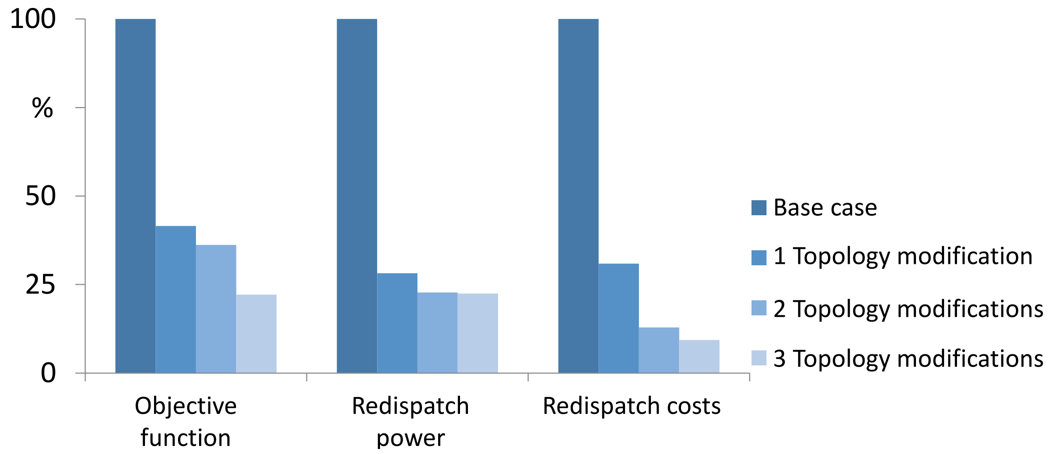


Fig. 3.3 Exemplary results topology optimization

The application of the developed algorithms on exemplary multi country test cases provides excellent results. Fig. 3.3 shows one of these results for the topology modification algorithm. It can be seen that even the selection of a few topology modifications can enable the reduction of redispatch costs and the decrease of redispatch power in this test case significantly. Due to the requirements of transmission system operators a limited number of topology modifications is hereby of importance.

Another result in Fig. 3.4 evaluates the benefits of post contingency control of redispatch measures. Assuming different amounts of redispatch power to be available for curatively post contingency control (0% equals base case; 10 to 30 % of nominal power available for post contingency control in “curative X%” scenarios), a reduction of redispatch costs in the order of

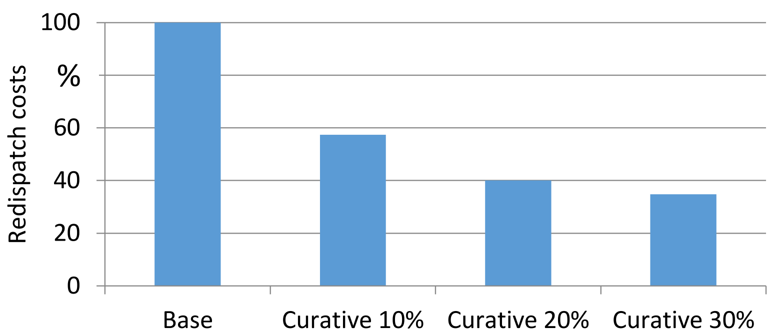


Fig. 3.4 : Exemplary results post contingency control

50% could be achieved in the particular test case if these options were considered in the optimization. Although this consideration increases the size of the optimization problem extremely, it can be solved in almost the same computational time compared to the optimization without consideration of curative measures due to an efficient data handling and management within the optimization methods.

Further information on our work is available in our deliverables [5] and recent and forthcoming publications [6, 7].

4 Risk-based Security Assessment incorporating Forecast Uncertainty and Cascading Events

Work Package WP4:	Risk based assessment
Working period:	January 2012 – December 2015
Work Package Leader:	ETH Zurich
Partners involved:	TenneT TSO GmbH, TenneT TSO B.V., Austrian Power Grid AG, Delft Technical University, Graz Technical University, RWTH Aachen, University of Duisburg-Essen, FGH e.V.

4.1 Objectives

The topic of Work Package 4 is risk-based security assessment, which encompasses both the probability and the severity of events. A risk-based measure carries more information than the deterministic criterion and allows for a quantitative definition of how secure the system is, as opposed to the binary N-1 criterion which only deems the system secure or insecure. A risk-based criterion allows for a more explicit definition of the trade-off between security and cost, and can lead to a more effective utilization of existing transmission capacity.

Due to the more comprehensive treatment of probabilities, risk-based methods are better suited for incorporation not only of outage probabilities but also of different kinds of forecast uncertainty. Special attention is paid to the influence of fluctuating generation resources on power system operation. Further, the developed methods include concepts that assess how cascading events, state-of-the-art technological measures (e.g. FACTS and PSTs) and how different market designs/cooperation rules between TSOs influence the overall system risk.

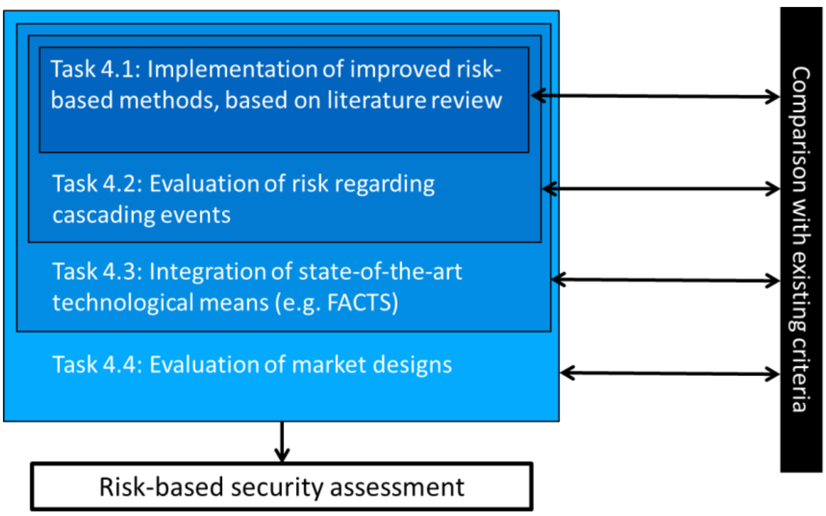


Fig. 4.1 : Objectives of WP 4

A summary of the objectives and tasks in WP 4 is given in Fig. 4.1..

