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**608540**

Project acronym:
**GARPUR**

Project full title:
**Generally Accepted Reliability Principle with Uncertainty modelling and through probabilistic Risk assessment**

**Collaborative project**

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# D11.1b
# Periodic Report No 2

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| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | X |
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The research leading to these results has received funding from the European Union Seventh Framework Programme under Grant Agreement No 608540.

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# 1 DECLARATION BY THE SCIENTIFIC REPRESENTATIVE OF THE PROJECT COORDINATOR

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [1]:
  - ☐ has fully achieved its objectives and technical goals for the period;
  - ☒ has achieved most of its objectives and technical goals for the period with relatively minor deviations.
  - ☐ has failed to achieve critical objectives and/or is not at all on schedule.
- The public website, if applicable
  - ☒ is up to date
  - ☐ is not up to date
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Oddbjørn Gjerde

Date: 07 / 11 / 2016 Oddbjørn Gjerde

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism and in that case, no signed paper form needs to be sent.

[1] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

## 1.1 Publishable summary

### Summary description of project context and objectives

Power system reliability management aims to maintain power system performance at a desired level, while minimizing the socio-economic costs of keeping the power system at that performance level.
Historically in Europe, network reliability management has been lying on the so-called “N-1” criterion: in case of fault of one relevant element (e.g. one transmission system element, one significant generation element or one significant distribution network element), the elements remaining in operation must be capable of accommodating the new operational situation without violating the network’s operational security limits. Today, the increasing uncertainty of generation due to intermittent energy sources, combined with the opportunities provided e.g. by demand-side management and energy storage, call for imagining new reliability criteria with a better balance between reliability and costs.

Within this context, the GARPUR project designs, develops, assesses and evaluates new reliability criteria to be progressively implemented over the next decades at a pan-European level, while maximizing social welfare. The seven main objectives of GARPUR are:

1. 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.
2. 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.
3. To develop a quantification platform able to compare different reliability management strategies in terms of their impact on the social welfare.
4. 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.
5. To validate the different reliability criteria with the help of pilot tests.
6. 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.
7. To define an implementation roadmap towards the use of the new reliability management practices.

To ensure progress beyond the state-of-the-art, GARPUR pursues five different aspects by which progress can be ensured and evaluated. These are defined as:

1. Model the spatiotemporal variation of the probabilities of exogenous threats and take into account the actual criticalities of service interruptions in the reliability management.
2. Take into account the increased possibilities of corrective control and its probability of failure in the reliability management.
3. Exploit the flexibility provided by demand-side management and energy storage, to achieve the reliability enhancement given the emergence of decentralized renewable generation.
4. Explicitly model the impact of system development and asset management decisions on the reliability management during operation,
5. Explicitly take into account the consideration of low-probability high-impact events, such as the ones originating from extreme weather conditions, possibly through climate change, or those originating from adverse behaviours of external entities.

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## Description of the work performed since the beginning of the project and the main results achieved so far

GARPUR has structured its work into nine technical Work Packages, one dissemination Work Package, and one management Work Package. The following paragraphs summarize the work performed and results obtained so far.

**WP1 "Revisiting reliability management methodologies"** has confronted the literature on power systems reliability with the reliability management approaches currently used by TSOs. The work in WP1 is finished and results indicate that there is a gap between the existing research literature and what is practiced by TSOs. Even if a diversity of probabilistic methods, including socio-economic impact assessment, are proposed in the literature, they are used in practice only to a very limited extent. Further it is revealed that current practices for reliability management mainly follow the N-1 criterion, but with different ad hoc implementations. Finally, the analysis showed that one of the important drivers perceived by TSOs to introduce probabilistic reliability management methods in practice is the need for a better balance between reliability and costs, while a lack of data in terms of probabilities of threats and socio-economic consequences of service interruptions is found to be one of the main barriers.

**WP2 "Development of new reliability criteria for the pan-European electric power system"** has developed a consistent probabilistic framework to both assess and optimize power system reliability in the different practical decision making contexts. The mathematical/computational models were developed with the goal to predict the expected locations, amounts and durations of supply shortages implied by power system reliability management decisions. WP2 is finished, and has worked in three logical steps to reach this objective:

1. Functional analysis of reliability management, decomposed into assessment and control tasks; 2. Mathematical formulation of the proposed reliability criteria and optimization problems;
3. Design of scalable algorithms for reliability assessment and optimization.

