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Ancillary services for the European grid with high shares of wind and solar power.

Frans Van Hulle, Hannele Holttinen, Juha Kiviluoma, Nicolaos Cutululis

Abstract— With significantly increasing share of variable renewable power generation like wind and solar PV, the need in the power system for ancillary services supporting the network frequency, voltage, etc. changes. Turning this issue around, market opportunities will emerge for wind and solar PV technology to deliver such grid services. In the European power system, adequate market mechanisms need to be developed to ensure that there will be an efficient trading of these services. For that purpose a range of (economic) characteristics of wind (and solar) power as providers of grid services need to be better understood. This relates both to the technical capabilities of the plants for delivering specific services and to the quantification of the needs.

The paper presents the approach of the European IEE project REserviceS, aiming at establishing reference guidance for the ongoing developments in Europe of network codes and electricity market design. Economic insights gained from REserviceS will be shaped into recommendations to be used when establishing electricity market mechanisms and Network Codes at EU level.

The project approach presented in the paper consists of two main parts namely (1) conceptually analyzing system needs for ancillary services and at assessing the technical aspects of and cost of delivering these services by solar PV and wind power, in scenarios of high renewable penetration. (2) Investigation of the need for ancillary services in typical transmission and distribution networks, and the cost and options to deliver these services at high penetration. The paper will give an overview of case studies envisaged, together with the intended methods used for the analysis.

The paper also gives some initial project results. It presents the outcome of the assessment of ancillary services that are especially relevant for wind and solar power. These are mainly related to frequency, voltage control and restoration of the system. In addition, based on existing experience and wind integration studies, the paper analyses impacts that high amounts of wind/solar will have on different ancillary services required by the power system.

Keywords: *wind power, solar PV, ancillary services, electricity market*

I. INTRODUCTION

A secure management of the European transmission and distribution systems will require a drastic change in strategy for the procurement of ancillary services when variable renewables will produce large shares (regionally up to 50%) of the electricity demand. The main objective of the REserviceS project is to contribute to efficient and economic integration of large shares of renewables in the European

power system by developing essential techno-economic guidance for the provision of ancillary services by wind and solar PV plants. For that purpose, the REserviceS is making a techno-economic assessment of needs and opportunities of provision of ancillary services by wind and solar PV plants to network operators. From there, recommendations towards the future design of a European market for ancillary services will be made, and to the drafting process of grid and market codes within the Third Liberalisation Package. The approach of this assessment is described in this paper. In a first stage the project is investigating system needs for services and how these needs are influenced by increasing share of variable RES. The initial results of this assessment work are presented in this paper.

II. CONSORTIUM AND BASIS PROJECT FACTS

REserviceS is a project funded by the Intelligent Energy Europe programme (April 2012 - September 2014, IEE/814/SI2.616374).

The consortium of the REserviceS project (www.reservices-project.eu) consists of the following partners: European Photovoltaic Industry Association (EPIA), VTT Technical Research Centre of Finland, Fraunhofer Institut für Windenergie und Energiesystemtechnik, Acciona Energía, University College Dublin, National University of Ireland, DTU Wind Energy, European Distribution System Operators for Smart Grids Association (EDSO4SG), Mainstream Renewable Power, SMA Solar Technology, GE Wind Energy. European Wind Energy Association (EWEA, coordinator).

The project organizes a number of regional workshops, in order to interact and communicate findings with the main stakeholders.

III. APPROACH OF THE PROJECT

A. OBJECTIVES AND GENERAL APPROACH

In the future European power system with high shares of variable renewables (from 25%, regionally up to 50%), there are two types of changes that will cause the provision of ancillary services by system users to change considerably from today. The REserviceS project addresses both issues:

- The future changed generation mix which will include more variable generation brings about changed needs and opportunities for providing ancillary services.

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- The liberalisation of the electricity market brings about the need for the development of an ancillary service markets.

REserviceS' focus on wind and solar PV is relevant in so far that these are mature variable renewables expected to jointly produce more than half of the 34% renewable electricity production needed to reach the EU's 2020 targets with wind at 492 TWh/a and solar at 103 TWh/a in the NREAPs [1]. The physical and economic principles addressed in this proposal are similar for other variable renewables notably ocean energy, small hydro, and solar CSP, and many of the study findings will apply to those as well.

