Economic grid support services by wind and solar PV

a review of system needs, technology options, economic benefits and suitable market mechanisms

REserviceS

Final publication of the REserviceS project

September 2014

Co-funded by the Intelligent Energy Europe Programme of the European Union

REserviceS

Economic grid support services by wind and solar PV

a review of system needs, technology options, economic benefits and suitable market mechanisms

Final publication of the REserviceS project

September 2014

Principal Authors:	Frans Van Hulle (XP Wind) Iván Pineda and Paul Wilczek (The European Wind Energy Association, EWEA)
Authors (project partners):	Manoël Rekinger (EPIA) Paul Kreutzkamp (3E) Hannele Holttinen and Juha Kiviluoma (VTT) Mariano Faiella and Diana Craciun (Fraunhofer IWES) Gustavo Quiñonez Varela (Acciona) Andrej Gubina (UCD) Nicolaos Cutululis (DTU Wind) Florian Chapalain (EDSO4SG) Joe Corbett (Mainstream) Bernhard Ernst (SMA) Stephan Wachtel, Goran Drobnjak, Bart Stoffer (GE) Pedro Godinho Matos (EDP Distribuição) Jorge Tello-Guijarro (Union Fenosa Distribución) Raphael Rinaldi (Enel Green Power)
Project coordination and review:	Sharon Wokke (EWEA)
Editing:	Zoë Casey (EWEA) Adrienne Margolis (freelance proofreader)

Acknowledgements (other project partners and Advisory Board):
Justin Wilkes, Manuela Conconi, Diletta Zeni (EWEA), Dana Dutianu (EASME), Gaëtan Masson, Myrto Papoutsi and Scarlett Varga (EPIA), Carlos Diercksens and Aurore Flament (3E), Javier Lasa Garcia (Acciona), Ciara O'Connor and Mark O'Malley (UCD), John Shaw (Mainstream), Christoph Frenkel and Oliver Führer (SMA), Christoph Gringmuth (GE), Carlos Costa Rausa (Enel).

Hans Abildgaard (Energinet.dk), Jacobo Alvarez and Pavla Mandatova (Eurelectric), Joachim Balke and Tadgh O'Briain (European Commission), Miguel de la Torre (Red Electrica), Javier de la Torre (Fenosa), Kristof De Vos (KU Leuven), Yves Langer and Thijs Engels (BELPEX), Alejandro Gesino and Andreas Thum (TenneT), Jon O'Sullivan (Eirgrid), Alexandre Torreele and Manuel Galvez (ELIA).

Acknowledgements (workshop speakers and other contributors):
Ricardo Bessa (INESC TEC), Denis Cagney (CER), Karel De Brabandere (3E), Caitriona Diviney (IWEA), Sophie Dourlens-Quaranta (Technofi), Eike Erdmann (Enercon), Pablo Frías Marín (IIT Comillas), Rubén Gutiérrez Otero (EDP Distribuição), Tony Hearne (ESB Networks), Miguel Lorenzo Sotelo (Red Electrica), Antonio Lopez Nicolas (European Commission), Jane McArdle (SSE), John Mc Cann (SEAI), Simon Muller (IEA), Sophie Müller-Godeffroy (BMU), Gennaro Niglio (GSE), Javier Paradinas (EFET), Eckard Quitmann (Enercon), Marcus Merkel (EWE Netz), Ricardo Prata (EDPR), Juan Rivier Abbad (Iberdrola Renovables), Stephanie Ropenus (BWE), Juan Saavedra (Fenosa), Irinel-Sorin Ilie (GE), David Trebolle (EDSO4SG), Andreas Wade (First Solar), Zoltan Zavody (RenewableUK).

Björn Andresen, Frank Martin, and Henrik Kodahl (Siemens), Christian Benz Harald (DanFoss), Martin Heidl (Fronius), Lourdes Garcia Caballero (Alstom), REpower, Luis Pascual (Sunedison), Michel Ryser (Solarmax), Mads Skjelmose (Vattenfall), Paula Souto de Perez (WindVision), David Martinez and Javier Villanueva (Gamesa).

Layout:	EWEA
Print:	Artoos
Production coordination:	Clara Ros and Zoë Casey (EWEA)
Cover photo:	Thinkstock

Coordinator

EWEA
THE EUROPEAN WIND ENERGY ASSOCIATION

Partners

Agreement no.: IEE/11/814/SI2.616374
Duration: April 2012 – September 2014
Coordinator: **The** European Wind Energy Association

Co-funded by the Intelligent Energy Europe Programme of the European Union

LEGAL DISCLAIMER
The sole responsibility for the content of this leaflet lies with the REserviceS consortium. It does not necessarily reflect the opinion of the European Union. Neither this document nor the information contained herein shall be used, duplicated or communicated by any means to any third party, in whole or in parts, except with prior written consent of the “REserviceS” consortium. Neither the EASME nor the European Commission are responsible for any use that may be made of the information contained herein.

Table of contents

1 EXECUTIVE SUMMARY AND POLICY RECOMMENDATIONS 11

1.1 RECOMMENDATIONS - EU ENERGY POLICY AND ELECTRICITY MARKET DESIGN 12
1.1.1 Recommendations for policy makers 12
1.1.2 Recommendations for market design - frequency support 13
1.1.3 Recommendations for market design - voltage support 14
1.2 RECOMMENDATIONS - EU NETWORK CODES AND NATIONAL GRID CODES 14
1.2.1 Requirements based on identification of system needs 14
1.2.2 Contents and quality of requirements for generators for service delivery 15
1.2.3 Management of grid code requirements 15
1.2.4 Harmonisation and standardisation 15
1.3 RECOMMENDATIONS - RESEARCH AND TECHNICAL DEVELOPMENT 15
1.3.1 Hardware 15
1.3.2 Software and methods 16
1.3.3 System operational procedures, methodologies and GSS deployment strategies 16
1.4.4 Standards 16

2 INTRODUCTION 17

3 RESERVICES MAIN FINDINGS 20

3.1 SYSTEM NEEDS FOR GRID SUPPORT SERVICES BY WIND AND SOLAR PV 21
3.2 TECHNICAL CAPABILITIES OF WIND AND SOLAR PV AS SERVICE PROVIDERS 21
3.3 ECONOMIC BENEFITS OF GRID SUPPORT SERVICES BY WIND AND SOLAR PV 22
3.4 MARKETS AND COMMERCIAL FRAMEWORKS 23
3.5 KNOWLEDGE GAPS AND NEED FOR R&D 24

4 SYSTEM NEEDS VS. GRID SUPPORT SERVICES FROM WIND AND SOLAR PV 25

4.1 INTRODUCTION 26
4.2 CHANGING SYSTEM NEEDS WITH INCREASING WIND AND SOLAR PV PENETRATION 26
4.2.1 General trend – increasing needs at rising penetration levels of VAR-RES 26
4.2.2 Need for frequency support services 28
4.2.3 Requirements for voltage support services 28
4.2.4 Requirements for system restoration services 28
4.2.5 Regional differences in service requirements 28
4.2.6 Methods of assessing system needs with VAR-RES are still evolving 29
4.3 RECOMMENDED KEY SERVICES FROM WIND AND SOLAR PV 29
4.4 HIGH VAR-RES PENETRATION ISSUES AT TRANSMISSION AND DISTRIBUTION LEVEL 30
4.4.1 Transmission level 31
4.4.2 Distribution level 31
4.5 INTERACTION OF NEEDS AND SERVICES AT TRANSMISSION AND DISTRIBUTION LEVEL 31
4.6 CROSS-BORDER ISSUES OF NEEDS AND SERVICES 31
4.7 SPECIFIC NEEDS REGARDING LARGE SCALE OFFSHORE WIND DEPLOYMENT 32
4.8 SPECIFIC NEEDS REGARDING DISTRIBUTED SOLAR PV 32
4.9 CONCLUSIONS – SYSTEM NEEDS 33

5 CAPABILITIES OF VAR-RES AS GRID SUPPORT SERVICE PROVIDERS 34
5.1 INTRODUCTION 35
5.2 TECHNICAL ASSESSMENT OF VAR-RES CAPABILITIES FOR SERVICE PROVISION 35
5.2.1 Existing capabilities to provide frequency and voltage support 35
5.2.2 Existing capabilities for system restoration support (SRS) from VAR-RES 36
5.2.3 Recent technical developments of capabilities for system services 37
5.3 POWER SYSTEM IMPACT OF SERVICES PROVIDED BY VAR-RES 37
5.3.1 Frequency Control 37
5.3.2 Voltage Control 37
5.3.3 Provision of GSS with offshore wind plants 38
5.3.4 Impact of aggregation and short term forecasting on GSS provision 39
5.4 TECHNO-ECONOMIC ASSESSMENT OF SERVICE PROVISION (GENERATOR LEVEL) 39
5.4.1 Comparing costs of providing GSS with wind and solar PV 39
5.5 CHALLENGES FOR ENHANCING CAPABILITIES AND SOLUTIONS 41
5.5.1 Enhanced frequency and voltage support with VAR-RES: challenges and solutions 41
5.5.2 System Restoration Support with VAR-RES: technical challenges and solutions 45
5.6 CONCLUSIONS - CAPABILITIES 46
6 ECONOMIC BENEFITS OF VAR-RES BASED SERVICES 47
6.1 INTRODUCTION 48
6.2 VAR-RES IN FREQUENCY SUPPORT 48
6.2.1 Cost-benefit of using VAR-RES in frequency support 48
6.2.2 Cross-border sharing vs. VAR-RES in frequency support 49
6.2.3 Other options for frequency support 49
6.3 COST BENEFIT OF VAR-RES IN VOLTAGE SUPPORT 50
6.3.1 Cost-benefit of using VAR-RES to support voltage at high voltage levels 50
6.3.2 Cost-benefit of using VAR-RES to support voltage at low/medium voltage levels 50
6.3.3 Other options for voltage management 51
6.4 COST-BENEFIT OF USING VAR-RES FOR SYSTEM RESTORATION 52
6.5 THE EXCESSIVE COST OF REQUIRING CAPABILITIES FROM ALL GENERATORS 53
6.6 CONCLUSIONS – ECONOMIC BENEFITS 53
7 MARKET CONCEPTS (COMMERCIAL FRAMEWORKS) 54
7.1 INTRODUCTION 55
7.2 THE ELECTRICITY MARKET – INTERFACE TO RESERVICES 55
7.2.1 Differences in self-dispatch market types 55
7.2.2 Markets for reactive power for voltage support 55
7.2.3 GSS market in Europe in monetary terms 56
7.3 IDENTIFICATION OF BEST PRACTICES IN DIFFERENT COUNTRIES 56
7.3.1 Frequency support services 56
7.3.2 Voltage support services 57
7.4 KEY MARKET DESIGN/PRODUCT ADAPTATIONS TO OFFER ON GSS MARKETS 57
7.4.1 Suitable product characteristics for frequency support services 57
7.4.2 Suitable product characteristics for voltage support services 59
7.4.3 Procurement models enabling TSO/DSO coordination of GSS 59
7.5 CONCLUSIONS – MARKET CONCEPTS 59

8 KNOWLEDGE GAPS AND FURTHER RESEARCH 61
8.1 INTRODUCTION 62
8.2 KNOWLEDGE GAPS 62
8.2.1 System needs for GSS 62
8.2.2 Technology 62
8.2.3 Markets/costs/economics 63
8.3 R&D NEEDS 64
8.3.1 System needs 64
8.3.2 Technology 64
9 THE RESERVICES PROJECT – A SYNOPSIS 65
10 REFERENCES 67
11 LIST OF RESERVICES REPORTS (DELIVERABLES) 69
System needs for GSS 70
Wind and PV GSS capabilities and costs 70
Wind and PV GSS in future systems – Case Studies 70
Recommendations for a future EU market for GSS 70

BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat and Power
DC	Direct Current
DEV	(project) Developer
DFIG	Doubly Fed Induction Generator
DG	Distributed Generation
DS	Distribution System
DSO	Distribution System Operator
eBOP	Electric Balance of Plant
ENTSO-E	European Network of Transmission System Operators for Electricity
ETS	Emission Trading Scheme
FACTS	Flexible AC Transmission Systems
FCR	Frequency Containment Reserve
FFR	Fast Frequency Response
FRCI	Fast Reactive Current Injection
FRR	Frequency Restoration Reserves
GC	Grid Code
GCR	Grid Code Requirement
GCT	Gate Closure Time
GSS	Grid Support Services
HV	High Voltage
ICT	Information and Communication Technology
IEM	Internal Electricity Market (EU)
LCOE	Levelised Cost of Electricity
LV	Low Voltage
MPP	Maximum Power Point
MV	Medium Voltage
NC	Network Code
NCR	Network Code Requirements
NPV	Net Present Value
NWP	Numerical Weather Prediction
OCGT	Open Cycle Gas Turbine
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
OS	Operating System
OLTC	On Load Tap Changer
OTC	Over The Counter
P	Power
PF	Power Factor
POC	Point of Connection
PQ	Active versus Reactive Power
PV	Photovoltaic
REG	Regulator
RM	Ramping Margin
RMSE	Root Mean Square Error
RoCoF	Rate of Change of Frequency
RR	Replacement Reserves
SCR	Short Circuit Ratio
SET Plan	Strategic Energy Technology Plan
SNSP	System Non-Synchronous Penetration
SO	System Operator
SRS	System Restoration Support
SSVC	Steady State Voltage Control
SVC	Static Var Compensator
TS	Transmission System
TSO	Transmission System Operator
VAR	Volt Ampere Reactive
VAR-RES	Variable renewable generation
WF	Wind farm
WPP	Wind Power Plant
WT	Wind Turbine

1 EXECUTIVE SUMMARY AND POLICY RECOMMENDATIONS

Wind power and solar PV technologies can provide ancillary or grid support services (GSS) for frequency, voltage and certain functions in system restoration. The REserviceS project confirmed that variable renewable energy sources like wind and solar PV generation (VAR-RES) meet most of the capability requirements for delivering such services, as prescribed in Grid Codes. Where enhanced capabilities would be required, technical solutions exist, but are not used today because of economic reasons due to additional costs, of which REserviceS has made an assessment. While in some countries financial incentives for VAR-RES with enhanced capabilities exist, this remains the exception rather than the rule in Europe. Appropriate operational and market frameworks are therefore needed for enhanced participation of VAR-RES in GSS.

The need for VAR-RES' participation in GSS provision, especially at high penetration levels, depends on the power system characteristics (for example its size and resilience) and how VAR-RES are integrated into it (for example its dispersion and technical characteristics). As GSS come with a cost, requirements for generator capabilities and service provision should demand only what is needed by the system to avoid excessive system costs. Importantly, REserviceS analyses found that frequency management can be adequately and economically achieved with only a fraction of all installed VAR-RES generators participating in frequency support.

Therefore, preparing for future for future electricity systems with large shares of VAR-RES requires detailed studies and simulations to make well-founded estimates of the needs and technical requirements. Moreover, detailed and clear specifications, as well as market designs and products taking into account the characteristics of VAR-RES, are crucial for their participation in GSS provision.

An increase of VAR-RES means that generating capacity is increased in Distribution System Operator (DSO) networks. Hence, DSO/TSO (Transmission System Operator) interaction will also be increasingly important in the future with large shares of VAR-RES. DSOs in particular will have an increasing role in the transition of electricity networks. Revised governance for DSO/TSO interaction to properly coordinate frequency and voltage support, as well as restoration services provided by VAR-RES, is needed.

If the political goal of achieving a truly integrated Internal Energy Market goes beyond the energy-only market model, the roll-out of GSS market models throughout the EU must be considered. Therefore, the following project recommendations need to be taken into account, in particular in the revision of the EU-wide Target Model and more specifically in the relevant network codes as well as in national grid connection requirements.

1.1 Recommendations - EU energy policy and electricity market design

These recommendations relate to regulatory frameworks at national and EU level directly affecting GSS provision from VAR-RES. These frameworks include present and future energy market design, the EU-wide target model, commercial frameworks, etc. The recommendations are primarily addressing the European Network of Transmission System Operators for Electricity (ENTSO-E), national TSOs and DSOs, market operators, the EU Agency for the Cooperation of Energy Regulators (ACER) and national regulators as well as the European Commission and national energy policy makers.

1.1.1 Recommendations for policy makers

- The role of GSS in the electricity market should be expanded in the context of an increased share of VAR-RES, and as part of a truly integrated Internal Energy Market (IEM). In order to reap the full benefits from GSS provided by VAR-RES, adequate market frameworks and technical requirements are needed;
- The right balance between a market system (which is harder to predict and controlled by the system operators responsible for power system stability) with multiple participants (to encourage competition and drive innovation) and the provision of GSS must be found in each power grid;

- Commercial provision of some GSS as alternative market-based revenue streams for all generators should be considered. This would increase investors' interest in power generation and help tackle any potential generation gap in the electricity sector in a market-based way, as opposed to a subsidy in the form of capacity remuneration mechanisms;
- Recommendations on frequency and voltage support need to be considered when implementing a revised EU-wide Target Model in the relevant network codes. Existing network codes must be amended or revised in light of the findings in this study and new ones considered to enable GSS provision from VAR-RES;
- The functioning of existing day ahead and intraday markets must be improved with shorter gate closure and more cross border integration in order to give VAR-RES producers (short term) opportunities to trade their imbalances. A shorter forecasting time horizon would not only help to set up a level playing field for balancing conventional and variable generation, but would also lower the system operation costs;
- Commercial provision of GSS should be taken into account in the revision of the EU-wide Target Model. Today GSS provision from VAR-RES is not considered in either intraday or balancing markets. Moreover, the development of GSS markets is not envisaged in the Target Model, even if GSS would constitute part of the IEM, alongside trading electricity;
- The revision of the EU-wide Target Model should be accompanied by an implementation roadmap describing the capabilities and GSS needed with increasing VAR-RES levels. There should also be a set of pre-qualification and procurement methods pointing at requirements to be included in existing and future network codes;
- Compulsory GSS requirements that are not remunerated should be minimised or replaced by remuneration schemes, as it is neither cost-efficient nor necessary to request services from all connected generators in most systems. Market based remuneration provides incentives for cost-reduction irrespective of whether these are VAR-RES or conventional plants;
- Policy makers should properly evaluate the cost/benefit ratio of the proposed solutions for market based frameworks and assign appropriate price ranges for the provision of GSS. To incentivise investments, prices — be they related to bid-based markets, auctions or capability payments to generators — should capture both the benefits provided to the system in terms of system operation cost savings and the value of such services;
- To ensure adequate stakeholder involvement, a regular multi-year consultation on the appropriate regulatory regime for GSS should be established including:
  - Governance and financial arrangements
  - Power system studies
  - Technical capabilities - definition and assessment;
- National and EU policy makers should require the relevant system operators and ENTSO-E to deliver mandatory cost-benefit analyses when EU network codes or national grid connection requirements are determined. Policy makers should also establish a clear framework for how to carry out a cost-benefit analysis (CBA) in conjunction with a functional commercial framework determining how GSS are procured and remunerated;
- In addition to working out precise network codes, which encompass the market design provisions laid out in the Target Model, a proper implementation and roll-out of GSS markets by the Member States and facilitated by ACER and national regulators is key;
- Using GSS will require extensive cooperation and clear boundaries between TSOs' and DSOs' rights and duties. With regards to the TSO/DSO interface, guidelines should be developed on how the distribution system can contribute to grid reliability and stability. Guidelines on implementing the results of system studies in grid code requirements should also be drawn-up.

1.1.2 Recommendations for market design - frequency support

- VAR-RES' capability to provide frequency support, in particular Frequency Containment and Frequency Restoration Reserve (FCR and FRR), to the extent that it is beneficial (reliability vs. cost) to the system should be financially compensated, as well as its readiness and utilisation costs;
- Characteristics of products such as low minimum bid sizes, separation of up- from downwards bids, inclusion of confidence intervals and aggregated bids and offers are important for allowing VAR-RES

to participate cost-effectively in GSS provision;
- Clear procurement rules together with clear technical specifications are of crucial importance for the participation of VAR-RES in GSS provision;
- Frequency support related GSS provided by VAR-RES require harmonised gate closure times as close as possible to delivery and minimised time frames (less than one hour);
- For cost-efficient offers to be provided with high certainty, the market design should encourage PV and wind to offer reserve products from aggregated portfolios of several PV and wind power plants, which can be spread across wider areas. Alternatively, the uncertainty can be aggregated over all units participating in the reserve. This function should be facilitated by the system operator and would eliminate the need for overlapping safety margins due to forecast inaccuracy, unexpected power plant failure and performance compliance;
- Market participants should be incentivised to be in balance in the Balancing Responsible Party's (BRP) perimeter after gate-closure time. Flexibilities of VAR-RES could then be used by the BRP manager when they prove to be the most cost-efficient. This would also reduce the need for reserve power for balancing by the TSO.

1.1.3 Recommendations for market design - voltage support

- 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 areas 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 offer (or best offers) is awarded with a fixed reimbursement for the reactive power provided to the system and a minimum off-take guarantee to ensure investment security.

1.2 Recommendations - EU network codes and national grid codes

Recommendations in this section are addressed to network operators, TSOs and DSOs. Some may specifically address ENTSO-E and its working groups.

1.2.1 Requirements based on identification of system needs

- System studies should constitute the principal basis for network codes and grid codes in their formulation of requirements for VAR-RES. The studies and their implementation in grid codes should consider frequency support needs and voltage needs at the appropriate system level (system wide and cross-border versus localised needs);
- Requirements based on system studies should take into account (expected) VAR-RES penetration. Network operators should not ask for more than needed but, as a unit can last more than 20 years, expected renewable energy penetration should also be taken into account when defining capabilities (to avoid costly retrofit and/or burdening new generators);
- Frequency control (FCR and automatic FRR) capability should not be required from all VAR-RES plants connected to the network as it would not be cost-effective. How much is needed and where, should be based on system studies and further research;
- Voltage control capability should only be required from VAR-RES when the analysis of the expected costs compared to all other voltage control provision

methods shows it is the most cost-effective solution for the particular combination of generator type and primary energy source, considering the likely future expansion of generation, demand and grids.

1.2.2 Contents and quality of requirements for generators for service delivery

- Network Codes and Grid Codes should provide detailed specifications for minimum technical capabilities for generators to participate in GSS. Requirements should be function-oriented in addressing design capabilities and delivery performance. They should not prescribe technical solutions to reach a certain performance;
- State of the art forecast methods should be implemented in the operation of VAR-RES. TSOs should improve their forecasting utilising state of the art techniques during operations, while increasing cross-border cooperation to reduce unexpected situations due to forecast errors;
- Requirements for generators should take into account their specific technology and the primary source driving it. Only by doing so can system service provision be optimised. Different types of generators (e.g. wind turbine conversion Type 3 and Type 4) and different energy sources (PV vs. wind) need different levels of investment to roll-out their GSS provision. In order to create a level playing field for all of them, these specifications need to be included in the requirements for specific GSS;
- When designing the requirements and the framework for the procurement of GSS at the distribution level, the spatial distribution should also be taken into account to avoid cost inefficiencies that could result from a one size fits all approach;
- Grid codes should consider the formulation of technical requirements for extremely fast frequency response (e.g. full response faster than ¼ second) for situations in the power system with low inertia;
- Requirements at the European and national level should, where possible, make reference to specifications in existing or upcoming European or international standards.

1.2.3 Management of grid code requirements

- In order to enable proper implementation and monitoring of requirements, network operators should organise the data exchange and visibility of distributed generators;
- Market frameworks should take into account the characteristics of available and future power sources and their capabilities: the requirements should be clear, precise and based on market design taking existing capabilities into account;
- TSOs and regulators should establish clear procedures and reporting rules distinguishing balancing/congestion management and curtailment for system security. They should coordinate the implementation of these rules with the DSOs.

1.2.4 Harmonisation and standardisation

- TSOs and DSOs should contribute to the development of European product standards (e.g. IEC, Cenelec) to avoid costly mismatches between grid connection requirements and product standards. Standardisation is based on best practices and is essential for LV and MV connected systems. The EN 50438 European Standard and the Technical Specification TS 50549 have to be considered when specifying new grid connection requirements;
- Exchange of data (including forecasts) between generating facilities and the relevant network operators (TSOs, DSOs) should be standardised. Common forecast platforms, procedures and file formats will improve information exchange and reduce errors;
- Prequalification processes and testing procedures for generators providing GSS should be harmonised.

1.3 Recommendations - research and technical development

REserviceS identified technology and process gaps that could be addressed by focused R&D efforts enabling improved (technically/economically) provision of services by VAR-RES. The recommendations consist of research topics in four categories: hardware, software and methods, system operation procedures and standards. Stakeholders for these recommendations include the VAR-RES industry, TSOs, ENTSO-E and the research community.