4.2 Developed methods and results

In 2012, the first task of WP4 was completed. Task 1 consists of a review of the state-of-the art methods for assessing system security, including both deterministic and probabilistic methods, as well as the implementation of existing and newly developed methods. The work has been documented in a report, namely deliverable D4.1 [8]

The developed method is a probabilistic security constrained optimal power flow (pSCOPF), based on DC power flow equations and random variations in wind power in-feed following a Gaussian distribution [9]. The security constraints are formulated using sensitivity factors, which are constant due to the linearity of the DC problem. The uncertainty of wind power in-feed is included in the formulation of the optimization problem through chance constraints, which are analytically reformulated into tractable constraints. The outcome of the pSCOPF is a generation dispatch which is N-1 secure with a given probability. The method can however also be used to estimate the cost-of-security (cost-of-SCOPF – cost-of-OPF) and cost-of-uncertainty (cost-of-pOPF – cost-of-OPF or, alternatively, cost-of-pSCOPF – cost-of-SCOPF), i.e., the cost increase related to enforcing security constraints and to ensuring security in presence of forecast errors.

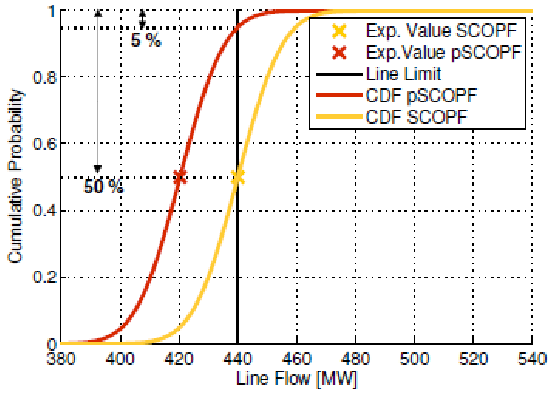


Fig. 4.2 Expected value of the power on line 23 after outage of line 7, as computed with SCOPF and pSCOPF. Superimposed on the exp. value is the cumulative distribution function (CDF) of the line flow. Because of the constraint tightening in the pSCOPF, the prob

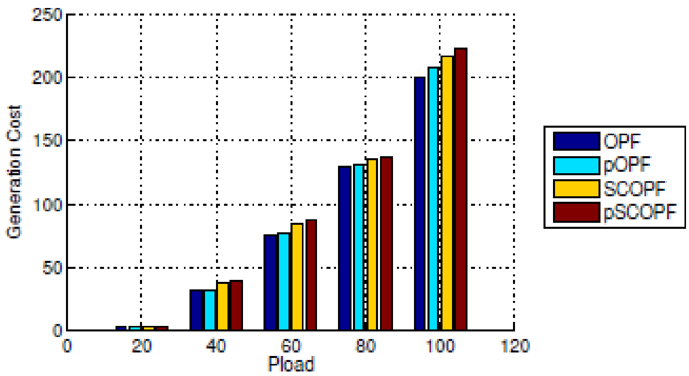


Fig. 4.3 Total (absolute) generation cost of the optimal dispatch for different load levels. The cost-of-security is higher than the cost-of-uncertainty at low load levels. At higher load levels, the cost-of-security and the cost-of-uncertainty are equal.

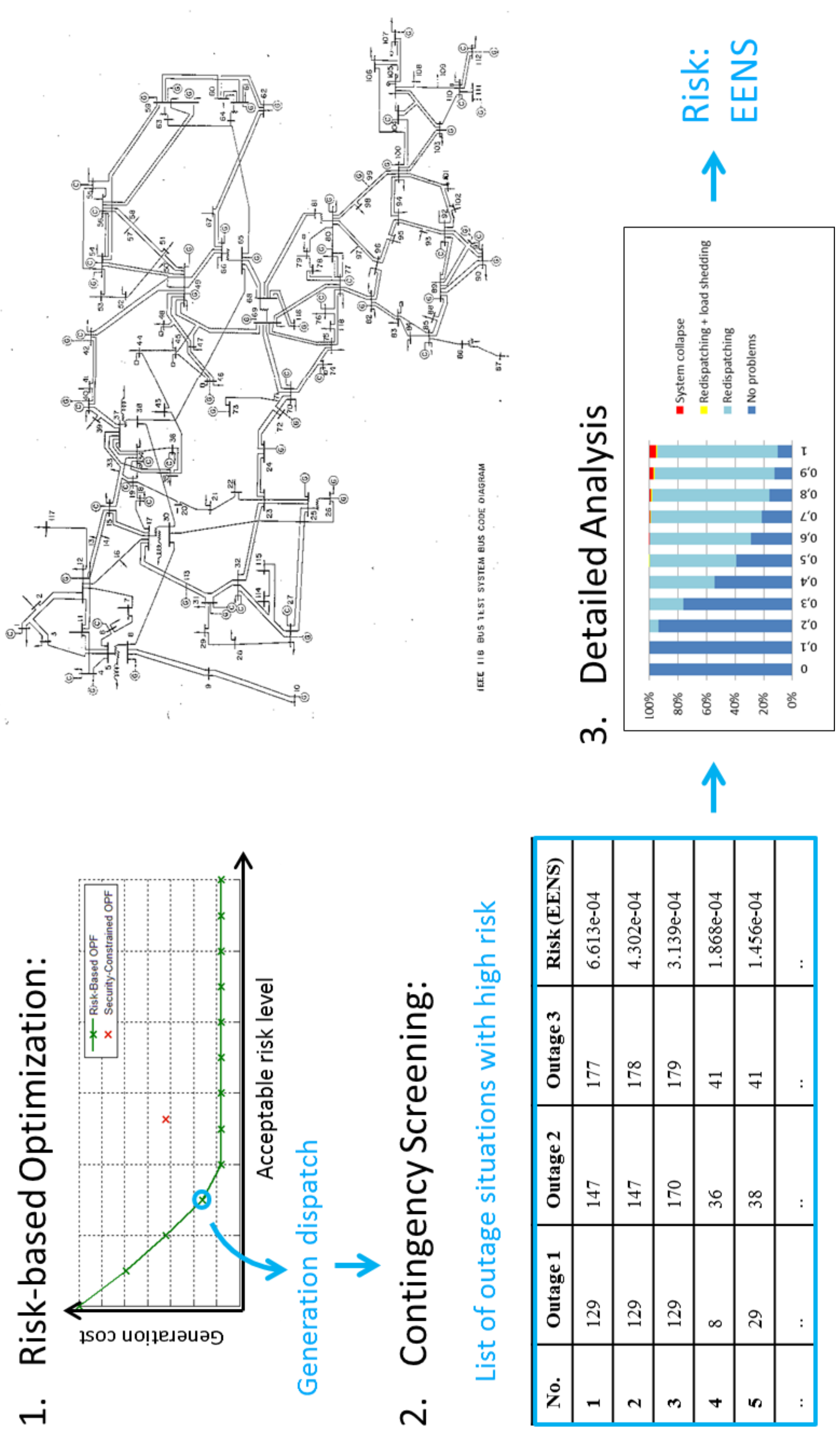
Throughout 2013, the main focus in WP4 has been on risk related to cascading events. The work is documented in deliverable D4.2 [10]. Presuming the occurrence of initial events, we develop measures to 1) assess the likelihood that such events evolve into a cascading outage and 2) evaluate the severity of such a cascading outage. In this way, additional information about the severity of the initial outage can be provided. This can be used to define appropriate remedial measures to reduce risk and to evaluate the risk level (likelihood and severity of cascading events) of a given dispatch.