The project aims at providing the following outputs:

- Quantitative assessment of needs and opportunities for providing ancillary services with wind and solar PV in scenarios with high renewables penetration (share in annual electricity demand from 25%, regionally 50% and up), backed up by simulations in representative areas of Europe;
- Assessment of specific costs of ancillary services as provided to network operators by wind (offshore and onshore) and solar PV, installed at transmission and distribution level. The services include frequency support, voltage control and system restoration services. The costs are structured according to type of delivery (capability cost, readiness cost and provision costs);

On basis of these techno-economic results, the project team will draft recommendations on economic aspects and cross border trading aspects of provision of ancillary services by wind and solar PV in view of designing a European market for ancillary services. However, concrete market design is outside the scope of REserviceS.

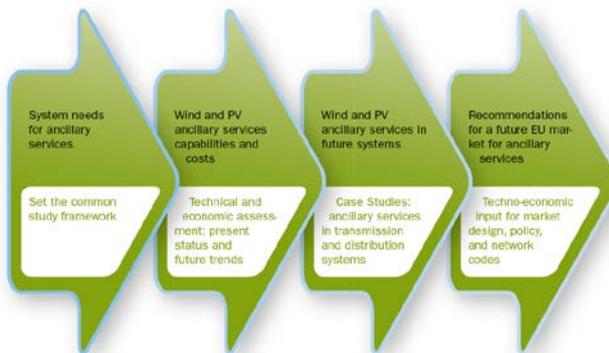


Figure 1: Main steps of the REserviceS project.

B. DETAILED DESCRIPTION OF THE APPROACH

1) System needs analysis

In the initial stage of the project looks at the different ancillary services (AS): which services are needed and how often from the system point of view, how they are provided by conventional generators today and how they are impacted by increasing wind and solar penetration levels. This sets the framework for common approaches and definitions for the technology specific analyses of wind power and solar PV later on within the project. It is intended to cover the most relevant ancillary services, focusing on those that are considered critical for variable renewables and/or are issues in current discussions: i.e. voltage, frequency and restoration.

Analysis of system need is directed in three main issues:

a) Forming a set of uniform definitions (types of services, types of costs)

Power systems all have different terminology for ancillary services (AS). Each power system has its unique aspects that set the boundaries for requirements of system services. The analysis lists current practices (generic options) based on the approaches developed for different grid codes and AS practices in Europe. Specific issues at pan-European level will be highlighted (for example related to cross border trading of the service such as capacity allocation for cross border frequency response etc.). Next, the most suitable approaches for quantification and modelling AS are selected (physical and cost). Cost models include costs for ability, readiness and actual provision of the services. Market prices for ancillary services will be collected. This is done where possible in consultation with the European system operators.

b) Searching for the most relevant ancillary services for different penetration levels (from existing studies and TSO/DSO interviews)

A consistent picture regarding the need for system services from the power system point of view for all different services, different systems and different renewable penetration levels has not yet been drawn before. In this respect, REserviceS gathers all existing information, and forms a consensus on what services will become important at low, medium and high penetration levels of wind and solar PV for different systems in Europe.

In order to analyse system needs, REserviceS will not design new tools or models, but will build on existing ones. The project intends to draw as far as possible on existing cost models and power system simulation results. Elements to build on are, for example, national system studies that have quantified additional reserves and related costs as penetration of wind increases.

For the estimation of system integration costs, necessary to make macro-economic analysis of the case studies (see further), the project, where relevant, builds on methods and approaches as followed in national system integration studies and recommended by IEA Wind Task 25 'Power systems with large amounts of wind power'. For solar PV, elements will be drawn from similar exercises carried out by IEA-PVPS Tasks 10 and 14 including national studies in different Member States analysing the impact of solar PV development on the grid mainly at the technical level.

c) Searching for input data for costs for conventional generators for providing the ancillary services studied.

Having a good overview of the ancillary service provision costs from different conventional generators is an essential precondition to compare the AS from conventional and renewable generators and to study their use in different system operational states. This will be based on gathering existing data, also from ancillary service markets.

2) Solar and wind capabilities and costs

In a second stage of the project the concrete wind power and solar PV capabilities are investigated as well as the related costs and (market based) methods of provision for delivering AS to transmission and distribution system

operators. Two dedicated project teams (one for solar and one for wind) will build further on services defined in the first stage, with particular emphasis on services supporting network frequency, voltage, provision of reserves and system restoration.

The following specific aspects that influence the capability and the cost will be given special attention:

- Wind and solar power variability and predictability;
- Plant visibility to the TSO and DSO from forecasting and now-casting (day-ahead to real time);
- Control options of wind and solar plants notably the possibilities from clustering and virtual power plants.

