Economic Grid Support from Variable Renewables

REserviceS project summary

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Abstract— **Grid support in the form of ancillary services will need to be supplied to an increasing extent by variable renewables, as these are replacing non-variable conventional generation. Opportunities and boundary conditions for cost-efficient provision are determined by many factors, including technology as well as operational and economical aspects that depend on energy market design.**

Wind and solar PV energy include a broad range of power plants, from small distributed PV to large concentrated offshore wind farm clusters. There are specific issues for transmission and distribution systems, and also how to coordinate system service provision from distribution systems to transmission system.

The paper summarizes the assessment of the above issues within the EU project REserviceS, finalised in September 2014. It also presents REserviceS recommendations for enabling market mechanisms for provision of grid support services in European power systems.

Keywords: ancillary (grid support) services, transmission systems, distribution systems, grid codes, market design

I. Introduction

The expected high contribution of wind and solar PV in the European electricity supply is a major factor of change in the way transmission and distribution network operators use grid support services from generators to manage network frequency, network voltage and system restoration. On the one hand, increasing shares of wind and PV will change the needs for grid support services in power systems. On the other hand the evolving generation fleet with its specific technology characteristics changes the technical and economic opportunities of providing these services. The REserviceS study was set up to assess the provision of these grid support services (GSS) by VAR-RES (variable renewable energy sources i.e. wind and solar PV) themselves, and to contribute to the design of ancillary services market mechanisms that would enable power systems in Europe to function safely, reliably and cost-efficiently with very high shares of VAR-RES. The study – carried out by a Consortium of renewable energy industries, research institutes and DSOs - has focused on wind and solar PV because these technologies are expected to jointly produce the lion's share of new renewable electricity production needed to reach the EU's 2020 targets. Intermediate results of the study have been discussed with European TSOs and market players and the feedback is integrated in the study conclusions. REserviceS is the first study to investigate wind and solar based grid support services at EU level.

Structure of the paper

After the overview of the project (Ch. II), chapter III addresses the (future) power system needs for grid support services as well as capabilities of VAR-RES to fulfil these needs. From there, the project recommendations are listed, mainly related to network codes and required R&D.

Chapter IV addresses the economic benefits of providing frequency and voltage support with VAR-RES and addresses the REserviceS recommendations for suitable market mechanisms and favourable characteristics of economic frameworks. Overall conclusions are given in Chapter V.

II. The REserviceS project

The EU REserviceS project (2012-2014) aims at developing techno-economic guidance for the provision of ancillary services by wind and solar PV plants in future European power systems with high share of VAR-RES. Based on the analysis of system needs, VAR-RES capabilities and case studies in transmission and distribution networks, recommendations are formulated for the main stakeholders: industry, network operators, regulators, policy makers. In the recommendations, actual policy processes at EU level are addressed for example the European Network Codes drafted by ENTSO-E.

The findings of REserviceS are documented in the project deliverables and can be downloaded from the project website: www.reservices-project.eu.

The first three deliverables describe the required ancillary services and the power system needs [1][2] and the basic cost methodology [3] for comparative assessment between different types of generation. Two deliverables are devoted to describe the technical capabilities and associated costs for providing GSS with wind [4] and solar PV [5]. Case Studies at transmission level are presented for Ireland [6], the Iberian Peninsula [8] and Europe (onshore) [9], considering a special study case for offshore wind power plants [7]; all transmission cases are evaluated, compared and summarized in [10]. At distribution level, the provision of ancillary services by wind and solar PV to the Spanish,

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Italian, Portuguese and German markets are addressed in deliverables [11] and [12]. The study findings are synthesized in deliverable [13]. Together with the recommendations [14] they are also summarized in the final publication [16].

III. SYSTEM NEEDS AND VAR-RES CAPABILITIES FOR GSS PROVISION

This chapter describes the results of the analyses of the (changing) system needs and of the capabilities for providing GSS by VAR-RES. It also presents the recommendations formulated based on these analyses. REserviceS assessment of system needs in European power systems focused mainly on frequency support and voltage support as the main ancillary services categories that are applicable to wind and solar PV generation (Table 1).

Table 1. Ancillary services relevant from VAR-RES

Frequency Support	***Voltage Support***	***System Restoration***
Frequency Containment Reserve FCR (< 5, 10 or 30s)	Normal Operation: control of power factor, reactive power or voltage	Black Start
Frequency Restoration Reserve FRR (< 15 min)		
Replacement Reserve RR (15 min to hours)		
Fast Frequency Response FFR (synthetic inertia) (< 2s)	Operation during system faults: Fast Reactive Current Injection	Islanding
Ramping Margin RM (1,3,8 hours ahead)		

System restoration services have not been analyzed with the same level of details due to the current lack of knowledge of their interactions with the VAR-RES.