Within Task 4.2, three methods to mitigate and assess the risk related to cascading events have been developed. For all three methods, the considered cascading mechanism is thermal overloading of transmission lines. The methods can be used as stand alone tools, or be combined to provide a full risk assessment.

The first method (1) is a risk-based DC OPF, which optimizes the generation dispatch subject to constraints on the risk of cascading events. The considered risk measure utilizes information about contingency probabilities as well the as pre- and post-contingency loading of transmission lines to estimate the probability that the initial outage will lead to the trip of another line. The risk measure is given as the probability that a cascade is initiated. The OPF method determines the generator dispatch, taking all N-1 contingencies into consideration. Among the three methods, this method has the most degrees of freedom but also uses the least accurate representation of cascade risk.

The second method (2) is a risk assessment for a given dispatch. The goal of the risk assessment is the identification of likely cascades. These are ranked according to their risk, which depends on both severity and probability of the cascade. For each N-1 contingency or set of N-1 contingencies, it evaluates the likelihood and the severity of a cascade, considering the full depth (all stages) of the cascade. It is thus possible to evaluate risk parameters reflecting risk to consumers such as EENS (Expected Energy Not Served). To avoid too heavy computation, a DC representation of the system and a normal distribution for the forecast errors is used. Due to these simplifications, it is possible to look at a large amount of outage scenarios to identify the potentially most dangerous situations.

The third method (3) is also a risk assessment for a given dispatch, but uses a full AC model of the system and a sample based approach to represent the forecast errors, which allows for more general distributions of the forecast errors. As for the DC risk assessment above, the risk is given in terms of overall system parameters like EENS. Because the additional accuracy in power flow and uncertainty representation comes at increased computational cost, this method is better suited to evaluate a few critical situations than for simulation of all possible outage scenarios.



No.	Outage 1	Outage 2	Outage 3	Risk (EENS)
1	129	147	177	6.613e-04
2	129	147	178	4.302e-04
3	129	170	179	3.139e-04
4	8	36	41	1.868e-04
5	29	38	41	1.456e-04
:	:	:	:	:

Fig. 4.4 Overview of the methods used for risk assessment of cascading events

Further, we are working on improved OPF formulations for better decision making and increased security. In [11, 12], we address two improvements compared to the traditional N-1 security assessment:

1) A risk-based extension to the N-1 security assessment is included to account for both probability and severity of contingencies. This assessment allows us to optimize for an adequate risk level, in order to find a better compromise between operating costs and security margins.
2) The forecast uncertainty of RESs in-feed, load consumption and trading volumes is accounted for in a comprehensive way throughout the operational planning process, in order to avoid operating points which have either too low (dangerous) or too high (economically inefficient) security margins.

We formulate and demonstrate a DC OP that accounts for both forecast uncertainty and outage risk. To achieve a solvable optimization problem, the chance constraints (constraints that have to be fulfilled with a given probability) are reformulated using the so-called scenario approach (a sampling-based method, which replaces the chance constraint by an adequate deterministic constraint). The result is a risk-constrained OPF that guarantees that the risk limits hold with a given probability. The probability of violation is chosen as an input to the optimization.

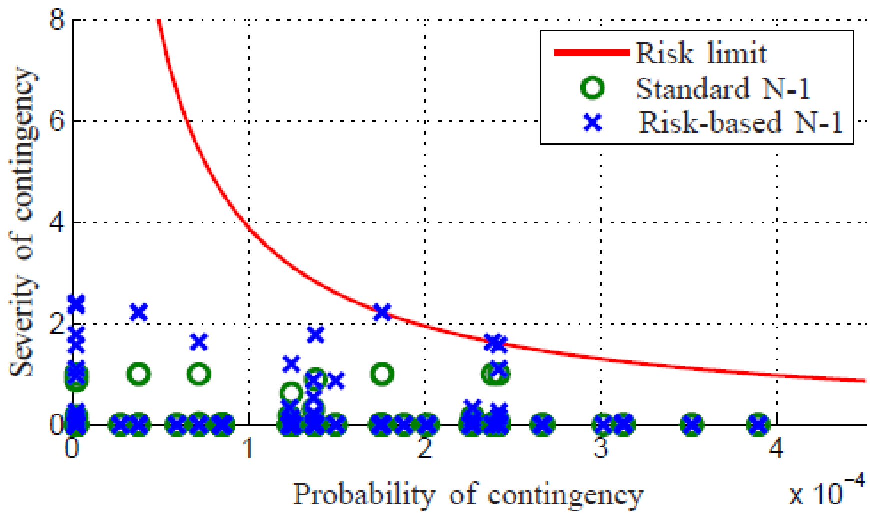


Fig. 4.5 Comparison between the severity of different contingencies

For the interested reader, our work has been documented in a number of reports and other publications:

The work results so far are documented in two Deliverables [8, 10] and two publications [9, 11]. Four presentations [12, 13, 14, 15] are planned for the year 2014 .