Estimations of investment costs and operational costs will be obtained via enquiry in the industry (manufacturers and developers) and comparative analysis will be carried out with AS from conventional generation. In the case of wind power, the cost analysis will also look at the impact of extended delivery of grid support on the cost of wind turbines and wind plants. The obtained cost models and data will be further applied in the case studies described below.

The solar and wind teams of REserviceS adopt a common approach and also will look into complementary aspects of wind and solar in the AS provision.

3) *Case studies*

In the third project stage (2013), the project will carry out a set of case studies on the use of AS from RES, divided into studies of transmission networks and studies of distribution networks. The broad common objective of all case studies is to assess future situations in concrete networks with respect to the need for AS, the opportunities for provision and related costs and benefits. Unit commitment and dispatch models will be used to calculate lost opportunity costs due to the provision of AS. At the same time, AS from variable renewables may increase the possible share of these generators in the power system, which can improve their economics. A common analysis framework, key assumptions that may affect the comparison of the case studies and parameters, and a common evaluation process will be used for all the case studies.

a) *CASE STUDIES TRANSMISSION NETWORKS:*

The previously defined AS from variable renewables with corresponding characteristic data will be assessed in the transmission systems, together with AS available from conventional generation. Simulated scenarios will be based on different RES penetration level cases making sure that similar penetration level scenarios will be available for the different cases. The case studies try to cover relevant cases for AS use as well as use existing data and simulations regarding the dynamics of the power system.

The transmission case studies where possible will build on available simulation study results and on experience and simulations made by TSOs from Denmark, Ireland and Spain/ Portugal. Additional simulations will be performed, where needed and possible, to give a broad picture for higher penetration levels in future. Estimates will be made on how often the AS from variable renewables are needed and procured, and on their cost effectiveness compared to conventional sources. Lessons will be taken from regions where detailed wind integration studies have been made and these will be applied to the larger European context.

Case studies are selected based on experience available (Ireland, Spain, Portugal) and including also an offshore case that is relevant for future power systems. A larger European case will draw from smaller system results and strive to make more general results for the whole of Europe. For the European system, the size of the area will force simplifications to the estimates. This is why smaller system cases are needed to add necessary detail to the results – e.g. Ireland’s case makes it possible to draw conclusions from simulations where a whole synchronous system is modelled in detail. Since the case studies focus on the power systems of different sizes, they will emphasise the differences and similarities in operational and planning issues of AS and how they scale in a complementary way.

Possibilities with cluster control of variable renewables will be investigated as well.

b) *CASE STUDIES DISTRIBUTION NETWORKS:*

Specific case studies also investigate the need for and the availability of AS from renewable technologies in distribution systems under different scenarios. Similar to the transmission case studies, the distribution cases will constitute the scenarios in which assessments will be carried out. These scenarios will consider:

- Different distribution system needs and requirements of services;
- Different penetration levels of renewables;
- Different mix of solar PV and wind generation;
- Availability of storage and controllable demand;
- Different demand structure (residential, tertiary, industrial mix).

The following case studies are planned:

- German distribution power system studying MV and LV power systems with different penetration levels of wind and solar PV;
- MV power system with high solar PV penetration in Southern Italy of Apulia;
- Study of provision of AS from controllable loads, storage technologies and wind and solar PV plants in a Spanish distribution network;
- Study of provision of AS from wind and solar PV to the Evora Smart Grid in Portugal;
- Ancillary services with different levels of solar PV in the Spanish distribution system of Navarra.

4) *Recommendations*

Based on the previous analysis, the ultimate project task is to:

- Synthesize the findings from the system analysis (needs), technology specific (wind and solar PV) analyses, and from the case studies;
- Formulate recommendations towards design of ancillary market, towards the process of drafting network and market codes. Recommendations will be split into actions needed on the short-term and long-term.

The recommendations will address the various key actors and stakeholders: network operators (TSO and DSO), energy regulators, European and national policy makers, market parties, and the renewables and electrical industry (wind and solar PV manufacturers, project developers, renewable plant operators, and engineering companies). Besides, the recommendations will build upon the relevant policy framework determining the present and future functioning of electricity markets.

IV. FIRST RESULTS

The first results for uniform definitions of AS categories and system needs are presented in this paragraph. The full results can be found in the report of the System Needs Analysis (first stage of the work, Work Page 2) [8].