A. System needs

Frequency and voltage control consists of several services with different response times (see Table I). At high penetration levels, VAR-RES will even have to provide more services in order to maintain the necessary performances in the overall generating fleet with less synchronous generation. In some cases VAR-RES will have to exhibit enhanced capabilities, such as faster responses, in order to achieve this. Refs D2, D3, D4, D7

Generally the need for all GSS services in the system will increase with high shares of VAR-RES. More need for frequency support in the system is observed especially for manually activated system reserves (<15 min) FRR and RR. VAR-RES may increase the need for voltage support and changes the availability of voltage support due to several reasons:

– Controlling voltage in distribution grids with high amounts of variable generation is not as straightforward as it was without variable generation.

– When variable generation replaces central power plants, the voltage control capabilities of those plants are not anymore available near the consumption centers. These will impact both steady state and dynamic voltage control. As voltage profile management becomes more complex with increasing shares of VAR-RES, it may open the scope for new services and/or enhanced capabilities of generators [ref D2.2 or then directly Task 25, Ireland reports?).

The needs for GSS with increasing VAR-RES in the system depend on the characteristics of the power system studied (for example its size and robustness), and how VAR-RES is built in the system (for example its dispersion, penetration levels and technical characteristics).

As GSS come with a cost, requirements for generator capabilities and service provision should ideally cover only what is needed by the system. Preparing for future systems with large share of VAR-RES thus requires studies and simulations on which to base the requirements.

A handicap for a comprehensive assessment of the needs for GSS in systems with high non-synchronous penetration levels (SNSP) is the absence of a common methodology to include VAR-RES and lack of investigation into combined effects of wind and solar PV. Thus, efforts to develop new approaches and tools are needed that would enable to better assess system needs.

Operating power systems with large shares of VAR-RES will highly benefit from more intensive DSO/TSO interaction. There is a further growing role for DSOs in the ongoing transition process in electricity networks. Data exchange and ability to control the multitude of small generation units will have to be organised. Governance on who is doing what needs to be established for coordinating frequency and voltage support, as well as restoration services.

B. Wind and solar capabilities for GSS

1) Technical assessment of capabilities

Systematic investigation of wind power [4] and solar PV technology [5] has been made through analysis and validated through an industry enquiry. The analysis confirmed that VAR-RES can deploy the necessary technical capabilities to provide GSS for frequency, voltage and (to a certain extent) system restoration assuming an adequate procedural and economic framework is present. The technical and operational functionalities required are either state of the art capabilities of the existing hardware or can be implemented at a reasonable cost. The feasibility of provision of services by enhanced plant capabilities is confirmed by TSOs. In Spain voltage control by wind power plants on the specific transmission nodes has been demonstrated to lead to a significant improvement with fast response. The German/Spanish case studies [12] within REserviceS demonstrate that allowing the DSO using ancillary services from VAR-RES connected to its own system contributes to cost-efficient voltage management. Participation of VAR-RES in system restoration has not yet been considered until now. Some of the necessary functionalities are available in principle (for example for islanding) but their implementation in specific restoration strategies requires further investigation [13].

In general, aggregation of multiple VAR-RES power plants is desirable because it reduces the relative implementation and operational costs. Also both for wind and solar PV, control strategies should be optimized to obtain the maximum performance and flexibility from VAR-RES. In this case, the precondition is to have clear and well-described requirements and procedures to integrate wind and solar PV as GSS providers. In this respect, poorly defined or nonexistent technical specifications in grid codes or pre-qualification procedures that allow VAR-RES to provide GSS constitute a significant barrier to overcome in the future. This is exacerbated by the lack of standardization and harmonization of procedures across Europe. As a necessary precondition, a EU wide GSS roadmap – e.g taking example from the recent dena study [14] - should be established describing the required capabilities and services in due time along with a set of pre-qualification and procurement methods with proper attention to the characteristics of the sources. VAR-RES can in some cases provide faster and better quality response than non-variable power plants. Network codes should utilize this possible capability when it makes sense to do so from economic and stability perspectives.

2) Additional costs for enhanced capabilities

Implementing enhanced capabilities will involve additional investment costs as will the deployment of the services. For both wind and solar PV the additional capex costs involved for enhanced provision are relatively low and – provided appropriate cost recovery / market mechanisms are in place – their deployment should be commercially feasible at higher VAR-RES penetration levels [13]. Only for small PV systems the impact of required communication components will result in high additional costs according to current estimates.