1.3.1 Hardware

Further development of hardware including designs enabling VAR-RES to provide GSS:

- Communication infrastructure for the provision of services by portfolios of MV/LV connected systems

such as solar PV systems and wind farms;
- Metering devices for the provision of services by portfolios of MV/LV connected VAR-RES;
- Reliable communication hardware for very fast system services;
- Monitoring systems to enable HVDC connected wind farms (WF) and/or WF clusters to provide reliable frequency support;
- Study of the effect of sustained GSS provision on wind turbine loads and possible impacts on its design.

1.3.2 Software and methods

Further development of software tools to improve technical and operational capabilities for the deployment of GSS by VAR-RES:
- Improvement of probabilistic forecasts to be used in system operation;
- Control and coordination algorithms to enable HVDC connected WF and/or WF clusters to provide reliable frequency support;
- Advanced control strategies for improved grid friendliness of VAR-RES and enhanced capability of providing system services;
- Better understanding of technical requirements and control strategies for VAR-RES operating in hybrid AC and DC multi-terminal networks.

1.3.3 System operational procedures, methodologies and GSS deployment strategies

Further development of methodologies and operational procedures for deploying GSS and improving system operation:
- Probabilistic planning and operational procedures (especially using probabilistic forecast methods) in power system operation;
- Optimisation strategies for the provision of GSS by portfolios of MV/LV connected systems such as PV systems or small wind farms;
- Common methodology for assessing system needs of GSS with large amounts of VAR-RES;
- Developing methods and tools power system models able to capture different operational time scales, i.e. models focusing on electromechanical dynamics (20ms to 30s), focusing on system balancing (5 min to 24h), focusing on frequency quality for services such as FCR and FRR (s to min), for power systems with high variability;
- Definition (technical and economic) of new GSS and study of 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. This would make the best of existing or future capabilities available at the distribution level;
- Investigation of technical requirements and operational practices for VAR-RES to be included in power system restoration processes.

1.3.4 Standards

Development of further 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 infrastructure;
- Communication protocols for very fast system services.

2 INTRODUCTION

The anticipated high shares of wind and solar PV in the European electricity system will require fundamental changes in the way transmission and distribution network operators use grid support services (GSS) from generators to manage network frequency, voltage and system restoration. These changes will be twofold: the power system needs for GSS will change as VAR-RES increase, and the technical and economic characteristics of VAR-RES change the way these services can be provided. The REserviceS study was set up to assess the provision of GSS by VAR-RES, in order to help design 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 the REserviceS consortium has focused on wind and solar PV because these are expected to jointly produce the lion's share of renewable electricity needed to reach the EU's 2020 targets.

The setting for GSS in future European electricity systems is characterised by the following important developments:

- Fundamental changes in the generation mix, resulting in fewer traditional providers of GSS, the entry of large numbers of decentralised renewable plants, predominantly at low and mid voltage level, driven by national and European climate and energy policies, increased competitiveness of VAR-RES and changing business cases for non-VAR-RES conventional plants;
- The political aim to create an integrated Internal Energy Market (IEM) in the EU and creating competition in wholesale and retail energy markets following the unbundling of vertically integrated utilities. This includes facilitating the entrance of new market players and the integration of electricity markets throughout Europe on all timescales which would entail GSS markets;
- A regulatory framework at EU level for power market integration enshrined in the EU-wide target model outlining principles of cross-border capacity allocation and market coupling, as well as increased TSO cooperation through European bodies such as ENTSO-E;
- A new legislative layer through binding EU regulations in terms of network codes covering market design and network management rules. So far network codes have only marginally covered intraday and balancing market design and have not yet been considered for GSS;
- Rapid developments in control and communication technologies with profound impact on control of generation plants (including VAR-RES) and management of electricity systems in general;
- An increased electrification of society, electricity consumers increasingly become "prosumers" by installing Distributed Generation (DG) at their facility (household PV, industrial PV and CHP etc.).

The REserviceS study has made a technical-economic assessment of the provision of GSS — notably frequency and voltage support — as well as preliminary analysis of system restoration by VAR-RES themselves. The study adds to existing knowledge to establish costs and values for GSS that can be provided on a large scale by wind power and solar PV, installed both at transmission and distribution level in the power system. The REserviceS project aims to contribute to the development of effective market-based approaches for GSS in Europe and to the design of electricity market mechanisms that enable the power systems in Europe to function safely, reliably and cost-efficiently with very high shares of VAR-RES.

Research questions in this report address five themes:

- System needs for GSS (frequency, voltage and system restoration) to develop when the shares of VAR-RES are very high;
- Technical and economic issues for VAR-RES to provide the necessary services;
- Economic benefits of large scale provision of services by VAR-RES;
- Suitable market conditions and commercial frameworks;
- Knowledge gaps and needs for R&D.

These topics have been analysed at several stages of the project. In the first stage, REserviceS analysed how system needs for grid services change in the growing presence of wind and solar PV, and identified key services that should be provided by these VAR-RES. In a second stage a technical and economic assessment was performed on the capabilities of wind and solar PV for the provision of such services. The third stage consisted of case studies looking at technical and economic impacts in transmission and distribution grids — simulating effects of large deployment of services and assessing costs and benefits. In the last stage the findings have been integrated into a combined report as well as a separate recommendations report[1]. The integration of the project findings included an initial exploration of procurement methods of frequency and voltage support services by TSOs and DSOs. It outlined possible market mechanisms in the context of the further integration of the European electricity market. The study also helped to identify knowledge gaps and topics for further research into the provision of GSS by variable generation.

This publication presents a summary of the key findings and recommendations of the project. More detail can be found in D7.1 REserviceS Synthesis Report[2]. This publication also contains references to specific reports (Project Deliverables) where detailed analyses and results can be found. A list of these Deliverables can be found at the end of this publication.

Policy recommendations are aimed at EU Network Codes (RfG, balancing, DCC, operation etc.), the EU-wide Target Model and related (regional) market models, energy policy processes and scenarios, (grid) infrastructure (e.g. ICT), energy regulation and SET Plan and R&D (see D7.2 Recommendations[3]). The proposals have been made by the REserviceS consortium, consisting of wind and solar energy industry associations and industrial companies, knowledge institutes specialising in VAR-RES energy markets and power system studies, as well as a European association of distribution system operators.

The REserviceS consortium also interacted with stakeholders (industry and network operators) during workshops[4], through surveys and discussions with the Advisory Board.

1 REserviceS D7.2
2 REserviceS D7.1
3 Available at http://www.reservices-project.eu/wp-content/uploads/140724_REserviceS_D7.1_Synthesis-report.pdf
4 For more information, please consult: http://www.reservices-project.eu/events/

3 RESERVICES MAIN FINDINGS

3.1 System needs for grid support services by wind and solar PV

REserviceS' assessment of needs in European power systems focused on frequency and voltage support as the main categories of grid support services (GSS) that wind and solar PV generation can provide. Frequency and voltage control constitute several services with different response times.

Generally, the system needs for identified frequency support services will increase with high shares of VAR-RES. There is a need for enhanced frequency support in the system especially for manually activated system reserves or Frequency Restoration Reserves (FRR) with activation times of less than 15 minutes. VAR-RES may increase the need for voltage support because reactive power sources, both steady state and dynamic, that are available today to the system operator are likely to be reduced in the future. Also, the voltage profile management will become more complex with increasing shares of VAR-RES. New services will be needed, mainly to achieve faster responses to deviations of normal operation conditions or faults as well as services/capabilities provided by synchronous generation (for example mitigation of negative sequence voltages and damping of harmonics). The contribution from wind and PV for system restoration services may need further assessment.

The need for GSS with VAR-RES depends on the power system studied (for example its size and resilience), and how VAR-RES are integrated into the system (for example it dispersion, penetration levels and technical characteristics). GSS come with a cost, so requirements for generator capabilities and service provision should demand only what is needed by the system in order to avoid excessive costs. Preparing for future systems with a large share of VAR-RES thus requires studies and simulations to make well-founded estimates of the needs and technical requirements. But there is a lack of a common methodology to include VAR-RES in estimating system needs for services and limited information on the combined effects of wind and solar PV. As the method of assessing system needs for GSS with VAR-RES is still evolving, new tools are needed.

DSO/TSO interaction will be increasingly important in the future with large shares of VAR-RES, and DSOs will have a growing role in the transition process in electricity networks. Data exchange and ability to control a multitude of small generation units should be structured. Roles and responsibilities for coordinating frequency and voltage support as well as restoration services need to be clarified.

3.2 Technical capabilities of wind and solar PV as service providers

Technology analysis of wind power and solar PV confirmed their technical and operational capabilities to provide GSS for frequency, voltage and certain functions in system restoration. This analysis was validated through industry enquiries and assumes adequate operational and economic frameworks are put in place. The technical and operational functionalities required are either state of the art using existing hardware, or can be implemented at a reasonable cost. The feasibility of providing services by enhanced plant capabilities is confirmed by TSOs, for example in Spain where voltage control by wind power plants on specific transmission nodes leads to a significant improvement with fast response. Case studies performed by REserviceS in Spain and Germany demonstrate that letting the DSO use GSS from VAR-RES generation connected to its own system contributes to cost-efficient voltage management. The participation of VAR-RES in system restoration has not yet been practiced.

For wind power, potential technical enhancements for frequency and voltage support services include: faster and reliable communication (a.o. between wind farms and system operators' control rooms), dedicated control tuned for delivering the required performances, estimation of available power/forecasting. Furthermore, structural, mechanical and electrical design changes in wind turbines need to be implemented to take into account the changes in loading involved with grid service 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. GSS 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 GSS regardless of the offshore wind condition. Technical standards and Network Codes currently in preparation are important enablers of offshore wind GSS.

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.

The implementation of better and faster communication systems together with the development of more accurate forecasts are essential for both wind and solar PV technologies. In general, aggregation of multiple VAR-RES power plants is desirable because it improves performance when providing a service and reduces the relative implementation costs. However, for very fast responses aggregation could cause additional communication delays. Also, both for wind and solar PV, control strategies should be tuned to obtain the maximum power performance and flexibility from VAR-RES.

A precondition for provision is to have clear and well-defined requirements and procedures to integrate wind and solar PV as GSS providers. In this respect, poorly defined or non-existent technical specifications in grid codes or pre-qualification procedures to allow VAR-RES to provide GSS constitute a significant barrier that needs to be overcome. This is exacerbated by the lack of standardisation and harmonisation of procedures across Europe. A clear GSS roadmap should be established describing the required capabilities and services along with a set of pre-qualification and procurement methods including proper attention to the characteristics of the sources.

Implementing enhanced capabilities will involve additional investment, and the deployment of the services will also involve costs. For both wind and solar PV the additional investment costs (CAPEX) for enhanced provision are relatively low and — provided appropriate cost recovery and market mechanisms are in place — their deployment should be commercially feasible. Only for small PV systems today the impact of required communication components will result in high additional CAPEX costs. In general, both for wind and PV, OPEX costs notably upward readiness cost represent the highest costs to make frequency services available. However, the enhanced capabilities should not be required if there is no need for them as this would incur unnecessary additional cost. In general, frequency related GSS can be provided by a portion of VAR-RES units and not all units need the capability. Utilising VAR-RES in voltage related GSS depends on their location in the network and should be judged on a case by case basis.

3.3 Economic benefits of grid support services by wind and solar PV

The REserviceS simulations of power systems of various sizes across Europe and with shares of VAR-RES up to 50% showed that it is beneficial to utilise wind and solar PV in frequency support. Moreover, system benefits increase as the share of VAR-RES increases. The greatest benefits in simulations were observed in downward Frequency Containment Reserves (FCR) with delivery times of less of five minutes and in automatic FRR. The 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 wind power plants.

Also, economic benefits were achieved even when only some VAR-RES participated in frequency support. In a sensitivity analysis, the frequency response and its corresponding economic benefits remain adequate with 25% of the total installed wind power participating in frequency support services. Thus it should be sufficient to only equip part of the VAR-RES with capabilities for FCR and automatic FRR services. Cross-border sharing of frequency reserves creates similar benefits as VAR-RES, but there are additional benefits when both VAR-RES and cross-border sharing are utilised.

REserviceS also performed case studies on voltage support at different voltage levels (HV/MV/LV) and with different VAR-RES shares. It concluded that the cost/benefit ratio of voltage support from VAR-RES is case-specific and that the provision of voltage support by VAR-RES should be compared to other technology alternatives. As there will be a high number of locations where voltage support can be sourced, common and robust methods to assess decisions of voltage sourcing with reproducible and comparable results are needed. The case studies demonstrate that voltage control capabilities from all VAR-RES generators are not always the best choice and, therefore, an across the board requirement may lead to excessive costs.