5 TSO Demands and Basic Requirements for the UMBRELLA-Toolbox

Work package WP5:	Synthesis and Prototyping
Working period:	July 2012 – May 2015
Work package leader:	Amprion
Partners involved	Tennet TSO GmbH, TransnetBW GmbH, Austrian Power Grid AG, FGH e.V., University Duisburg-Essen

The main objective of this work package is the provision of a toolbox which supports TSOs with the handling of the tasks and challenges arising from the growing share of electricity generation from intermittent renewable energy sources. Two different parts of a TSO's field of work are concerned, the operational planning as well as the real-time operation process. The first step to achieve the main objective is the identification of methods most appropriate and promising for these two processes. The respective methods are provided by the research activities carried out in the framework of the work packages 2, 3 and 4 and have to be evaluated based on the demands expressed by TSOs. Afterwards, the major challenge of this work package is the synthesis of the different methods and concepts into one integrated toolbox which can be operated by a TSO as a part of the operational planning and real-time operation processes. The results of this synthesis are presented in the deliverable D5.1 of this project which summarizes the requirements of the toolbox based on the TSOs' demand and expectations and the first results of the research activities. Based on this summary, algorithms will be developed in order to transform the academic results of the work packages 2, 3, and 4 into a toolbox applicable in the daily operation of a TSO. The algorithms of the different work packages need to be synthesized with an emphasis on the necessary interfaces and – dependencies. Once the synthesis of the algorithms is completed, the implementation of a prototype of the toolbox is the final step of the work package. Fig. 4.6 provides a schematic overview of the objectives and steps forming work packages 5.

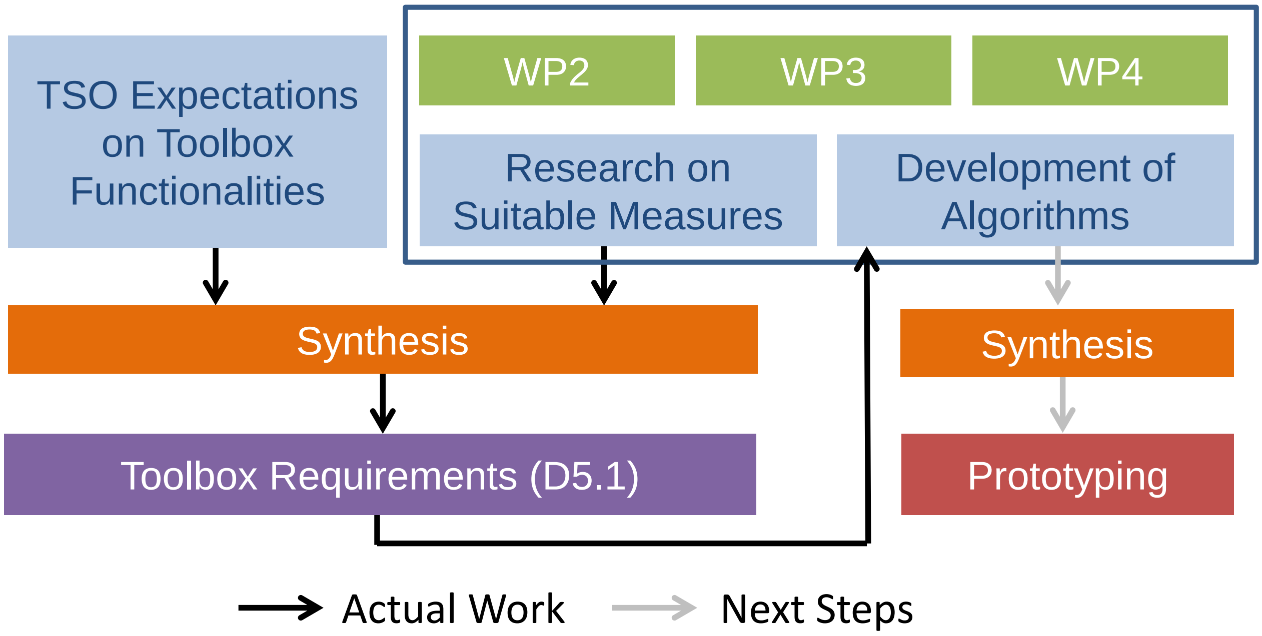


Fig. 4.6 : Objectives of WP 5

In order to achieve the objectives, the work packages is organised in four tasks. The relationship between the tasks is depicted in the following figure (see Fig. 4.7).