3) Areas for further technical development

For wind power, potential technical capability enhancements for frequency and voltage support services include: faster and reliable communication (a.o. between wind power plants and system operators' control rooms), dedicated control tuned for delivering the required performances, estimation of available power/forecasting. Furthermore some structural, mechanical and electrical design changes in wind turbines need to be implemented to take into account the changes in mechanical load spectrum involved with GSS oriented operation. Specifically for offshore wind power service provision needs to consider the differences between connection technologies (HVAC or HVDC) as these have a fundamental impact on the provision of voltage services and fast frequency support. AC connected offshore wind plants can provide active power reserve and frequency response (in all time domains: FCR, FRR, RR, FFR) in the same manner as onshore AC wind plant projects. Ancillary services can be augmented by aggregating multiple offshore wind plants or clusters of wind plants. Regional coordination of offshore wind plants in providing reactive power and voltage control at their respective onshore POC would strengthen system reliability. In the case of HVDC offshore grids, the onshore VSC HVDC can provide reactive power/ voltage ancillary services regardless of the offshore wind condition. Technical standards and Network Codes currently in preparation are important enablers of offshore wind ancillary services

For solar PV, potential enhancements of capabilities include: estimation of available power/forecasting, faster and reliable communication and control within the plant, control strategies for portfolios composed of numerous small and medium sized units, improving interoperability of different networks and enhancing compliance to a multitude of non-harmonised grid code requirements, while improving visibility and controllability/.

Implementation of better and faster communication systems together with the development and implementation of more accurate forecast systems are essential required improvements for both wind and solar PV technologies.

C. Recommendations

Recommendations formulated by REserviceS concerning system operation relate mainly to Network Codes (Grid Codes) and areas for further R&D.

1) Network Codes

a) Requirements traceably based on identification of system needs

– System studies should be the primary basis for network codes and grid codes in their formulation of requirements for VAR-RES. The studies and their implementation in the grid codes should consider frequency support needs and voltage needs at the appropriate system level and should be coordinated between TSOs and DSOs, as a significant part of VAR-RES is connected to the MV/LV network.

– Requirements based on system studies should appropriately take into account (expected) VAR-RES penetration. Network operators should not ask for more than needed but expected future renewable energy penetration should also be taken into account when defining capabilities (to avoid costly retrofit programs of all or part of the existing generators and/or burdening new generators). A properly functioning market for ancillary services owners can be expected to inherently provide the necessary pay-back for retrofits to provide a service which is scarce.

– Frequency control (FCR and automatic FRR) capability should not be required from all VAR-RES plants connected to the network. It is sufficient to have the capability in a part of them as requiring it from all would not be cost-effective. How much is needed where should be based on further research.

– Voltage control capability should only be required from VAR-RES when the analysis of the expected CAPEX and OPEX costs compared to all other voltage control provision methods shows it to be the most cost-effective solution for the particular combination of generator type and primary energy source, considering likely future expansion of generation, demand and grids.

b) Requirements contents

– Grid Codes should provide in a clear and exhaustive way the specifications for minimum technical capabilities for generators to be connected and to participate in grid support services. The formulations of requirements should be function-oriented in addressing design capabilities and delivery performance. They should never prescribe technical solutions to reach a certain performance.

– For optimum service provision, requirements for generators should take into account their specific technology type and which primary source is driving it. Different types of generators (e.g. wind turbine conversion type 3 and type 4) and different energy sources (PV vs. wind) need different level of investment for capability of different GSS provision. In order to create a level playing field, the specificities need to be accounted for in the requirements for specific GSS.

– When designing the requirements and the framework for the procurement of ancillary services at the distribution level, the spatial distribution of VAR-RES should be taken into account to avoid cost inefficiencies due to the "one size fits all" approach.

- Formulation of requirements should be considered for extremely fast frequency response (e.g. faster than ¼ sec, to be studied) for situations in the power system with low inertia.
- Grid code requirements should where possible make reference to specifications in European or International standards (e.g. EN 50438 or TS 50439).

c) Process / management of grid code requirements

- Requirements should be coordinated and agreed among different stakeholders – notably TSOs and DSOs - and they should jointly establish a clear definition of responsibilities in the coordination of the grid support services.
- In order to enable proper implementation and monitoring of requirements, network operators should organize the data exchange and visibility of distributed generators.
- Markets shall keep into account the characteristics of the sources and their capabilities; Requirements shall be clear and precise and based on market framework, which considers existing capabilities
- TSO's and regulators should establish clear procedures and reporting rules distinguishing balancing/congestion management and curtailment for system security. The implementation of these rules should be coordinated with the DSOs.

d) Harmonisation and standardisation issues

- TSO and DSO should further contribute to the development of European product standards (e.g. IEC, CENELEC) to avoid costly mismatches between GC requirement and product standards
- Exchange of data (including forecasts) and corresponding communication interfaces between generating facilities, and the relevant network operators (TSOs, DSOs) should be standardized to improve information exchange and to reduce errors.
- Prequalification processes and corresponding procedures for generators providing services should be harmonized, for example by developing a set of specifications which can fulfill needs by country/region and technology specific settings.