The main results achieved in WP2 are the, **general mathematical formalization of reliability management approaches and criteria (RMAC)**, in the form of a multi-stage stochastic programming problem explicitly stating a decision making horizon, a socio-economic objective function, and a reliability target in the form of a chance-constraint, and completed by a “discarding principle” prescribing a sought level of accuracy and a “relaxation principle” prescribing how to manage situations where the reliability target cannot be reached. Further, **algorithmic implementations** of this mathematical model have been developed both for real-time reliability management (preventive and corrective control) and mid-term reliability management (outage scheduling). Directions for extending these ideas to short-term reliability management (operation planning) and long-term decision-making (system development, and maintenance policy choices) have been identified. Finally, the main steps needed for the practical implementation of its results, in the form of **guidelines** for further work during the last year of the GARPUR project, and beyond its termination, have been identified. The proposed framework explicitly takes into account uncertainties (e.g., meteorological conditions, renewable generation, etc.) and enables the exploitation of several opportunities (e.g., post-contingency corrective controls, demand-side response, etc.) with the objective of optimizing socio-economic welfare by means of the various TSO activities. The use of machine learning techniques in order to automatically build proxies of the shorter-term decision-making processes when addressing the longer-term reliability management problems has been identified as a main direction of complementary methodological research.

**WP3 "Socio-economic assessment of reliability criteria"** has developed a methodology to quantitatively evaluate the socio-economic impact of different reliability management strategies that could be implemented in the European electric power system. With the completion of WP3 a socio-economic impact assessment methodology has been formulated and illustrated. The methodology is based on social welfare analysis of the electricity system and allows quantifying the costs, benefits, and surplus of all stakeholder groups: electricity consumers, electricity producers, the TSO, the government surplus from taxes on electricity and environmental surplus from electricity-related externalities. The methodology details how to calculate interruption costs, TSO costs, producer costs, environmental costs and congestion costs on different time horizons. A general mathematical formulation of these surpluses is given for different nodes, generation technologies, consumer types, time of occurrence and duration of interruptions, interruption moments and pollutants. It is also illustrated how to apply the methodology to a numerical test case in each GARPUR timeframe. The methodology is also extended by providing an analysis of possible responses of electricity market stakeholders to changes in the reliability level, electricity prices and taxes. Furthermore, interactions between multiple TSOs, multiple countries and the distributional effect on different consumers, are analysed. Data requirements and data availability is also considered, and a roadmap for further development of the framework is suggested.

**WP4 "System development"** refines the methods developed in WP2 and WP3 in the light of the practical needs of system development in the context of long-term decision-making in a multi-area/multi-TSO system. A four-step approach has been proposed consisting of: screening of operating states, grid planning, and a 2-step optimisation (first identifying the promising target topologies, and later to define for each of them the optimal grid development path). The framework takes market aspects (producer and consumer surplus), reliability aspects and possible grid investments into account. Among progress we can mention a novel contingency screening methodology (based on Inverse Matrix Modification Lemma), a methodology for sampling of spatially correlated long-term wind speed based on historical records different clustering algorithms for grouping load snapshot records (developed and being validated based on data with a 15-min resolution, of different customers from Belgium), and a methodology for the selection of credible operating states is starting to be drafted. An important finding is that use of a market tool is crucial in the process of generation credible operating states.

**WP5 "Asset management"** refines the methods developed in WP2 and WP3 in the light of the practical needs of asset management. For upgrading reliability management in the context of asset management consistently with the GARPUR principles, the assessment of outage schedules (mid-term) and the assessment of maintenance policies (long-term) have been addressed, resulting in the development of algorithms based on Monte-Carlo simulations, combined with proxies of system operation and outage scheduling activities. Main modelling topics that are analysed are load forecasting, RES forecasting, influence of the weather on the failure rates, maintenance scheduling, failure rates and outage durations. Theoretical models have been identified to represent the ageing process of the assets, as well as the benefits brought by maintenance activities. These models can be customized to account for extra features, such as the faster degradation of assets located in hostile climatic areas. However, tuning these models based on real-life data remains highly challenging, and expert knowledge will be required. One of the main challenges in this latter context is the definition of relevant classes of assets to exploit past statistics. In addition, the ageing models, which are defined at the subcomponent level, need to be synthesized at the level of the whole assembly. The use of machine learning approaches to build faster proxies of shorter-term decision making context needed to carry out asset management studies has been explored and identified as a promising further direction of work.