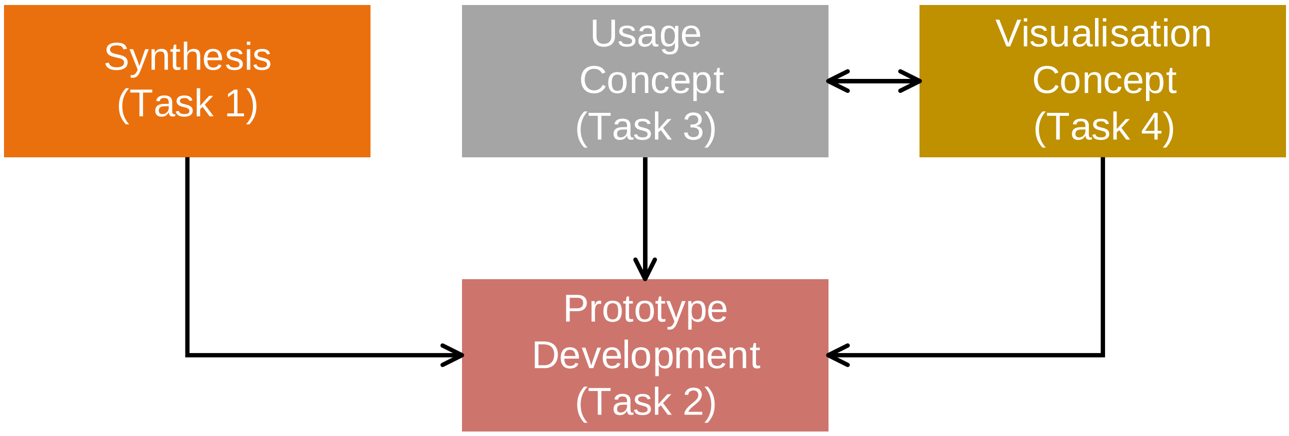


Fig. 4.7 Task structure of WP5

The focus of the synthesis step is on the synchronisation of the demands and expectations on the toolbox functionalities formulated by TSOs with the results of the research activities which are the subject of each of the work packages 2, 3 and 4. Given the fact that the research activities are still a work in progress, the synchronization process will continue until the end of this task.

The comparison of the expectations by TSOs regarding the functionalities of the toolbox and the first results of the scientific research carried out in the course of the work packages 2, 3 and 4 has been finished and the results are the subject of the deliverable D5.1 of the UMBRELLA project. The data requirements to be met in order to fulfil the expectations of the TSOs on the one hand and to facilitate the application of the methodologies and algorithms on the other hand are addressed very detailed in order to emphasize the importance of this aspect. Furthermore, the interfaces and interdependencies between the work packages 2, 3 and 4 represent a major challenge.

Fig. 4.8 provides an overview of the interfaces and –dependencies between the specific work packages of the project UMBRELLA. The results of WP2 provide input data for the optimisation and the risk-based assessment tasks within WP3 and WP4 as well as a direct input for the toolbox prototype. Work packages 3 and 4 exchange information and data on a bidirectional basis. Both work packages deliver methodologies and algorithms for the toolbox prototype. The data requirements and exchange of the different work packages have to be considered for the implementation of the tool box prototype. Furthermore, the sequence of the different functionalities and the time required by the algorithms developed by the work packages need to be merged in an appropriate way.

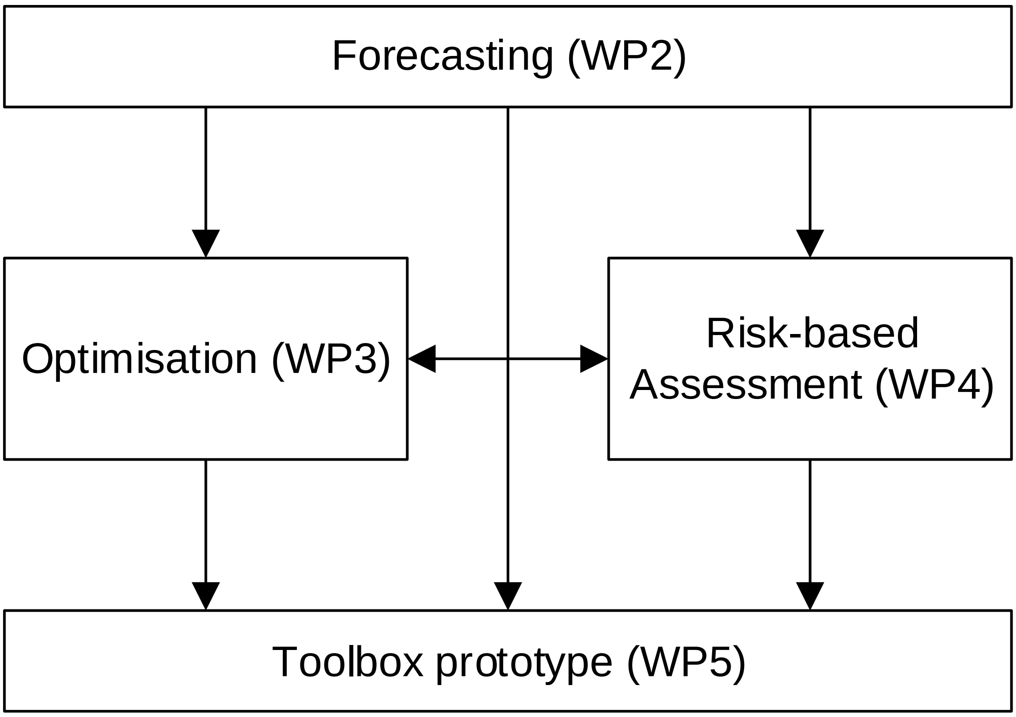


Fig. 4.8 Interfaces and dependencies of work packages and toolbox functionalities

The objective of the prototype development task is the development of a common prototype which joins the methodologies and algorithms invented in work packages 2, 3 and 4. The toolbox prototype has to allow the proof of the applicability of the concepts developed. The appropriate tests comprise close-to-reality networks as well as load and generation data provided by TSOs. Even if the development of the algorithms and methodologies is not completed yet, the realization of the prototype has already started. In order to enable an efficient realization of the toolbox based on the research work done in WP 2 to WP 4 the analysis of the developed methods, algorithms and concepts is a work in progress. Here, some parts of the preliminary, more academic/rapid developments in the work packages WP 2 to WP 4 might be used in the toolbox directly (e.g. modules for offline data processing if sufficient for reasonable amount of data). However, the close-to-reality tests need an integration of all developed algorithms into one common toolbox platform with the ability to process large systems in a reasonable computation time.