3.4 Markets and commercial frameworks

In today's energy-only markets the contribution of GSS 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 their utilisation can decrease operational costs of the power system, there should be sufficient incentives to obtain these benefits along with the capability and availability requirements for VAR-RES. Currently, only a few markets (e.g. Ireland, Great Britain) provide arrangements for enhanced services where VAR-RES are incentivised to participate. In future systems with high shares of VAR-RES, revenue from GSS is bound to increase, even if it remains a small part of total system costs and revenues.

However, if the political goal of achieving a truly integrated Internal Energy Market goes beyond the energy-only market model, the roll-out of GSS markets throughout the EU must be envisaged. In terms of necessary regulatory frameworks, the specific project recommendations on commercial frameworks in this section need to be considered in the revision of the so-called EU-wide target model and more specifically in the relevant network codes. In order to enshrine the necessary market design in enabling legislation, existing network codes should be amended or revised and new ones considered, in light of these findings.

Not all generators in a system have to provide GSS to ensure safe system operation. Mandatory capability/provision for GSS is often not cost-efficient. Market based remuneration, on the one hand, stimulates cost reductions by incentivising provision by plants with the lowest costs, irrespective of whether these are VAR-RES or non-VAR-RES plants. On the other hand, in a market based approach it is more difficult to control where the VAR-RES units with enhanced capabilities are located. This can be crucial when utilising grid support services. As a consequence, particular GSS could be required in locations where the capability would be needed the most.

Detailed and clear specifications are of crucial importance for the 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. Requirements should be defined in close cooperation between the TSOs and VAR-RES industry via consultations, as is the case in Ireland[5].

To enable the provision of GSS by VAR-RES, a multilevel procurement process should be defined involving TSOs, DSOs and generators connected to their networks. On the one hand, the participation of VAR-RES in a GSS market — run by the TSO — could breach certain operational limits in the distribution grid. On the other hand, by solving local issues (congestion or voltage management) with GSS provided by VAR-RES, the actions of DSOs could have repercussive effects on the transmission grid operation. Given the complexity of coordinating the respective tasks, a hierarchical definition of the supervision and control actions is necessary. A clear hierarchy of functions between TSO and DSOs should be established.

[5] http://www.eirgrid.com/operations/ds3/

In order to enable full utilisation of the capabilities of VAR-RES for the provision of GSS, the design of markets and products should be adapted to take into account the characteristics of VAR-RES. Characteristics of products such as separation of bids up from downwards, inclusion of confidence intervals and aggregated bids and offers are fundamental for allowing wind and solar PV to participate cost-effectively in GSS provision.

Provision of voltage support services induces costs for the VAR-RES. Therefore, ideally these services should be remunerated. There are several possible methods for doing so, such as a regular bidding process, auctioning arrangement or contracting for short or long time horizons. An alternative is to require voltage support in grid connection arrangements and to compensate the cost directly through the support policies. Also, a non-remunerated mandatory band as part of the grid code requirements could be complemented with a payment for additional support to grid operation, provided such costs are recognised by the regulator and recoverable by the system operator.

3.5 Knowledge gaps and need for R&D

Streamlined and consistent R&D efforts will play a key role in the timely and effective enhancement of VAR-RES to provide GSS. The REserviceS study defined several areas of system needs assessment, VAR-RES technologies and market designs, where research is needed to fill knowledge gaps, and to improve methods and solutions. These include hardware, software and related methods, system operation procedures and standards.

The identified research needs to link with several other European activities by major stakeholders: ENTSO-E, the European Electricity Grid Initiative and the European Solar and Wind Industrial Initiatives.

4 SYSTEM NEEDS VS. GRID SUPPORT SERVICES FROM WIND AND SOLAR PV

4.1 Introduction

Increasing VAR-RES raises system needs for GSS. However, VAR-RES can also provide some of these services. Despite this, more studies of system requirements and value of services are needed to better scope grid code requirements, volume of service and remuneration to generators. Ideally, remuneration should be relative to the value to the system and should reflect the long term cost of service provision. Such information will be fundamental for allocating costs and benefits between consumers and grid support service providers.

Today, generators connected to the high voltage (HV) transmission system are the main providers of GSS to TSOs. A significant part of VAR-RES is connected at lower voltage levels and while DSOs mostly operate these — typically MV and LV — in some places they also operate HV lines. Hence, both TSOs and DSOs are users of GSS offered by generators.

For example, frequency control is managed by TSOs with the help of generators connected to the transmission network. Frequency is a global load balance indicator in a synchronous power system, and can in theory be controlled from any location in the grid. Hence, generation at distribution level can also participate in frequency control. With the rising share of VAR-RES, this will certainly be the case in future.

In contrast to frequency, voltage is a local/regional measure in power grids. Both TSOs and DSOs require voltage control that differs fundamentally at transmission and distribution levels. Active grid management at distribution level is increasing, moving from passive-only low voltage (LV) operation and partly passive medium voltage (MV) operation to a more active LV/MV level operation.

Nevertheless, provision of services to TSOs from the distribution level is not currently standard practice. GSS at the distribution level have not really been defined, as they were singled out only after the introduction of the wholesale electricity markets and as such entrusted to the TSOs.

Therefore, grid management has to be set up to include both transmission and distribution levels. Visibility (online data) and controllability of VAR-RES becomes essential alongside increasing communication systems between transmission and distribution. Joint planning for GSS provision by VAR-RES will reduce the need for grid reinforcements. DSOs will no longer rely on grid extensions to ensure the power quality and connection of existing and new loads and generation.

4.2 Changing system needs with increasing wind and solar PV penetration

4.2.1 General trend – increasing needs at rising penetration levels of VAR-RES

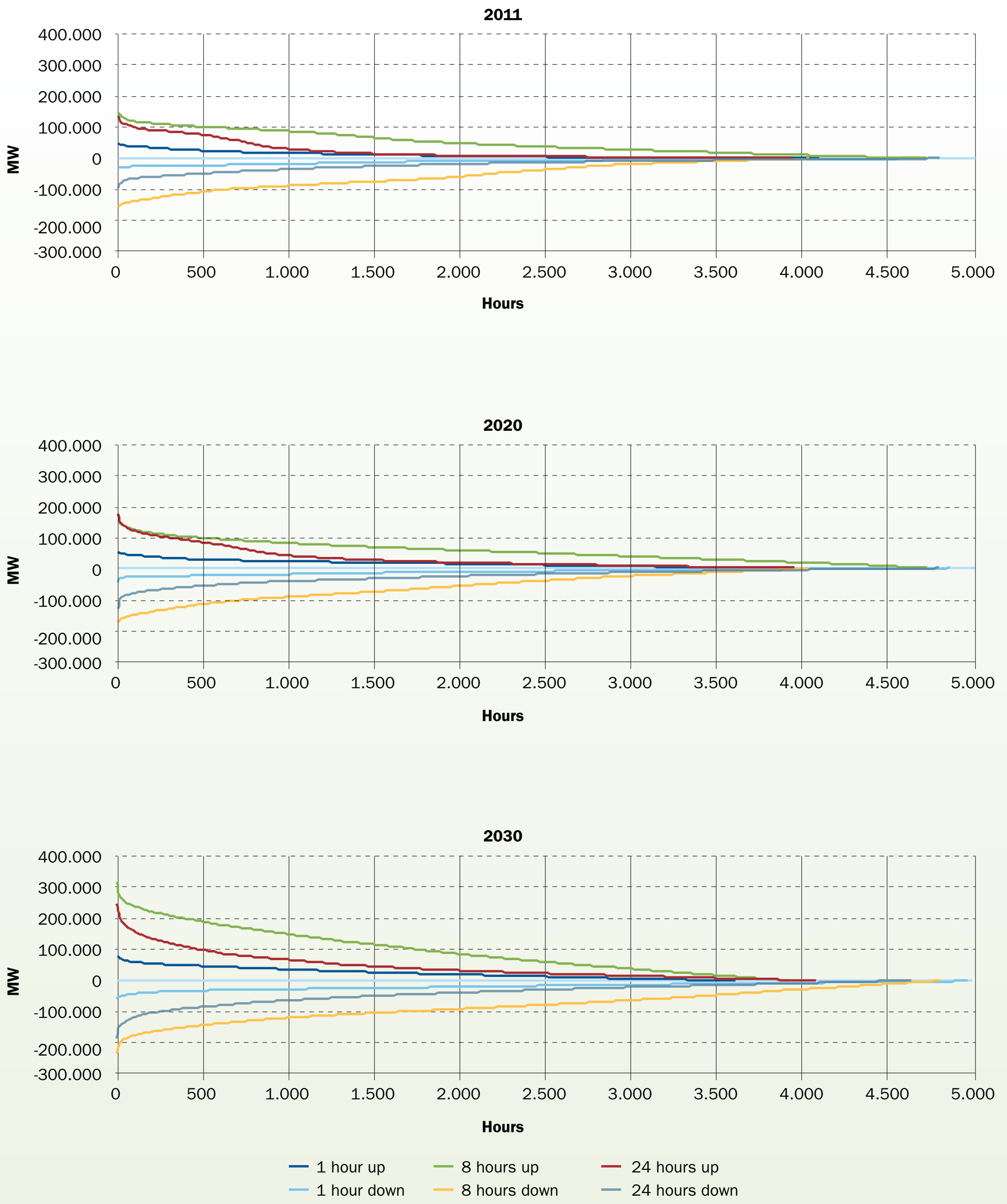
Studies on how renewables impact system needs for GSS are still limited, especially considering combined effects of wind and solar PV. Existing knowledge mainly stems from experience and estimates made in renewable energy grid integration studies. However, there is no indication how far the needs for frequency and voltage support have actually increased due to additions of wind and solar power.

For example in Germany, the sharing of frequency restoration reserves between the four TSOs has actually reduced the needed frequency support although it was expected that the growing shares of wind and solar PV would have increased this need. In Ireland VAR-RES curtailments have occurred due to concerns about low inertia. In general, estimates for a single generation technology like wind and solar (PV) are difficult to extract because system services are assessed simultaneously for the entire power system.

The main impacts of VAR-RES on grid support needs are due to the increased variability (Figure 1) and uncertainty that will result in more balancing needs, impacting both frequency and voltage control needs. At increasing shares of VAR-RES, the non-synchronous[6] characteristics of VAR-RES generation become important, causing firstly a greater need for grid support services and secondly a lack of synchronous (non VAR-RES) sources to provide such services during high wind and sunny hours.

[6] Non-synchronous generation employs generation technology that does not rely on the synchronous generator and hence does not employ rotating masses in synchronism with the system frequency. Such generation does not exhibit some of the intrinsic network-stabilising properties like synchronous inertia.

FIGURE 1: INCREASING RAMPING REQUIREMENTS OF THE NET LOAD IN EUROPE, FROM EPIA AND EWEA SCENARIOS FOR THE INSTALLED CAPACITY OF WIND AND PV



Source: Connecting the Sun, EPIA, 2012; Pure Power, EWEA, 2011

4.2.2 Need for frequency support services

The need for frequency related services rises with increasing penetration levels of wind and solar PV. At a 5-10% penetration rate an increase in the use of short term reserves is observed, especially for reserves activated on a 10-15 minute or longer time scale. Small wind and solar PV projects do not impact contingency reserve requirements as large amounts of generation (>1-3 GW) will not trip off in seconds. However, in special extreme weather events large non-anticipated changes in generation can occur in an hour. For example, storm cases[7] for wind or fog for solar PV.

No significant impacts for frequency control services activated in less than 30 seconds have been observed to result from wind power variation. For solar PV, the morning and evening ramps are expected to be challenging at larger penetration levels (>10%). This requires detailed planning of the use of short term and longer than 30 minutes restoration reserves (RR) in interaction with dispatch of plants on the day-ahead and intraday markets[8]. Impacts depend on what time scale of uncertainty is planned for when determining short term reserve needs. Operational practices used in a power system, therefore, will be key for the needed frequency support services.

If dispatch decisions are updated frequently, the impact of wind (and solar PV) on reserve requirements will be smaller.