A. Ancillary services categories and definitions

Regarding scope and definitions of AS at European level there is not yet an integrated viewpoint of national TSOs nor uniform approach across the synchronous system. Therefore, the REserviceS study team has reviewed categories used by Eurelectric [1] and [2], CIGRE [4], BERR [5] and ENTSO-E [6].

Three main groups of services are used by Eurelectric, CIGRE and BERR:

- **Frequency control:** services related to the short-term balance of energy and frequency of the power system; they include automatic (primary/secondary) and manual (tertiary) frequency regulation and operational reserves. Frequency control is the main service from generators, but can also be provided from flexible loads.
- **Voltage control:** services related to balance of generation and consumption of reactive power. In the event of a disturbance to the system, dynamic reactive power response is required to maintain system stability. Voltage control includes reactive power supply (injection or absorption). Also loads and network devices can be used to provide this service, and network reinforcements will strongly impact on the amount needed.
- **System restoration:** services related to the system ability to return to normal operation after a blackout has occurred; when looking from the generator point of view it includes mainly black start capability. Operation under islanding conditions is also related.

Table 1: Proposed list of ancillary services from generator point of view.

	Frequency support	Voltage support	System restoration
Current services	Frequency Containment Reserve FCR (<5, 10 or 30s) Frequency Restoration Reserve FRR (<15 min) Replacement Reserve RR (15 min to hours)	Normal Operation: control of power factor, reactive power or voltage	Black start
Foreseen new services	Fast frequency response (synthetic inertia, < 2s) Ramping margin	Fast reactive current injection (<100 ms) Dynamic voltage control (<1s)	Islanding

The subdivision of frequency control contains different terminology in all the approaches reviewed. We have adopted the division proposed by ENTSO-E [6]:

- Frequency Containment Reserves (automatic and local),
- Frequency Restoration Reserves (automatic or manual, centrally coordinated)
- Replacement Reserves (manual)

Some literature has reserves as a separate category (like BERR). We consider that the ENTSO-E list of frequency control services will cover also reserves. Eurelectric lists stability as different category, however, for example Eirgrid/SONi [7] have included the stability under Frequency and Voltage control, and we have followed their approach.

In addition to lists of services used today, we need to consider the future of power systems with large amounts of variable renewables. In the island of Ireland there is already work on-going in defining new services. We have taken three new services: Fast frequency response (providing synthetic inertia), Ramping margin service, and Dynamic voltage control.

The proposed list of services with three categories is presented in Table 1. Several services, such as long term (planning) reserve will not be investigated. Some services are included in our table from different view point, like congestion management (can use the manual frequency support service), and grid loss compensation (part of voltage control). Some services are not included as they are not procured from generators (coordination with TSOs and DSOs, Emergency control actions). To help following the categories defined for the REserviceS project, a table listing how these go together with existing terminology in some European countries will be presented in the report [8].

For the future project work regarding costs from wind and solar PV, the ongoing work package provided a more detailed specification of the AS, as well as technical descriptions on the required capabilities and possible current practices for the service procurement. Consequently costs will be estimated for capability, readiness and provision of different AS.

The technical specifications related to AS are to a large extent based on the requirements for capabilities, described in Grid Codes. In Europe there is high divergence among Grid Codes: requirements and their applicability are different in almost every country. In the light of the on-

going formal process (Third Package) of creation of Network Codes intended to streamline the requirements in Europe, REserviceS takes the ENTSO-E Network Code for Requirements for Grid Connection applicable to all Generators (NC RfG) [3] as a primary reference document, rather than taking requirements from all present Grid Codes in Europe. The NC RfG intends to bring more consistency primarily for the requirements relevant for cross border system management. For REserviceS, this is most useful for the frequency response capabilities, where the NC RfG contains quite detailed specifications. However, the NC RfG leaves many other requirements open for detailed specification at national level, with limited guidance. This is particularly an issue for the reactive power capabilities. Therefore in REserviceS we have to regard how these requirements are specified in national codes. Finally, it should be remarked that the specifications in the ENTSO-E NC RfG have to be regarded as preliminary as long as they have not reached the status of European law.

Regarding procurement for services, it will be especially important for variable renewables to know the time scales of offering and delivering the services. These may also result in recommendations on future ancillary services in order to enable variable renewables to bid to the markets.