2) Recommendations for R&D

The recommendations for R&D efforts enabling improved (technically / economically) provision of services by VAR-RES consist of a listing of research topics in four relevant categories: hardware, methods and software, system operational methods and standards.

a) Hardware

- Further development of hardware including design for enabling sustained deployment of GSS (notably for wind plants).
- Communication infrastructure for the provision of services by portfolios of MV/LV connected VAR-RES, including metering devices and specific reliable communication hardware for very fast system services
- Monitoring systems to enable HVDC connected WF and/or WF clusters to provide frequency support in a reliable and robust way.

b) Software and methods

- Improvement of probabilistic forecasts methods to be used in the system operation
- Control and coordination methods to enable HVDC connected WF and/or WF clusters to provide frequency support in a reliable and robust way.
- Better understanding of technical requirements and control strategies for wind power operating in hybrid AC and DC multi-terminal networks
- Advanced control strategies for VAR-RES to improve GSS capabilities and performances

c) System operation and GSS deployment strategies

- Probabilistic planning and operational procedures (especially using probabilistic forecast methods) in power system operation
- Optimisation strategies for the provision of grid support services by portfolios of MV/LV connected systems such as PV systems or small wind farms
- Common methodology for assessing system needs of ancillary services with large amounts of VAR-RES.
- Improvement of power system models able to capture different time scales, i.e. models focusing on (i) electromechanical dynamics (20 ms - 30s), (ii) system balancing (5 min - 24h), (iii) frequency quality for services such as FCR and FRR (s - min), etc.
- Definition (technical and economic) of new system services and study their impact on the system
- Practices and tools for system planning and voltage profile simulations including the use of services provided by inverters and novel components in order to make the best of existing or future capabilities available at the distribution level
- Investigation of technical requirements and operational practices for RES to be included in power system restoration processes

d) Standards

- Development of further technical standards required for large scale deployment of GSS by VAR-RES
- IT standards to assure the secure and reliable operation of the power system's strategic and sensible infrastructure
- Communication protocols for very fast system services.

IV. MARKETS AND COMMERCIAL FRAMEWORKS

The basic goal of REserviceS was to contribute to market design for GSS. For this purpose first an analysis was performed of the economic benefits of service provision in different types of networks. This analysis – together with the technical analysis presented in Chapter III constituted the basis for formulating recommendations for market design.

A. *Economic benefits of service provision by VAR-RES*

The economic benefits of service provision have been investigated through a number of case studies, which included simulations and analyses on the technical and economic impacts of provision of GSS by VAR-RES in concrete grid situations – both in transmission and distribution networks.

1) *Frequency support*

Simulations of transmission systems of various sizes across Europe and increasing share of VAR-RES (up to 50%) show clear and increasing system benefits of GSS from VAR-RES. The benefits were calculated by comparing the overall operational costs of power generation with and without using VAR-RES for frequency support. The largest benefits are observed in the downward FCR and in the automatic FRR. The operational benefits for the system operator in the simulations are higher than the cost of equipping all VAR-RES with the capability to participate in the frequency support, especially for onshore wind power plants – but currently not for residential solar PV. In a sensitivity analysis the frequency response and its corresponding economic benefits remained similar when only a fraction of all VAR-RES had the capability to participate in frequency support services. Thus from an economic point of view it should be sufficient to only equip a part of VAR-RES with capability for FCR and automatic FRR services to achieve adequate system operation. Cross-border sharing of frequency reserves creates similar benefits as VAR-RES, but there are additional benefits when both variable generation and cross-border sharing are utilized.

2) *Voltage support*

The REserviceS case studies analyzing different MV/LV networks with different VAR-RES shares conclude that the cost/benefit ratio of voltage support from VAR-RES is very case specific and that provision of voltage support by VAR-RES should be compared with alternatives. As there will be a high number of locations where individual decisions need to be made from where voltage support will be sourced, there is a need for universal and robust methods to make the assessment with reproducible and comparable results.