4.2.3 Requirements for voltage support services

Traditionally, reactive power requirements in the distribution network were covered by large generators connected to the transmission system. At high levels of generation in the distribution network, reverse power flows may occur upstream to the transmission system. This phenomenon is often accompanied by voltage rises and may result in high compensation penalties for DSOs when the power flows over the HV/MV substation are outside a predefined PQ-band. Other impacts can arise[9] but solutions such as coordinated central control strategies at the MV level involving VAR-RES services can help to optimise reactive power exchange between HV and MV levels.

In general, the need for voltage support services increases with higher penetration levels of VAR-RES. However as VAR-RES usually have reactive power capabilities (see chapter five), the increasing trend in the need is not straightforward. VAR-RES can either decrease or increase grid losses depending on their location. Smaller amounts of VAR-RES sited near consumption usually help reduce grid losses, but at higher penetration rates they do the opposite. In cases where voltage control is provided by VAR-RES, the impact can be reversed to become positive. For example, voltage support from VAR-RES can reduce losses and increase hosting capacity of the grid, postponing grid reinforcements[10].

4.2.4 Requirements for system restoration services

A third important category of GSS is restoration services. There are some studies on general strategies for system restoration in the presence of VAR-RES[11] but there is no experience nor study on wind/PV impact system restoration during an islanding situation or a black start[12]. So far, there is no evidence that wind and solar PV would increase the risk of black out.

To integrate renewable energy sources in system restoration schemes, participating VAR-RES need to be controlled directly by the TSO.

4.2.5 Regional differences in service requirements

The characteristics of power systems that impact the system needs with increasing shares of VAR-RES are:

- Operational practices of dispatch and timing of bidding of services as well as the use of advanced forecasting tools. The shorter the dispatch time

[7] Twenties project D16.6, 2013
[8] IEA, 2014
[9] REserviceS D7.1 p.23-24
[10] Twenties; REserviceS D6.2
[11] REserviceS D7.1 p.25
[12] Islanding operation refers to the continuation of power supply from generators isolated from the local or national grid. Black start refers to the capability of a generating unit to start up without an external power supply. For detailed definitions of islanding and black start, see REserviceS D2.2

intervals, the lower the amount of imbalances in the system[13];

- Power system resilience or its flexibility and ability to endure changes. This comprises existing needs of GSS from loads and generators, capability of sharing needs with neighbouring countries and power system size and robustness characteristics[14];
- Network strength and topology, which affect the needs for voltage control and frequency support over a larger balancing area;
- Diversity in distribution networks, different voltage levels with different characteristics such as load location (spatially concentrated with numerous reactive power sources in urban areas while dispersed, weakly connected and chronically underfed in rural areas) and different protection settings and control of network devices.

The location and technical characteristics of VAR-RES also affects the system requirements for grid support and involves locational/regional aspects.

- Location of VAR-RES: is it built in a strong or weak grid, what are the electrical distances of units to the DSO/TSO interface?[15]
- Dispersion of VAR-RES units: The degree of concentration/dispersion in locations of VAR-RES determines the impact of wind and solar PV on the total variability and predictability of VAR-RES in the system;
- Enhanced technical capabilities of VAR-RES, and operational strategies of VAR-RES in critical high-VAR-RES share hours. This is the central focus of REserviceS, and is addressed in detail in chapter five.

For frequency support services the main regional differences arise from the power system size, existing flexibility of non-VAR-RES generators, interconnectors and how they are used and operational practices like gate closure times.

For voltage support services the main regional differences are related to grid strength (short circuit levels and impedance), multiplicity of voltage levels, VAR-RES dispersion and distance to load, the difference between peak load and grid capacity, electrical distances to the DSO/TSO interface, observability/controllability of transformers (OLTC) and other grid components such as lines.

4.2.6 Methods of assessing system needs with VAR-RES are still evolving

TSOs traditionally used deterministic rules for managing uncertainty. Managing increasing amounts of VAR-RES requires new methods for handling uncertainty together with improved demand response. Probabilistic reserve allocation has been tested in Spain and Portugal alongside deterministic methods with the intention of gathering evidence to convince both TSOs and regulators that probabilistic tools provide the same level of system security. Assessing needs with stochastic tools and even having the potential to make stochastic bids is one of the long term options to integrate large shares of VAR-RES.

There should be a link between the requirements for generator capabilities and system needs. Ideally legislation and requirements should not demand more than needed by the system. In practice system operators define the need and design the requirements based on their experience of power system operation. But with the rise of variable, non-synchronous and decentralised generation, traditional approaches could lead to inefficiencies in the definition of requirements. TSOs and DSOs have to rely more on detailed studies that take the expected increasing shares of VAR-RES into account when estimating system needs.

4.3 Recommended key services from wind and solar PV

REserviceS identified the main categories of frequency support, voltage support and restoration services that can be provided by VAR-RES (see Table 1). Power systems with large shares of VAR-RES will probably also need other services than those in use today[16].

- Frequency control – services related to the short-term balance of power and frequency of the power system; it includes automatic (FCR/FRR) and manual (FRR/RR) frequency regulation and

13 Milligan et al, 2011
14 REserviceS D7.1 p.27
15 Abele, 2013
16 REserviceS also identified other services that can be provided by the system operator itself rendering them out of the scope of the project. For more details see REserviceS D7.1 p.35

TABLE 1: GRID SUPPORT SERVICES CATEGORIES RELEVANT FOR VAR-RES PROVISION OF SERVICES (RESERVICES D2.2) - THE LOWER SECTION OF THIS TABLE CONTAINS SERVICES THAT ARE NOT CURRENTLY USED

Frequency support services (Delivery time)	Voltage support services	System restoration
Frequency Containment Reserve (FCR) (5, 10 or 30 seconds)	**Normal operation:** control of power factor, reactive power or voltage control	**Black start**
Frequency Restoration Reserve (FRR) (<15 minutes)		
Replacement Reserve (RR) (15 minutes to hours)		
Fast frequency response (synthetic inertia) (<2 seconds)	**Operation during faults:** fast reactive current injection	**Islanding**
Ramping margin (1, 3 and 8 hours ahead)		

operational reserves. This is the main service provided by generators (online for automatic services and online or offline for longer term activated services). It can also be provided from flexible loads, and storage units.

- Voltage control – services required for maintaining the power system voltage within the prescribed bounds during normal operation and during disturbances by keeping the balance of generation and consumption of reactive power. Voltage control includes reactive power supply (injection or absorption) and can be provided by dynamic sources (generators, synchronous compensators) and static sources such as capacitor banks, static voltage controllers and Flexible AC transmission systems (FACTS) devices, including Unified Power Flow Controller as well as network equipment like tap-changing transformers in the substations and loads. In the event of a disturbance to the system, dynamic reactive power response is required to maintain system stability. Network reinforcements and reconfiguration will impact on the voltage control needed.
- System restoration – services required to return the power system to normal operation after a blackout; from the generator point of view it includes mainly black start and will in the future also include islanding operation.

Other possible services needed where functions provided by synchronous generators are no longer present in the power system. These include[17]:

- Mitigation of negative sequence voltages — in particular during unbalanced faults. Further research is needed to determine the requirements more precisely depending on power system characteristics. This may result in the definition of services (like negative sequence reactive current injection) to be locally provided;
- Damping of low-order harmonics that are normally short-circuited in the windings of synchronous generators. A possible service that could be provided by inverter based VAR-RES is active filtering, based on local power system needs;
- Damping of power system (inter-area) oscillations, traditionally performed by power system stabilisers (PSS) installed in synchronous generation. Further research is needed to assess the risk that these oscillations may change in the future (due to reduced rotating mass in the system and which frequency range a possible service by VAR-RES may tuned at).

4.4 High VAR-RES penetration issues at transmission and distribution level

REserviceS identified particular challenges for GSS with higher penetrations of VAR-RES. However, if VAR-RES provides these services itself, many of these challenges can be overcome. Possible solutions and benefits of using GSS by wind and solar PV are summarised in chapter six.

[17] Quitmann, 2013

4.4.1 Transmission level

At transmission level frequency control and balancing is more challenging with increased ramping needs when few non-VAR-RES generation sources are online. At higher VAR-RES penetration levels, provision of system inertia will be an issue for smaller islanded systems and possibly for medium size interconnected systems. Cross-border sharing of frequency support (and intraday trade) will help the balancing task (see section 4.6). However, the issues of fast response to frequency deviations and stability need more research.

For voltage control, the available amount and location of reactive power in the system will change and VAR-RES provision of voltage support can mitigate most issues.

During rare occurrences of system restoration, the issue is adequacy of black-start units in the system. VAR-RES could in principle contribute to the restoration process. However, this would probably be done after some generation units have started the restoration process (today mostly hydro generators, where available, are used to start the process). New processes limiting the variability inherent in their generation need to be created for VAR-RES to participate in system restoration.

4.4.2 Distribution level

Similarly, high levels of generation connected to distribution networks introduce complexity in the operation of the distribution system and could create voltage disturbance and grid congestion at times of high VAR-RES generation and low local demand. At the same time, reactive power control from VAR-RES can help compensate for losses or can increase the hosting capacity of the distribution network. Also, variability of power output leads to changing voltage profiles and needs closer control. To reduce line congestions, VAR-RES could be curtailed with optimisation algorithms and widespread use of dynamic line rating.

Moreover, high amounts of VAR-RES lead to diminishing fault current in the systems and can have a negative effect on the protection schemes (unintentional islanding). To mitigate this, modification or reconfiguration of protection systems is required. Finally, the uncertain and variable nature of the VAR-RES limits the reliability of supply during intended islanding of a distribution feeder when disturbance occurs at transmission level.

4.5 Interaction of needs and services at transmission and distribution level

An increase of VAR-RES means that generating capacity is increased in DSO networks and potentially decreased in TSO networks. Consequently, DSOs will start playing a bigger role in coordination of VAR-RES and voltage control. Hence, governance for DSO/TSO interaction to properly coordinate frequency and voltage support, as well as restoration services provided by VAR-RES, is needed.

Topics of importance include the organisation and coordination of data exchange between VAR-RES, DSOs and TSOs; clear responsibilities for frequency and voltage support not only in the presence of VAR-RES connected at distribution networks but also with FACTS; and demand side management is needed too. Such coordinated strategy should be reflected in Network Codes[18].

4.6 Cross-border issues of needs and services

VAR-RES affect the need for cross border trade of GSS, mainly for frequency related services because this trade can help in pooling scarce resources. Cross-border trade enables the provision of services to a larger market covering several countries and TSOs.

Cross border trading of frequency support is beneficial for system operation and it is recommended. With increasing shares of VAR-RES, the need for balancing resources increases. Cross border trade can help in two ways: by pooling-in more balancing resources and by reducing the total needs for services (reserve requirements). Cross border sharing of frequency reserves as well as trading in real-time balancing

[18] The increasing need for data transfer between TSO/DSO is for instance covered by new requirements described in the ENTSO-E operational security network code (ENTSO-E, 2012).

markets (FRR manual) already works in some places, like the Nordic market — even across two synchronous systems (West Denmark and the Nordic system).

For voltage support, there can be cross border issues during events, like the disappearance of reactive power due to network faults. Sharing voltage support cross border is not happening today. It is not considered necessary for the foreseeable future, and service provision is thus not recommended at this stage.

Nevertheless, the provision of voltage support in scenarios with increasing cross-border active power imports creates the need to produce reactive power locally due to the inconvenience of transporting reactive power over long distances. The future reduction of conventional power plants providing voltage support and the higher penetration of VAR-RES will create possibilities where renewable power plants would supply part of the required reactive power.

4.7 Specific needs regarding large scale offshore wind deployment

Large offshore wind power plants up to 500-1000 MW represent large amounts of concentrated generation, connected to few onshore nodes. There are limits to the share of frequency support coming from one network node (max 10%), so TSOs cannot rely on services coming only from offshore wind power plants.

For offshore wind, the choice of AC or DC connection has an impact on system needs. AC connected offshore wind plants can provide active power reserve and frequency response in the same manner as onshore AC wind plant projects, however there may be some issues related to providing services from a longer distance. Larger distance transmission brings higher losses and higher reactive power generated by the cable. Steady state voltage control (SSVC) can in general be solved by the onshore installations (e.g. FACTS). Fault current injected during/after network faults (FRCI) needs to be addressed separately.

4.8 Specific needs regarding distributed solar PV

Solar PV is different from other generation technologies because of its modularity. The range of applications starts from the small residential system connected at the low voltage level (a few kW) to large ground mounted installations connected at the high voltage level (a few hundred MW). The speed at which numerous PV systems can be installed as well as the voltage level at which they are connected creates new needs for the operation of power systems and the procurement of GSS.