B. System needs

1) Impacts

Information regarding how renewables impact AS at different penetration levels and in different systems have been collected from literature and system operators. The conclusions toward the needs for the identified categories of services are being made: How much frequency control is required today versus future high penetration rates? How much voltage control? How much black start capability? Renewables will also increase the need for new transmission and distribution lines and the capacity adequacy of the power systems – these impacts are not related to AS/operation of the system and are not discussed.

The main impacts of variable renewables are due to more variability and uncertainty. Moreover during high wind and sunny hours, less conventional units will be online to provide frequency support and inertia, as well as voltage support and congestion management. By participating in AS variable generation can avoid curtailments due to keeping other generation online to provide services (unless loads or network components can do it with lower costs).

There is experience from significant wind penetration levels in Denmark since year 2000 when wind power exceeded the 10 % share of domestic electricity consumption and since several years from Spain, Portugal, Ireland and Germany. There is also experience of solar power (PV), mainly from distribution networks but also some first system level impacts when the shares of PV have exceeded 1-2 % in recent years in Germany, Spain.

2) Needs for network support from generators

Increased variability and uncertainty will result in more balancing needs and can impact frequency control. Experience of wind integration shows that when reaching penetration levels of 5-10 %, an increase in the use of short term reserves is observed, especially for reserves activated on a 10-15 minute, or longer time scale [8]. In Spain, the frequency control activating in 30 seconds has not been

impacted by wind power with about 15 % penetration level [10]. The same experience is from the other highest wind penetration countries Denmark and Portugal: no significant frequency impacts have been observed that are the result of wind power variation [11]. So far, no new reserve capacity has been built specifically for wind power [12]. In Portugal and Spain, new pumped hydro is planned to be built to increase the flexibility of the power system, mainly to avoid curtailment of wind power [13]. As there have been other changes in frequency control or balancing schemes also, it is difficult to get direct, quantified information about how much the balancing needs have actually increased due to additions of wind power.

Impact of inadequate system services have mainly been seen as curtailments: In Spain, curtailments of wind power due to inability to maintain power balancing have occurred since 2008 (when penetration exceeded 10 %) and they have slowly been increasing (0.5 % of total wind generation curtailed due to insufficient operating reserve in 2010, with >16 % penetration)[14]. In Ireland some curtailments have been due to concerns about low inertia [15] and consequently susceptibility to instability in the system due to high instantaneous wind penetration and low system load. Currently, the issue of low inertia is unique to small systems like Ireland and possible solutions are being investigated [16].

Managing the short-term variability of solar PV will be somewhat similar to that of wind power. The variability of solar PV systems can be considerable in partly cloudy weather and also with fog or snow [17]. The ramping up and down during morning and evening of solar output, even if highly predictable and sometimes coinciding with load ramping, can also impose a large variation for electrical power systems with large amounts of solar PV energy [18].

Studies show that combining different variable renewable sources will be beneficial in smoothing the variability and decreasing overall uncertainty.

Impact of generation embedded in distribution networks, traditionally built for one-way distribution of electricity to customers, can be seen changes in voltage profiles. Voltage rise in distribution grids has been an issue for PV integration [19]. There are multiple voltage levels and each will often have different characteristics leading to different effects. Voltage support from distributed renewable generation is already used widely and this is an example where providing ancillary services may turn the negative impacts to supporting the system.

V. CONCLUSIONS

The growing share of wind and solar PV in the European power supply brings both technical needs and economic opportunities for these variable sources to participate in delivery of ancillary services to the network. Ahead of the establishment of proper market based mechanisms for procurement of these services in the frame of an integrated European electricity market, the REserviceS project focuses at assessing the technical and economic aspects of supply of ancillary services by wind and solar PV, in order to generate qualified input for market design. The assessment of REserviceS - the first in its kind in Europe focusing both at wind and solar PV - is forward looking into situations with high penetrations – typically time horizon 2020 and beyond.

In the absence of a common practice at Europe for categorizing all relevant services, REserviceS drafted a specific categorization, common definitions and terminology to apply in the project for the services considered relevant in the area of frequency support, voltage control and system restoration. For each of the selected services, the corresponding technical requirements have been identified from Network (Grid) Codes. Besides, an analysis has been made of the needs for such services in systems with significant shares of variable renewables, based on reports on experience in concrete systems. Inadequate provision of ancillary services may at times lead to curtailment and in general to technical and economic obstacles for integrating renewables. The work done will constitute the basis for the more detailed technology specific assessment (wind and solar PV) and the case studies in transmission and distribution networks.

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