B. *Markets and commercial frameworks for GSS*

In today's energy-only market, dominated by synchronous generation, the contribution of ancillary services in the system costs and revenues to generators is very low compared to energy and capacity payments. As it is clear that VAR-RES can provide GSS and that their utilization can decrease operational costs of the power system, sufficient incentives should be made available to obtain these benefits along with the capability and availability requirements for VAR-RES.

REserviceS analysis (see above) showed that not all generators in a system need to provide ancillary services (especially for frequency support) to ensure safe system operation. Thus a mandatory request for ancillary services is often far from cost-efficient. Market based remuneration stimulates cost-reduction and incentivizes the provision by plants providing the cheapest services.

Detailed and clear specifications are of crucial importance for the commercial participation of wind and solar PV in GSS provision. Without these, market participation and procurement of such services is delegated to incumbent generators with long-term contracts already in place. Specifications of requirements for service capabilities should be developed in close cooperation between the TSOs and VAR-RES industry via consultations, such as in Ireland.

Currently, only a few markets (e.g. Ireland, GB system) provide arrangements for enhanced services where variable renewables are incentivised to participate. In future systems with high shares of VAR-RES the ancillary services part will increase, even if it still will be a smaller part of total system costs and revenues.

C. *Recommendations for market design and system operation*

1) *Frequency services*

In order to enable full utilization of the frequency capabilities of VAR-RES, markets and service products design should be adapted. Characteristics of 'service' products such as separation of upward bids from downward bids, inclusion of confidence intervals and aggregated bids and offers are fundamental for allowing wind and solar PV to participate cost-effectively in GSS provision. REserviceS recommendations include the following:

- TSO should allow a certain amount of balancing power to be offered with a confidence tag stating the probability of the offered power.
- For smaller systems or for smaller portfolios of variable renewables, a low minimum bid size is crucial for entering the market or not, as the resulting increased competition in the market may reduce procurement costs.
- A short time lapse between the gate closure and the delivery of frequency support is crucial to allow for wind and PV cost-effective participation because of the reduced forecast errors.
- Products for reserve power provision by wind and solar PV should have short blocks of a few hours or even blocks of less than one hour, to decrease the handicap of weather dependency and high forecast uncertainty.
- All products should be split in upwards and downwards products to enable PV and wind to offer downward reserves at relatively low costs. Other flexible resources and demand in the power system would also benefit from such product design.
- Offering reserve products from aggregated portfolios of several PV and wind plants spread across wider areas permits cost-efficient offers with high certainty and thus significantly facilitates the participation of renewables.
- Implementation of a reactive market approach should be considered, allowing real-time balancing of the BRPs perimeters. Flexibilities of VAR-RES can then be used by the BRP manager in case they prove to be the most cost-efficient. This would also reduce the need for reserve power for balancing by the TSO.
- State of the art forecast methods should be implemented in the operation of VAR-RES. Continuous efforts should be made to keep the forecast methods up to date. The reliability of forecasts should influence reserve requirements where applicable. TSOs should improve

their forecasting methods utilizing state-of-the-art techniques during operations, while increasing the cross-border cooperation to reduce unexpected situations due to forecast errors.

2) voltage services

Voltage support induces costs for VAR-RES but can, in some cases, help system operators to manage their network in the most efficient way. In grids with only a small amount of VAR-RES plants providing the service needed by the network operator, a non-remunerated mandatory band requirement as part of the grid code could be complemented with payment for additional support to grid operation, provided such costs are recognised by the regulator and recoverable by the system operator. If the number of service providers is large enough to create a competitive market, voltage support could be reimbursed in a competitive process, either in a regular bidding process or an auctioning arrangement, irrespective of whether the contracting is for short time horizons i.e. from days to weeks, or for longer time horizons up to several years.

If a tendering or auctioning process is applied, it should involve:

– An analysis of the need for reactive power carried out by the relevant network operator (TSO/DSO) and a forecast for future locational needs;
– Based on such an investigation, a tender for reactive power within a certain perimeter should be published or an auctioning system should be put in place to receive the lowest cost reactive power provision;
– The best offers are awarded with a fixed reimbursement for the reactive power provided to the system and a minimum off-take guarantee to ensure investment security

V. CONCLUSION

Solar PV and wind power capabilities and economic aspects have been reviewed together with future needs in highly VAR-RES driven power systems with the aim to extract recommendations for their cost effective participation in provision of grid support services to European electricity network operators. Techno-economic feasibility of large scale service provision by VAR-RES has been analyzed as well as boundary conditions for commercial operation and market frameworks. Recommendations are formulated for improved network (grid codes), market design and further research to be taken up by the relevant stakeholders. The paper provides a basis for discussion.

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