When providing services, the electrical distance to the transmission grid has an effect on the performance of the service provided. In addition, the growth of small PV systems is sometimes faster in specific communities or regions, leading to an uneven overall distribution of installations in a country. At the distribution level, the spatial distribution should also be taken into account to avoid cost inefficiencies that could be due to a one-size-fits-all approach. Reverse power flows could occur toward upstream voltage levels, often accompanied by voltage rises. Using the control capabilities of modern solar PV inverters (active and reactive power control) for local voltage support can reduce the necessity of additional grid reinforcement measures. Currently, in addition to the conventional means of grid reinforcement, PV systems installed in Germany are required to support the local voltage by the provision of reactive power and active power curtailment.

The need for data exchange and control strategies changes completely, considering millions of units in comparison to the thousands of conventional non-VAR-RES units currently operating in the EU. To secure the network's stability, part of the generation capacity needs to be controllable. The increasing role of communication in power system operation also raises the question of cyber security.

4.9 Conclusions – system needs

This assessment of the system needs in European power systems focused on frequency support and voltage support as the main categories of grid support services that could be provided by wind and PV. Frequency and voltage control constitute several services with different response times. With high shares of VAR-RES new services will be needed to be provided by them — mainly faster responses — as well as services that were inherently provided by retreating synchronous generation. Generally the system requirements for these GSS will increase with high shares of VAR-RES. Enhanced frequency support in the system is observed especially for manually activated system reserves (<15 min) FRR. VAR-RES may increase the need for voltage support because online available reactive power sources, both steady state and dynamic, available to the system operator to manage network voltage will change. In any case, voltage profile management will become more complex with increasing shares of VAR-RES.

The needs for GSS with VAR-RES depend on the power system studied (for example its size and robustness), and how VAR-RES is built into the system (for example its dispersion, penetration levels and technical characteristics). As GSS come with a cost, ideally requirements for generator capabilities and service provision should demand only what is needed by the system. Preparing for future systems with large shares of VAR-RES thus requires studies and simulations on which to base the requirements. A barrier to a comprehensive assessment is the absence of a common methodology that includes VAR-RES in estimating system needs for services, as well as the limited information on the combined effects of wind and solar PV. Since the process used to assess system needs for GSS with VAR-RES is still evolving, new tools must be developed.

DSO/TSO interaction will be more important in the future with large shares of VAR-RES, and there will be an increasing role for DSOs in the transition process in electricity networks. Data exchange and ability to control the numerous small generation units should be organised. Governance over who is doing what needs to be established for coordinating frequency and voltage support, as well as restoration services.

© Acciona Energía

5 CAPABILITIES OF VAR-RES AS GRID SUPPORT SERVICE PROVIDERS

5.1 Introduction

This chapter deals with wind and solar PV capabilities to provide GSS in current and future VAR-RES dominated scenarios. It also outlines the technical and economic obstacles to VAR-RES playing an active role in supporting the power system.

5.2 Technical assessment of VAR-RES capabilities for service provision

5.2.1 Existing capabilities to provide frequency and voltage support

REserviceS found that the technical capabilities of wind and solar PV for the provision of GSS depend on the plant size and the extent of their output aggregation[19]. These two aspects were used as criteria for rating the degree of deployment of technical features enabling the provision of GSS by both technologies.

Also, technical capabilities were evaluated against industry standards, prequalification procedures, connection and operational requirements contained in grid codes[20] and the so-called European Network Codes. However, REserviceS found that these documents may not always contain technical requirements for GSS or may be inadequately defined.

The assessment of technical capabilities is shown in Table 2. The criteria and rating scale used is shown below the table. Table 2 also contains numerical references to further details described in Table 3.

TABLE 2: WIND AND SOLAR PV TECHNOLOGY CAPABILITIES FOR GSS PROVISION

			Wind System Size				Solar PV System Size					
			Wind Farm		Cluster		Small scale		Large scale		Portfolio	
		GSS	Tech. feat.	Rqmnts.	Tech. feat.	Rqmnts.	Tech. feat.	Rqmnts.	Tech. feat.	Rqmnts.	Tech. feat.	Rqmnts.
Frequency	FCR	Existing	green circle	red triangle 3	green circle	yellow triangle 8	red circle 10	red triangle 12	yellow circle 14	yellow triangle 12	green circle	yellow triangle 8
Frequency	FRR	Existing	green circle	red triangle 3	green circle	yellow triangle 8	red circle 10	red triangle 12	yellow circle 14	red triangle 12	green circle	yellow triangle 8
Frequency	RR	Existing	green circle	red triangle 3	green circle	yellow triangle 8	red circle 10	red triangle 12	yellow circle 14	red triangle 12	green circle	yellow triangle 8
Frequency	FFR	New	yellow circle 1	yellow triangle 4	yellow circle 7	red triangle 9	red circle 10	yellow triangle 4	green circle	yellow triangle 4	yellow circle 15	red triangle 9
Frequency	RM	New	green circle	red triangle 5	green circle	red triangle 9	red circle 10	red triangle 12	green circle	red triangle 12	green circle	red triangle 9
Voltage	SSVC	Existing	green circle	green triangle	green circle	red triangle 9	green circle	green triangle	green circle	green triangle	green circle	red triangle 9
Voltage	FRCI	New	yellow circle 2	yellow triangle 6	green circle	red triangle 9	yellow circle 11	red triangle 13	green circle	yellow triangle 6	green circle	red triangle 9

LEGEND

Tech. feat. (Technical features enabling provision of services)	Rqmnts. (Requirements in grid codes, standards, prequalification procedures and Network Codes)
green circle: Implemented	green triangle: Well defined requirements/specifications in most procedures at European level.
yellow circle: Partially implemented/implementable/low cost or investment to enable the required capabilities.	yellow triangle: Poorly defined requirements/specifications or not addressed in most of the procedures.
red circle: Not implemented/high cost to implement	red triangle: Not defined/not possible due to requirements in all or most Procedures.
pink box: Existing GSS	light green box: New GSS

[19] The aggregation of multiple local wind power plants (WPP) jointly managed is usually referred as a cluster; the same aggregations of PV plants are referred to as a portfolio.

[20] Grid codes in the EU differ regarding content and requirements for the VG, connected to the DS. A general overview of technical requirements regarding grid support services in the national grid codes, the overview of the practical issues and solutions with the integration of distributed renewable generation and the GSS provision seen from the DSO perspective, has been investigated in the INCREASE project.

TABLE 3: EXPLANATIONS AND REFERENCES FOR TABLE 2

Ref	Service(s)	Tech	Rationale and further references
1	FFR	Wind	Discrepancy of wind turbine capabilities, lack of standardisation and unclear possible contribution. Uncertainty of impact on design loading and fatigue impact on wind turbine. No uniform reliable solution for detection of fast frequency deviations.
2	FRCI	Wind	Not yet considered as GSS. Depending on Type 3/Type 4 control and detection methods to be improved[21]. Provision of negative sequence support to be improved[22].
3	FCR, FRR, RR	Wind	Capabilities clearly defined in grid codes. Most countries in Europe (except DK) do not allow provision due to lack of specific pre-qualification procedures (uncertainty in availability of primary source).
4	FFR	Wind	Unclear or missing definition of specific behaviour in most grid codes.
5	RM	Wind & PV	Service proposal in Ireland[23].
6	FRCI	Wind	Capability not properly defined in grid codes[24].
8	FCR, FRR, RR	Wind	The ENTSO-E Network Code for Energy Balancing mentions the "reserve providing group"[25] as the group or aggregation of units that can provide balancing services. However, at national level, limitations imposed at power plant level to provide GSS (e.g. in national GC or ENTSO-E's RfG) will not allow such aggregation.
9	FFR, RM, SSVC, FRCI	Wind	Absence of specification for aggregation of power plants to provide such services. Some experience at research level performed by the Spanish TSO.
10	FCR, FFR, RR, FRR, RM	PV	The required communication system, sensor installation and control software implementation to manage small PV residential installations are a challenge in terms of costs. For all mentioned services besides FRR the availability of accurate forecasts is still an issue. For FRR and FCR improved frequency measurement techniques are required[26].
11	FRCI	PV	Very fast controlled response is a challenge for the converters, which would require improved control strategies. Also it is mandatory to recognize fault types for unbalanced faults by improving sensing and control[27].
12	FCR, FRR, RR, RM	PV	TSO requirements for Delta Active Power Control are unclear[28]. Communication standards between DSOs, TSOs and PV systems to enable these services are absent[29].
13	FRCI	PV	Lacking specification of number of FRT occurrences in Grid codes[30]. Grid codes do not define the detection procedure[31].
14	FCR, FRR, RR	PV	Active Gradient and Delta Active Power Control modes are not fully developed and need further software development. Communication between the PV plants and DSOs/TSOs must be improved to provide those services[32].
15	FRCI	PV	Faster communication methods are required[33].

5.2.2 Existing capabilities for system restoration support (SRS) from VAR-RES

5.2.2.1 Wind plant capabilities to provide system restoration support

Islanding network operation is similar to the operation in a small power system with low system inertia and low short circuit ratio (SCR) at the point of connection (POC). Generally modern wind turbines (Type 3 and 4)[34] have successfully proved that they can operate reliably under such conditions. They can be connected at locations that would not allow the stable connection of a thermal plant with a synchronous generator of a similar size. Furthermore, wind turbines can change their active power output very quickly over a wide range and operate continuously at a low minimum generation level, typically exceeding the capabilities of larger thermal plants. Reactive power can also be provided in a dynamic way, especially from Type 3 and 4 wind turbines or additional WPP-components on electric balance of plant (eBOP)-level (e.g. STATCOMs). These WPP features are desirable and even necessary capabilities in the context of SRS.

21 REserviceS D3.1, p.36-38
22 REserviceS D3.1, p.38-39
23 Delivering a Secure Sustainable Electricity System (DS3) Study by EirGrid and SONI in Ireland [D2.2, p.21; D2.1].
24 REserviceS D3.1, p.38, 63
25 REserviceS D3.1, p.27
26 REserviceS D4.1, p.81-83
27 REserviceS D4.1, p.41-42
28 REserviceS D4.1, p.28
29 REserviceS D4.1, p.34
30 REserviceS D4.1, p.83
31 REserviceS D4.1, p.42
32 REserviceS D4.1, p.82
33 REserviceS D4.1, p.34
34 For a description of conversion concepts, please refer to REserviceS D3.1, p.12-13

5.2.2.2 Solar PV capabilities to provide system restoration support

The PV industry has long experience with standalone and island systems as solar PV power was first used as a source of electricity for remote locations. Commercial products are available for island systems up to a few hundred kW. For these islands systems, small inverters (up to 10 kW) are clustered and act as a voltage source. The control is fast enough to ensure the stability of an island system and it starts without batteries or a diesel generator. Currently some demo projects are exploring the same principles in the MW range[35]. These projects are relying on other components such as flywheels to operate the system. Pure inverter based concepts for island systems in the MW range need further development. The capabilities used in large island systems could serve as a basis of capabilities for the provision of SRS by solar PV plants.

5.2.3 Recent technical developments of capabilities for system services

During the industry consultation for defining technical capabilities for GSS provision, the REserviceS consortium encountered some technical developments that, while out of the scope of the services defined for wind and solar PV, are relevant for future GSS provision or enhanced capabilities to existing services. These include 'negative sequence fast fault current' provision from Type 3 wind turbines and the integration of battery energy storage systems (BESS) in wind turbines and PV systems. Further analysis is recommended through research projects. A brief description can be found in the REserviceS synthesis report[36].

5.3 Power system impact of services provided by VAR-RES

5.3.1 Frequency Control

Simulations performed in the REServiceS case studies[37] found that the main impacts in power systems with VAR-RES offering frequency support are related to the speed of response, the ramping capabilities and the amount of frequency response needed.

In particular, for FCR, the critical impact is in the delay of the response at the plant and cluster or portfolio level. If not mitigated this could result in unstable frequency responses. To provide a faster response, the frequency detection should take place at the turbine, or enhancements to existing communications are needed. Alternatively new control algorithms could be developed, that would moderate the response in relation to system inertia and to units under FCR. In DC-connected wind power plants (for example in future offshore grids) the frequency has to be detected on the AC side and the signal has to be communicated to the turbines through other means.