Basic functionalities needed for the processing of input data within the test cases were already developed. For instance, algorithms were implemented which extract relevant information out of the available data formats and store it in a database suitable for further data processing. Subsequently, a methodology was developed which converts a series of grid data sets (e.g. DACF-Files) to one common data model. This functionality is needed in order to consider the temporal development of grid utilization in the timeframe of power system operation and operational planning as well as inter-temporal constraints within the optimization.

A crucial factor for the success of the toolbox is the practicability and the acceptance of the functionalities by the control room staff of TSOs. Accordingly, the realisation of an appropriate concept for the visualisation of the toolbox results is the objective of task 5.4. Due to the fact that this topic has been addressed by several previous research projects, the starting point for the development of a visualisation concept for the project UMBRELLA is the analysis of existing approaches. These approaches need to be adjusted and if necessary enhanced to meet the requirements defined by the functionalities of the toolbox. The first and ongoing step of the visualisation task is the review of previous research carried out. One example for a previous project also performed within the seventh framework programme dealing with visualisation aspects for control room staff of TSOs is the project “Pan European Grid Advanced Simulation and State Estimation (PEGASE)”. Due to the recent start of the task and the complexity of the topic addressed in this task the amount of results obtained is limited. Nevertheless, the results will be part of the deliverables D5.2 and D5.3 that are scheduled for February and August 2015, respectively.

6 Critical grid situations - input for (and benchmarking of) the toolbox

Work package WP6:	Demonstration and Testing
Working period:	September 2012 – November 2015
Work package leader:	TransnetBW GmbH
Partners involved	Tennet TSO GmbH, Amprion, ČEPS, a.s., Elektro-Slovenija, d.o.o, PSE S.A., swissgrid ag, TenneT TSO B.V., Austrian Power Grid AG, University Duisburg-Essen, FGH e.V.

6.1 Objectives

In this work package the functionality of the developed toolbox is demonstrated using appropriate test cases. First of all, the tests need to be specified by the participating TSOs. The required testbeds have to be made available to all functions developed subsequently in order to run the tests. The test cases have to represent a sound basis for additional analyses such as sensitivity analysis and scenario assessment. Due to the fact that the participating TSOs are significantly afflicted by the increasing share of infeed from renewable energy sources, special attention will be focused on cases with a high infeed of renewables resulting in stressed grid situations that require remedial actions. Beyond the evaluation of the toolbox, the test results will particularly be used to identify needs for further harmonisation of operational requirements in TSO cooperation rules.

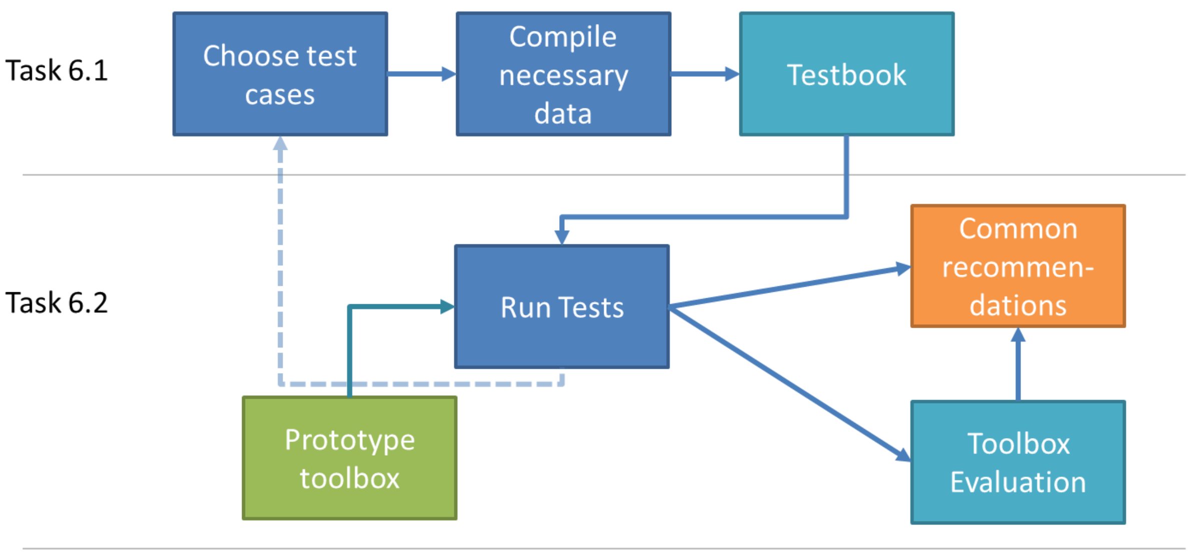


Fig. 6.1 Basic illustration of the main work within work package 6

6.2 Progress and results

Since the main workload of working package six is concentrated in the last third of the UMBRELLA project, there is an assessable amount of results for the time being. The first set of test cases has been compiled and made available to the research partners. Furthermore a common test scenario “cold snap in February 2012” was harmonized with the related FP7-project iTesla. At the end of this reporting period the draft of the testbook (D6.1) is underway.

So far it is already conceivable, that a considerable amount of data has to be added to current DACF-datasets (e.g. information on power plants, compensation elements and others), which thus far have not been or at least not explicitly been included.

To identify relevant test cases every participating TSOs individually proposed timestamps with stressed grid situations. On this basis test cases have been identified where several TSOs are affected by high load flows. Main challenge for the participating TSOs are situations with high North-South flows especially during periods of high wind in feed in the Northern part of Germany. As common test case with iTesla the cold snap period in February 2012 was chosen.

7 Dissemination

Work package WP7: Dissemination
Working period: January 2012 – December 2015
Work package leader: Delft Technical University
Partners involved Tennet TSO GmbH, Delft Technical University, ETH Zurich, Graz Technical University, RWTH Aachen, University of Duisburg-Essen, FGH e.V.