In addition to the modelling of failures where the component ageing state plays a role, one must consider the failures caused by other triggering factors, such as the current weather conditions. One important aspect that is not properly taken into account by the TSOs today is the failure bunching effect. In case of a storm, the failure rates in a local area suddenly increase a lot compared to regular weather conditions. Consequently, the probability of multiple outages occurring simultaneously becomes significant. At least, the probability of N-k events should not be approximated by using annually averaged values of the failure rates of individual assets.

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**WP6 "Power system operation"** refines the methods developed in WP2 and WP3 in the light of the practical needs of system operation in a multi-area/multi-TSO system. WP6 has developed reliability assessment algorithms for real-time operation and short-term operational planning. They aim at supporting the decision-making process of TSOs under uncertainty. The framework is based on (i) a reliability criterion that explicitly considers scenarios of the uncertain exogenous parameters (such as load, RES production and occurrence of contingencies) and their probability and (ii) methods to assess this reliability criterion. The new GARPUR reliability criterion states that the probability that the system state is acceptable must be higher than a pre-defined reliability target.

The methods to assess this reliability criterion are structured around (i) a discarding principle that allows discarding scenarios of the uncertain exogenous parameters to make the problem tractable, (ii) algorithms to check the reliability criterion and (iii) an indicator of socioeconomic surplus that is used to compare different candidate decisions. The risk is defined explicitly as the expected costs of service interruptions and is integrated into the socioeconomic surplus.

In real-time operations the random occurrence of contingencies is considered by using appropriate threat-based models of their probability of occurrence. In addition, special attention is given to the possible failure of corrective actions. Neglecting this aspect would favour too optimistically the use of corrective actions instead of preventive actions. In short-term operational planning the uncertainty in the load, production, exchanges and probabilities of the contingencies are considered. Appropriate models are proposed for these exogenous parameters.

**WP7 "Development of a quantification platform for reliability criteria"** develops a testing environment via a computational quantification platform, to assess the impact of different reliability criteria before putting them into service in real-life. The quantification platform is aimed at simulating the use of the methodologies brought forward by WP2 and WP3 and further refined in WP4-5-6, and comparing them with the current methods in use (based on the N-1 criterion). A functional description of the quantification platform has been established for both an ideal and a prototype platform, and the prototype is being developed progressively. The ideal platform is seen as the generic version of the prototype, having more options and possibilities. The prototype version has two objectives. On the one hand, it needs to be able to perform the pilot tests as specified in WP8. This requires a platform able to deal with existing TSO data and models. On the other hand, the tool should allow one to benchmark different reliability management methods and reliability criteria through the use of various academic test systems. Currently the prototype is being enhanced in order to allow its use in the context of the pilot tests specified in WP8.

**WP8 "Pilot scale validation"** aims at testing the new proposed methods for selected TSOs, or group of TSOs, both in a given control zone and throughout the pan-European system. Eight possible pilot tests have been identified and prioritised, covering both pilot tests utilising the prototype quantification platform as well as the so called "near real-life" pilot tests using adapted versions of the TSO's own tools. So far detailed specifications have been written for three high priority pilot tests, and an adjusted second version of the quantification platform prototype GQP is tested on the RTE pilot test. The two near real-life pilot tests at Elia and Landsnet are currently under preparation.

**WP9 "Recommendations and roadmap for migration"** collects the lessons in all the previous Work Packages, WP1 to WP8, to analyse challenges for applying the proposed methods in practice, and to define a roadmap of R&D and policy decisions that are suited to make the evolution towards the practical use of new probabilistic reliability management methods possible at the pan-European level. The analyses of GARPUR results, including feedback from dissemination events, are continuously ongoing.

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Preparations are also being made for finalizing the recommendations and road map during the last year of the project.

**WP10 "Dissemination"** accompanies the research activities and the pilot tests by approaching the TSO community within EU27 and beyond, in particular through the GARPUR Reference Group of TSOs which are involved in output quality checks and dedicated dissemination tasks towards their own control zone stakeholders, as well as other impacted stakeholders through interactive workshops. ENTSO-E members have expressed strong interest for results developed by GARPUR. In addition to the seven TSOs in the consortium four TSOs and two TSO organisations are in the GARPUR reference group. Contact has also successfully established with regulators and energy ministries representatives, and interaction has been established with the iTesla and Umbrella projects.