The precise impact on the ramping duty at a point in time will depend on the level of wind and PV generation but also on the time horizon considered. Higher ramping capabilities are likely to be required as the time horizon extends, due to increase in potential forecast error[38]. However, the characteristics of the cluster or portfolio will have a greater impact on the ramping capability of the system[39]. Simulations of REserviceS with a simple load frequency model have shown that, for FCR, it is not always necessary for FCR, it is not necessary that all VAR-RES participate in frequency support[40].

5.3.2 Voltage Control

Impacts on voltage control can be significant if VAR-RES do not offer voltage support services. At high instantaneous SNSP levels (in excess of 60%) transient stability of generators connected at the transmission network can be compromised. In the absence of mitigation strategies, reactive support would be insufficient to maintain the security of the power system. At distribution level, VAR-RES can increase bus voltages beyond statutory limits due to uncontrolled active power injections and the current practice of controlling them using the same voltage set-points.

35 Marble bar project, ABB, 2013
36 REServiceS D7.1
37 REserviceS D5.1 to D5.5
38 REserviceS D5.1
39 REserviceS D5.1, p.13
40 REserviceS D5.3

REserviceS case studies analysed how new voltage control techniques could solve these issues. Benefits were observed in enabling DSOs to utilise SSVC to actively manage their networks[41]. Local control strategies are efficient up to a certain level of VAR-RES connected[42]. Central control strategies are necessary when local voltage control does not fulfil control criteria[43] or when global benefits are considered. Centrally coordinated control of SSVC services from PV plants in the MV grid can significantly reduce the reactive power flows at the DSO/TSO interface point (HV/MV substation). This is more efficient (and less costly) than fixing reactive power flow requirements with additional devices at this interface. However, central control cannot always prevent an overrun of the reactive power values outside the PQ-bands.

Voltage support from VAR-RES clusters connected to the transmission network has demonstrated reductions in voltage deviation[44,45]. This leads to less curtailment due to voltage-related aspects and lowers overall system costs.

There are significant efficiencies to be gained from a small increase in the dynamic reactive power response from VAR-RES compared to the installation of alternative solutions (e.g. capacitor banks, FACTs, synchronous compensators, etc.). Enhancing dynamic voltage support during disturbances is required to increase system transient robustness in high instantaneous VAR-RES penetration levels. Improving the response from VAR-RES units could mitigate some, if not all, of the issues.

However, there are strong dependencies attributed to network topology, impedance (R/X ratio), and load/generation distribution and location. The electrical distance of the VAR-RES plant to the DSO/TSO interface is important for how it can provide useful voltage support[46]. The following needs to be considered:

- From TSOs: target values for the reactive power exchange;
- From DSOs: VAR-RES units with short electrical distance to the TS, and suitable controller and ICT infrastructure;
- Appropriate oversizing of the VAR-RES inverter so that the required reactive power can be supplied even under maximum active power injection from the respective renewable source.

5.3.3 Provision of GSS with offshore wind plants

In the case of AC offshore networks, wind power capabilities to provide frequency and voltage support are similar to onshore networks. Cable length due to distances and the required reactive power compensation are issues that can be managed, up to a certain distance. Here, the concentration of VAR-RES in a single or few connection points becomes an issue due to the variability of the source.

DC-connected wind plants impose new challenges to the system because:

- Large amounts of frequency-decoupled and concentrated power require fast communication infrastructure to remotely measure and allocate set points to provide frequency support;
- Unplanned interactions between converters on weak grids with low available short circuit power.

Nevertheless, the onshore VSC-HVDC station can provide voltage support services regardless of the offshore wind condition and GSS can be augmented by aggregating multiple offshore wind plants or clusters of wind plants[47]. In such cases limitations are imposed by the converter stations onshore.

The case studies show that the factors affecting the capability of offshore wind power to provide GSS are: the selected offshore grid technology, the grid topology and the operational procedures enabling a more efficient utilisation of the offshore wind plant.

The selected offshore grid technology sets out how a specific service can be provided:

- For frequency support, sophisticated communication is required between the offshore AC grid and the HVDC link to shore for measuring frequency and to

41 REserviceS D6.2 p.72
42 REserviceS D6.2
43 CENELEC standard EN50160
44 Arlaban et al. in Voltage control by multiple wind power plants: field test results, reviewed within REserviceS D5.3
45 Twenties. D9.2, 2013
46 Abele, 2013
47 REserviceS D5.2, p.37

provide the required support;

- for voltage support in HVAC grids, this can be provided by the wind turbine and/or other equipment (e.g. FACTS) as in onshore installations;
- In HVDC grids, voltage support can be provided by the converter stations onshore independently from generators.

5.3.4 Impact of aggregation and short term forecasting on GSS provision

Accurate forecasts are key to the cost-efficient provision of GSS with VAR-RES since the availability of wind and sun changes stochastically. It is important to recognise the need for different types of forecasts for different kinds of GSS. The most important time horizons for GSS are the short- and shortest-term forecasts (from day-ahead to minute scale). Medium-term forecasts are required to plan the operation of the grid at seasonal, week or for few days in advance, and only partly relevant for GSS.

A further reduction in the uncertainty can be achieved by using probabilistic forecasting reaching confidence intervals similar to non-VAR-RES power plants. Therefore, the use of probabilistic forecasts — together with pre-qualification methods adapted to the characteristics of wind and PV power — is an essential enabler for the efficient participation of VAR-RES in GSS provision.

The forecast accuracy depends on numerous parameters, such as local climate, forecast horizon and whether forecasts apply to a single point or cover a wide geographic area. Forecast is the determining factor for the costs of reserve provision. REserviceS analysis showed[48] that an individual solar PV system located in the Benelux countries would lose 60% of its annual production by offering day-ahead upward reserve for all days of the year with current forecast techniques. These losses could be reduced to 26% if the service is offered by a portfolio spread over an area of the size of the Benelux thanks to reduced forecast error. This demonstrates the importance of forecasting as enabler of GSS provision by PV.

Furthermore, probabilistic or ensemble forecasting could form the basis of GSS provision and other novel approaches for VAR-RES dominated system operation such as probabilistic unit commitment.

5.4 Techno-economic assessment of service provision (generator level)

5.4.1 Comparing costs of providing GSS with wind and solar PV

Table 4 provides an overview of the additional costs involved in enabling different services by VAR-RES technology and by system size and challenges to implementation. This additional cost assessment is based on the REserviceS analysis[49] backed up by industry interviews. The service costs are split into capability costs, readiness costs and provision costs. The colour scheme depicts the technical difficulty and associated costs for the provision of a service (or set of services). Green indicates that a service could already be provided at low additional cost, yellow indicates a moderate additional cost.

For frequency support services the readiness of upward reserve is quantified as the loss of generation that otherwise would be available, when the generators were not providing services.

To correctly interpret the aggregation column it is necessary to keep in mind that:

- Communication costs for aggregation are additional costs to those needed to enable the services at WF or PV plant level;
- CAPEX-related costs regarding frequency support are considered as a fraction of the WF costs or PV plant;
- Lost energy calculation considered on the upward readiness item is similar to WF, but the energy loss is lower due to the aggregation and the lower forecast error[50] (between 8-10% for WF and between 4-6% for clusters/aggregations);
- For SSVC costs considered at aggregation level extra communication equipment is needed to coordinate the compensation at plant level.

[48] REserviceS D4.1, p.68
[49] Reservices D3.1 and D4.1
[50] REserviceS D3.1, p.56

Table 4 shows that — in terms of costs — the provision of all mentioned services with wind or solar PV is feasible. Additional investment costs range from 1% to 5%; the impact of the current relative costs for the required communication and sensing components is only high in small PV systems.

Readiness to provide upward reserves from VAR-RES necessitates that it is dispatched down from what is available. The corresponding financial loss depends on the actual market value of generation. VAR-RES will be used for upward reserves only when market prices are relatively low and therefore this cost is likely to be low.

TABLE 4: COMPARING COSTS FOR PROVIDING GSS WITH WIND AND PV

			Wind System Size		PV System Size		
			Wind Farm	Cluster	Small scale	Large scale	Aggregation
Communication costs to all services below			€	€	€ to €€	€	€
Freq. Support	Technical Challenge		🟢	🟢	🟡	🟢	🟢
	Investment[51]		Minor costs, mainly communication costs				
	Readiness	Upward	€€ to €€€€€	€ to €€€€	€€€€€	€€€€€	€€€ to €€€€
		Downward	-	-	-	-	-
	Provision		-	-	-	-	-
Voltage Support	SVC	Technical Challenge	🟢	🟢	🟢	🟢	🟢
		Investment[52]	€ to €€	€ to €€	€	€	€
		Readiness	-	-	-	-	-
		Provision	-	-	€	€	€
	FRCI	Technical Challenge	🟢	🟢	🟡	🟢	🟢
		Investment[53]	<€	n/a	<€€	-	n/a
		Readiness	-	-	-	-	-
		Provision	-	-	-	-	-

LEGEND			
	€€€€€	>20%	of the system CAPEX for investments lost electricity share on the overall production
	€€€€	<20%	
	€€€	-10%	
	€€	-5%	
	€	-1%	
	-	insignificant	
	n/a	not applicable	
	🟢	no technical challenges	
	🟡	technically challenging	
	🔴	not feasible	

51 Additional investment costs to enable the provision of GSS, as considered in REserviceS D3.1, p. 54-59 and D4.1, p.70-80
52 Idem
53 Idem

5.5 Challenges for enhancing capabilities and solutions

5.5.1 Enhanced frequency and voltage support with VAR-RES: challenges and solutions

Challenges that significantly impact the cost of the provision of frequency and voltage support with wind and solar PV have been compiled from industry survey and stakeholder discussions. These have been reported in detail in the project deliverables[54]. Summaries of challenges and possible mitigation actions (addressed to specific stakeholders in parenthesis) are presented in the tables 5-12.

TABLE 5: WIND: COMMUNICATION SYSTEMS RELATED TO GSS

Challenges	Possible Migitation
Faster remote controls for a plant and to change set-points, particularly for clusters	Implementation of faster communication technologies (OEM/DEV/SO)
Lack of clear & complete technical specifications for communication systems	Improve technical specifications (Grid Codes) (SO)
Diversity of existing technical specifications	Development of International standards (OEM/DEV/SO)

TABLE 6: WIND: FREQUENCY SUPPORT SERVICE CAPABILITIES GSS, IN GENERAL

Challenges	Possible Migitation
Providing the service in a cost-effective way	• Implementing forecasts (OEM/DEV/SO) • Reduce LCOE (OEM/DEV/SO) • Implementation/use of storage (OEM/DEV/R&D/SO)
Limited forecast accuracy	• Improved forecast methods (OEM/DEV/R&D) • Adopt market rules and operational schemes to available forecast performances. • Implementation/use of storage (OEM/DEV/R&D)
Need for wind turbine redesign & recertification Lack of design feedback on operation beyond certified ranges	Including providing GSS as design load case in the certification process (OEM/REG)
Limitations of wind turbine control and actuation systems	New control strategies/systems required (OEM/R&D)
Unclear TSO requirements for Delta ΔP[55]	Improve specifications taking into account RES technology characteristics (OEM/R&D/SO)
Insufficient TSO/DSO coordination	TSO/DSO governance must be clarified considering DG

[54] See REserviceS D3.1 and D4.1
[55] Refer to "Active Power Delta Control Mode" in REserviceS D3.1, p.18

TABLE 7: WIND: SPECIFIC ISSUES FOR CAPABILITIES FOR FREQUENCY SERVICES FCR, FRR, RR, RM

Challenges	Migitation actions
Decrease uncertainty of investment costs related to FCR impact on the components' life-time	• Make structural design adaptations (OEM/R&D) • Develop improved wind turbine controls (OEM) • Add storage devices (OEM/R&D/SO)
Measuring the frequency with sufficient high resolution	• Improvements on measuring techniques (R&D/OEM) • Improved specification (OEM/R&D/SO)
Deal with need for higher rating of auxiliary electrical/ electronic systems	• Clear definition of the TSO regarding the need and requirements (SO). • Implement the existing technology accordingly (OEM)
Not all large wind turbine types are capable of providing fast ramping	Improved wind turbine design methods (OEM/R&D)
Unstable controls at high penetration levels & very low system inertia	• Improve controller structures to avoid inherent instabilities (OEM/R&D) • Minimise delay times by speeding up communications (OEM) • Adaptive controller (settings) (OEM/R&D)
Increased wind turbine loading at low and high power (specifically for FRR)	Control and design adaptations (OEM)
Improve accuracy of short term forecast (specifically for RM)	Implement advanced forecast techniques (probabilistic, ensemble) to improve accuracy (R&D/SO)