7.1 Overview

The main objective is to ensure that this project and its results are brought to the attention of those parties for which this project and its results are of interest. This group contains those that are directly involved in the project, the stakeholders and external parties. The group consists of TSO's, electricity producers, local regulators, research institutions etc. Special attention has to be given to the non-project partners. If appropriate, a specific action will be attuned with any other on-going projects that are related to the one under consideration.

7.2 Progress and results

This work package does not contain individual sub-work packages, but a collection of tasks/milestones/deliverables within the WP 7.

- Kick-off Meeting was held in Cologne in February 2012. The group picture is shown in Fig. 7.1.

Fig. 7.1 : UMBRELLA Kick-off Meeting

- An internal workshop was held in January 2013 in Aachen, where TSOs and researchers exchanged operational practice of transmission grid and corresponding modelling ideas/approaches.

- A project website named www.e-umbrella.eu has been designed and maintained by

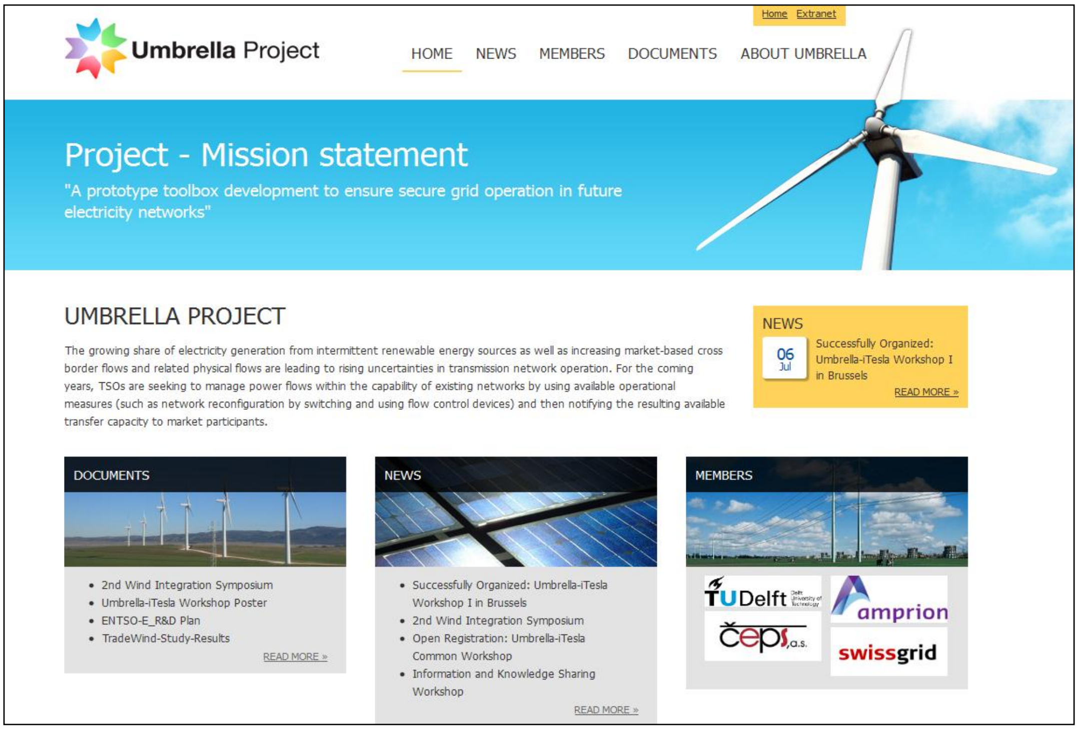


Fig. 7.2 : Homepage of the UMBRELLA project

subcontracting to a web design company (Inforaction BV, www.inforaction.nl). The selection of the subcontracting procedure is strictly respected as described in Description of Work Annex I section 2.3.5. The website contains an external area that is accessible to all visitors and an internal restricted area where only authorized members can view the content. The content management system allows the authorized members to upload and download the 'member-only accessible' files, whereas unauthorized visitors can only download the 'publicly accessible' files. The homepage of the UMBRELLA project is shown in Fig. 7.2.

- The project logo in Fig. 7.3 was also designed by Inforaction BV and approved by consortium members. The design concepts for the logo were the following:
  - The shining star in the centre of the logo symbolizes a source of energy and electricity.
  - The pentagonal star also references the stars in the European Union logo and the European collaboration in the UMBRELLA project.

- The stakeholders involved in the project are represented by the coloured arrows which point to the centre of the star from all directions.
- The total sum of the logo symbolizes an UMBRELLA viewed from the top.
- A European (Swiss) font was used for the typography: Helvetica Neue 75 Bold and Helvetica Neue 55 Roman.

Fig. 7.3 UMBRELLA logo

- A power point presentation template was developed and uploaded to the extranet of the website.
- After the submission of deliverable D7.1 [16], this dissemination plan was regularly updated, emphasizing on current and upcoming international workshops, conferences, and other events. The internal document is titled 'Actualisation of Communication Plan' and available to all consortium members in the extranet area.
- Internal workshop on information and knowledge sharing was held in Frankfurt in April 2012. Detailed information regarding DACF files was presented by the TSOs to universities and the research institute.
- Deliverable D7.2 [17] was submitted to the Commission in August 2012. The common workshop, co-organised by UMBRELLA and iTesla, was held successfully at ENTSO-E premises in Brussels in June 2012. Approximately 50 participants from industry, academia, government officials etc. joined the common workshop, with full support by ENTSO-E. A picture of panellists is shown in Fig. 7.4.

Fig. 7.4 : Common iTesla – UMBRELLA workshop: Panellists (from left to right): Hubert Lemmens (ENTSO-E Convenor RDC), Irena Bonvissuto (EC officer), Frans van Hulle (EWEA coordinator) and Rudolf Baumann (ENTSO-E Convenor SOC-RG-CE)

- An internal workshop was held in January 2013 in Aachen, where TSOs and researchers exchanged operational practice of transmission grid and corresponding modelling ideas/approaches.
- A Newsletter has been created and distributed to the partners and interested parties to inform them about the progress of the project and coming activities.
- Several editorial houses have been contacted in order to get permission to upload and show the content of papers and reports that have been created during the project.
- An application for the second round of EEGI labelling was tabled. In December the EEGI Core Label was awarded to the UMBRELLA project (ref. http://www.e-umbrella.eu/eegi-label-awarded).
- Several project partners attended the Grid+ Webinars inter alia on project scalability and replicability on 21st of November. GRID+ is a FP7 EU project that runs the EEGI platform. The lessons learned during the webinar will be of use particularly to the “demonstration” and “dissemination” packages.
- Attendance of various events including conferences and workshops ref. to 7.3. A list of publications is given in 7.4.