The GARPUR website is being updated continuously and linked to existing relevant information sources. There are 4,978 unique visitors on the project website and 2,175 downloaded files from December 2013 to August 2016. http://www.garpur-project.eu/

Regarding scientific publishing 18 papers have already been published or accepted so far, while 13 other papers are in progress.

**WP11 "Coordination and management"** secures an efficient communication and decision-making process for the consortium. The GARPUR project is up and running and most deliverables have been submitted to the EC according to the plan. All internal procedures and routines are in place, and are being further developed when needs arise.

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## The expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far)

It is believed that GARPUR will show that new criteria for reliability management of the pan-European transmission system can and should depart from the N-1 criterion, by using a probabilistic approach that ensures pan-European system reliability while optimizing social welfare. The diagram below summarizes the expected outcomes.

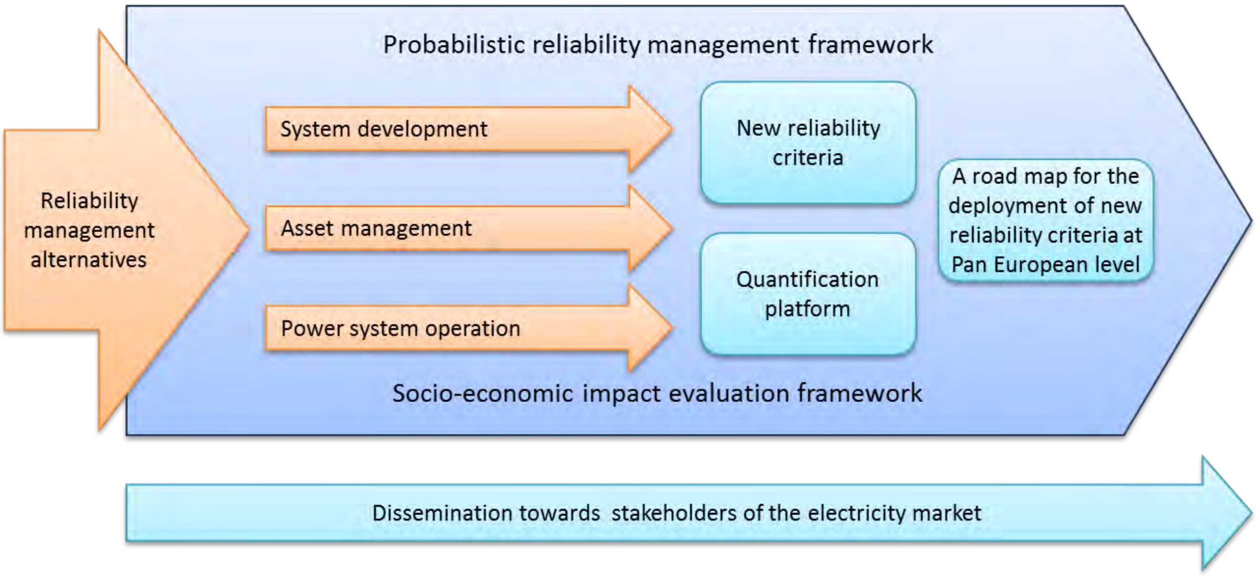


Figure 1: GARPUR outcomes

GARPUR develops a comprehensive and coherent probabilistic methodology covering the different TSO activities (system development, asset management, operations). For each studied reliability management alternative, the Quantification Platform links the socio-economic consequences of their implementation. This is mathematically modelled as an optimization problem, based on two consistent frameworks: one for probabilistic reliability management and another for socio-economic impact evaluations. The deployment roadmap for the new reliability criteria will show relevance at the pan-European level for applications by TSOs within the three time horizons.

There will probably be extra investments involved to deploy the probabilistic reliability management framework. Yet the extra benefits of providing adequate levels of reliability may override the required costs as it will be possible to show by the use of the quantification platform. Indeed:

- information technology capable of extensive data processing and network simulations tools make a probabilistic approach to reliability management increasingly realistic.
- in the future TSOs must cope with potentially critical situations due to the massive arrival of stochastic generation, the development of a pan-European electricity market leading to massive cross border exchanges, and the opportunities to leverage new sources of flexibility in the context of operation as well as in the context of long-term planning.

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