7.3 Attendance of various events, including conferences and workshops

Table 7.1 Attended events

Name of the event	Date	Location	General scope of the event
Innogrid2020+ workshop	Feb 23-34, 2012	Brussels, Belgium	European Research and Development Dissemination Seminar
Wind integration symposium	May 8-9, 2012	Frankfurt, Germany	Managing renewable generation
Control of Power Systems	May 15-17, 2012	Tatranské Matliare, Slovakia	Scientific conference
Cigré Canada	Sept 24-26, 2012	Montreal, Canada	General power system conference
USAEE/IAEE North American conference	Nov 4-7, 2012	Austin, Texas	Possible challenges and opportunities for the transition to sustainable energy era
Wind integration workshop	Nov 13-15, 2012	Lisboa, Portugal	Power system with wind energy integration
Innogrid2020+ workshop	Feb 20-21, 2013	Brussels, Belgium	European Research and Development Dissemination Seminar
WIPFOR workshop	June 5-7, 2013	Paris, France	Time series forecasting techniques using stochastic methods
IEEE PowerTech Conference	June 16-20, 2013	Grenoble, France	General power system conference

7.4 Publications and References

The dissemination activities were accomplished by [18, 19, 20] and documented in two deliverables [16, 17] and one forthcoming [18]:

[1] UMBRELLA WP2, "Deliverable 2.1 - Report on uncertainty modeling," http://www.e-umbrella.eu/documents, 2013.

[2] R. Becker and C. Weber, "Using Time-Adaptive Probabilistic Forecasts for Grid Management - Challenges and Opportunities," in *31st USAEE/IAEE North American Conference*, Austin, Texas, USA, 06.11.2012.

[3] R. Becker and C. Weber, "Probabilistic Wind Power Forecasting in Transmission Grids - Making use of Spatial Correlation," in *WIPFOR: 2nd Workshop on Industry & Practices for Forecasting*, Paris, France, 06.06.2013.

[4] M. Schoeneberger, P. Schäfer, O. Scheufeld, S. Krahl and A. Moser, "Forecast of vertical reactive loads considering the influence of renewable energy sources using artificial neural networks," in *Submitted to PSCC*, Wroclaw, Poland, 2014.

[5] UMBRELLA WP3, "Deliverable 3.1 - Report on deterministic algorithms for EOPF," http://www.e-umbrella.eu/documents, 2013.

[6] K. Vandyshev, D. Gijswijt and K. Aardal, "Topology Optimization Methods in Electric Power Systems," in *EURO2013: 26th European Conference on Operational Research*, Rome, Italy, 1-4 July, 2013.

[7] J. Eickmann, C. Pasch, N. Rotering and A. Moser, "Including Reasoning in Congestion Management Expert Systems," in *submitted to CIGRE conference*, Brussels, Belgium, 2014.

[8] UMBRELLA WP4, "Deliverable 4.1 - Risk-based Assessment Concepts for System Security – State-of-the-art review and concept extensions," http://www.e-umbrella.eu/documents, 2012.

[9] L. Roald, F. Oldewurtel, T. Krause and G. Andersson, "Analytical reformulation of security constrained optimal power flow with probabilistic constraints," in *IEEE PowerTech*, Grenoble, France, 2013.

[10] UMBRELLA WP4, "Deliverable 4.2 - Risk assessment methods," http://www.e-umbrella.eu/documents, 2013.

[11] Vrakopoulou, M. and et al., "A Unified Analysis of Security-Constrained OPF Formulations Considering Uncertainty, Risk, and Controllability in Single and Multi-area Systems," in *IREP Conference*, Crete, Greece, 2013.

[12] L. Roald, M. Vrakopoulou and F. Oldewurtel, "Risk-Constrained Optimal Power Flow with Probabilistic Guarantees," in *submitted to PSCC*, Wroclaw, Poland, 2014.

[13] L. Roald, B. Li, F. Oldewurtel, T. Krause and G. Andersson, "An optimal power flow (OPF) formulation including risk of cascading events," in *submitted to XIII SEPOPE*, Foz du Iguazu, Brazil, 2014.

[14] M. d. Jong, G. Papaefthymiou, D. Lahaye, C. Vuik and L. v. d. Sluis, "Impact of correlated infeeds on risk-based power system security assessment," in *submitted to PSCC*, Wroclaw, Poland, 2014.

[15] K. Köck and H. S. J. Renner, "Probabilistic Cascading Event Risk Management," in *submitted to PSCC*, Wroclaw, Poland, 2014.

[16] UMBRELLA WP7, "Deliverable 7.1 - Website, basic communication plan and dissemination strategy," 2012.

[17] UMBRELLA WP7, "Deliverable 7.2 - Workshop results on innovative operational tools," 2012.

[18] K. Maslo, "Power system dynamics modelling," in *10th International conference control of power systems*, Tatranské Matliare Slovak Republic, May 2012.

[19] Liu, Z. et al., "Challenges Experiences and Possible Solutions in Transmission System Operation with Large Wind Integration," in *11th International Workshop on Large-Scale Integration of Wind Power into Power Systems*, Lisbon, Portugal, November 2012.

[20] Liu, Z. et al., "Innovative operational security tools for the development of a stable pan-European grid," in *Cigré Canada*, Montreal, Canada, September 2012.

[21] UMBRELLA WP7, "Deliverable 7.3 -: Open Workshop on intermediate results together with iTesla," 2014.