TABLE 8: WIND: FREQUENCY SUPPORT SERVICES FAST FREQUENCY RESPONSE (FFR)

Challenges	Migitation actions
• Deal with increased wind turbine wear and tear due to more frequent actuation of blade pitch systems • Uncertainty of impact on design loading/Fatigue impact on wind turbine • Increased wind turbine mechanical loading at high ramp rates	• Improved specifications of requirements in grid codes to enable accurate load cases definition (SO) • Develop and implement improved frequency measurement method (OEM) • Design loads and structural design adaptations (OEM) • Clear definition of FFR by TSO (SO)
Enhanced loading of wind turbine electrical subsystems	Enhanced dimensioning of electrical equipment (OEM)
Quantify the interaction with power system	System studies (SO/R&D)
Reliable detection of df/dt: accurate measuring and producing reference signal	Develop clear definition of FFR by TSO (SO) Develop and implement improved frequency measurement method (OEM)
Limited availability of the FFR functionality from manufacturers	Develop clear definition of FFR by TSO (SO)
Additional investment costs due to re-certification	Implement appropriate cost recovery mechanisms

TABLE 9: WIND: VOLTAGE CONTROL SERVICES

	Challenges	Migitation
SSVC	• Deal with high reactive power requirements for dimensioning of inverter. • Deal with design limitations of the inverter	• Oversizing of electrical equipment, especially at MV level (OEM/DEV) • Control improvements are required (OEM) • Use external devices (reactors, synchronous condensers, STATCOMS) (DEV)
SSVC	Enhanced mechanical loading at idling level when providing high Q for prolonged time	Redesign (structural, mechanical) of wind turbine (OEM)
SSVC	Lacking requirements for negative sequence current provision	• System studies (SO) • mprovement of grid code requirements (SO) • Development of WT control methods (OEM)
SSVC	• Parallel operation of plants in voltage control mode/ Voltage stability, avoiding hunting phenomena and oscillations • Availability of wind turbines in the market with capability to provide SSVC/PQ without external additional equipment	• Clear definition and justification of the Grid Code requirements (SO) • Control strategies (OEM)
SSVC	Dealing with uncertainty about control behavior of wind turbine outside+/-5% of U rated	Design of auxiliary equipment for over and under-voltages (OEM)
FRCI	• Improved control on Type 4 wind turbines. • Very fast controlled response (Short rise times) • Recognise fault type for unbalanced faults • Complexity of FCRI according TSO specs with actual technology	• Sub-cycle rise times require complete new design/ Improve sensing and control • Develop tuning methods for controllers • Improve simulation methods and models

TABLE 10: SERVICES WITH SOLAR PV: COMMUNICATION HARDWARE AND CONTROLS

	Challenges	Migitation
Communication Hardware	• For FRR, RR, RM, fast communication hardware is needed for remote control of the system and to change set-points • FCR, FFR and FRCI, SSVC is commonly an automatic response; however set-point changes could improve the behavior and might be needed. The communication software for rather rare set-point changes for the automatic response might however be less costly • The communication hardware can be a significant cost factor in particular for smaller systems (% of CAPEX) • Cyber security is an important challenge and could be a cost driver • The lack of communication standards for small generators and portfolios can be a cost driver • Communication with TSO needs to be clarified. International standards would be useful • Better TSO-DSO coordination is needed	• The main cost driver is the hardware for communication infrastructure. To reduce costs the following solutions are needed: – *Development/adoption of improved communication methods* – *Design of control systems and reliable communications between PV system controller and single inverters* – *Communication with TSO/obtaining set-points from TSO* – *Communication standards between DSOs, TSOs and PV systems/portfolios*
Control Software	• Control software needs to be developed when larger portfolios need to be operated as a “swarm” to provide one service in particular FRR, RR or RM	• Standards for portfolio controls and interfaces for several entities (TSO/DSO/markets participants/ manufacturer/operator) can bring down the costs

TABLE 11: SOLAR PV: FREQUENCY SUPPORT SERVICES

	Challenges	Migitation
FRC	• Hardware: – *For small household systems temperature and irradiation sensors would be needed to calculate the available power. This is technically no challenge but relatively high costs compared to the system size* – *For larger systems, measurement equipment has in general already on site* – *Improved frequency measurements* • Software development for active gradient and delta control modes: – *Unclear TSO requirements for Delta P (especially regarding the availability and accuracy of Delta P)*	• The costs for sensor installation and software developments need to be taken into account, but they are comparatively low • Better Delta P requirement definitions are needed
FRR and RR	• Idem FCR: Sensor hardware • Better power forecast or alternative proof methods can reduce the costs of lost power significantly. In particular intraday large improvements can be made: snow forecasting, cloud movement forecasting etc. Non-scheduled based proof methods could avoid high power losses • Market designs that favour conventional generation or do not allow aggregated bids from portfolios can largely increase the costs	• Develop PV portfolio control strategies and software taking into account forecasts with confidence intervals • Market design adaptations that allows biddings by portfolios including PV
RM	• Power production forecast accuracy. In particular adapted evaluation tools for forecast accuracy for different time resolutions are needed	• R&D in forecasting
FFR	• An additional battery bank can provide this service. Costs would however be high • Alternatively the system is run down-regulated at all times. In this case there are high costs of lost power	• Significant cost reductions for storage solutions could reduce the costs for this service. The cost of FFR provision will anyway be reduced by the decrease of PV LCOE

TABLE 12: SOLAR PV: VOLTAGE SUPPORT SERVICES

	Challenges	Migitation
SSVC	• High reactive power requirements might require inverter oversizing, which however has a limited cost impact (10% cost increase oversizing, is 1% cost increase on system level) • For night-time reactive power design changes are needed • Higher power losses for large scale systems • Need for reactive power provision is unclear. The value could be increased by cross-voltage level provision	• Before night-time reactive power is requested the effectiveness should be evaluated and compared to the costs • Design changes will be medium costs. As an additional service is provided that is of value for the TSO/DSO (see first bullet) some compensation for night-time reactive power provision should be considered • TSO-DSO coordination
FRCI	• New hardware and firmware developments needed for roof-top and commercial (up to 3% of the system costs). For large system a STATCOM might be a solution if the inverters are far away from the PCC • Software development for unbalanced fault recognition • Lacking specification of number of FRT occurrences	• Apart from improvement of sensing and control no addition a cost mitigation measures can be taken • The grid code requirements for FRCI need to be clarified

5.5.2 System Restoration Support with VAR-RES: technical challenges and solutions

Wind turbines and solar PV systems are not specifically designed for islanding network operation, nor participation in black start, although some useful features are present (see section 5.2.2). Until now system restoration support from VAR-RES has remained largely unexplored. Detailed requirements and technical specifications are almost absent in grid codes and standards[56].

Any analysis regarding the technical capabilities of WPPs or PV systems to deliver SRS should start from the stochastic, hence neither controllable nor fully predictable nature of the wind or solar irradiation as the prime mover. In a critical situation of a blackout the reliability of supply — in terms of capability to unconditionally deliver the service — is of great importance. This needs sufficient information about the wind and solar conditions. By integrating storage into wind turbines or WPP and solar PV systems the predictably and reliability of power production can be drastically increased, which would strongly improve the participation in SRS. Assuming that there is sufficient wind or sun to start up, there are additional physical limitations, described below.

5.5.2.1 Islanding network operation

Robustness against wide and fast frequency and voltage variations and stable operation at low short circuit ratios can become challenging and current technological capabilities would need to be enhanced. This may require changes in the controls and/or even resizing wind turbines and solar PV systems. Synchronisation and re-connection with other islanded networks or with the remaining power system has to be possible, too. This requires a function on WF or PV system level to receive information about the voltage in different network areas and to send commands to the WTs or the PV systems to alter the voltage or frequency to allow resynchronisation. During the entire process a signal interface to the system operator has to be maintained to interrupt and change the procedure at any time, to guarantee a restoration.

5.5.2.2 Islanding WPP/PV system operation

Wind turbines are not currently designed as a standalone source of power supply to serve loads. Wind turbines synchronise themselves onto the "external" voltage of the power system at their POC. However, modern wind turbines comprising self-commutated semi-conductor switches (Type 3 or 4) are in principle able to generate their "own" symmetrical three-phase voltage system and act more like a voltage source. Putting this capability in place would require major changes in their control systems. But most of the required technical capabilities are feasible in modern wind turbines. Frequency control can become a challenge as wind and load may vary significantly. Energy storage could mitigate this challenge. An extreme scenario would be a trip to house load that would require the wind turbine operating at a very low loading level. Further research could establish whether trip to house load will bring significant benefits to system restoration.

For solar PV, full-inverter based concepts for island operation are commonly used in small power systems up to a few hundred kW, sometimes even without batteries. Commercial products exist for island systems up to a few MW (such as mines) but in that case PV inverters have to be complemented by other devices such as flywheels and/or diesel generators to ensure the safe operation of the island system. The possibility of upscaling a full inverter based concept to a MW range system and the hybrid concept (flywheels/genset/PV) to a few hundred MW needs further development.

5.5.2.3 Black Start

Black start capabilities are based on the ability to operate in islanding WPP/PV system. In order to black start a WPP or a PV system, it needs a reliable power source to supply all necessary auxiliaries including, in the case of wind, DC links to generate a three-phase voltage. Batteries in wind turbines or at WPP level or a diesel generator on WPP level could be used as a reliable source of auxiliary power for such a SRS. In a critical grid situation like a blackout, the reliability of supply is of great importance. Therefore, reliable participation of wind or PV power in the restoration process, at least as one of the main suppliers of the service, needs much further investigation. A suggested approach for wind or PV power is not to constitute the first line of restoration by providing black start capability, but to contribute in later stages of the restoration process (Islanding Network Operation), when there are already other generators running.

[56] ENTSO-E, 2012

5.6 Conclusions - capabilities

Systematic investigation of wind power and solar PV technology, confirms that they are technically capable to provide grid support services for frequency, voltage and system restoration assuming an adequate procedural and economic framework is present. The technical operational functions required are either state of the art capabilities of the existing hardware or measures that can be implemented at a reasonable cost. The feasibility of providing services by enhanced plant capabilities is confirmed by TSOs, for example in Spain where voltage control by wind power plants on the specific transmission nodes leads to a significant improvement with fast response. The German/Spanish case studies within REserviceS demonstrate that letting the DSO use GSS from VAR-RES generation connected to its own system contributes to cost-efficient voltage management. Participation of VAR-RES in system restoration has not been considered until now. Certain required functionalities are available but their implementation in specific restoration strategies needs further investigation.

For wind power potential technical enhancements for frequency and voltage support services include: faster and reliable communication (e.g. between wind farms and system operators' control rooms), dedicated control tuned for delivering the required performances, estimation of available power/forecasting. Structural, mechanical and electrical design changes in wind turbines need to be made to accommodate the changes in mechanical load spectrum involved with grid service 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. GSS can be augmented by aggregating multiple offshore wind plants or clusters of wind plants. Regional coordination of offshore wind plants that provide 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 GSS regardless of the offshore wind condition. Technical standards and Network Codes currently in preparation are important enablers of offshore wind GSS.

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.

Better and faster communication systems together with more accurate forecast systems are essential for both wind and solar PV technologies to offer GSS. In general, aggregation of multiple VAR-RES power plants is desirable because this improves performance when providing a service and reduces implementation costs. Also for both wind and solar PV, control strategies should be improved to obtain the maximum power performance and flexibility from VAR-RES. In this case, the precondition is to have clear and well-defined requirements and procedures to integrate wind and solar PV as GSS providers. Poorly defined or non-existent technical specifications in grid codes or pre-qualification procedures that allow VAR-RES to provide GSS constitute a significant barrier that needs to be overcome. This is exacerbated by the lack of standardisation and harmonisation of procedures across Europe. A clear GSS roadmap should be established well in advance describing the required capabilities and services along with a set of pre-qualification and procurement methods that pay proper attention to the characteristics of the sources.

Implementing enhanced capabilities will involve additional investment, and the deployment of the services will also involve costs. 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. Only for small PV systems the impact of required communication components will result in high additional CAPEX costs. In general, both for wind and PV, OPEX costs — notably upward readiness costs — represent the highest costs required to make frequency services available.


© Acciona Energía

6 ECONOMIC BENEFITS OF VAR-RES BASED SERVICES

6.1 Introduction

This chapter describes the economic benefits of providing frequency and voltage support services with VAR-RES, as investigated in the case studies of REserviceS. It will also consider other options to provide the same services that were not necessarily investigated in the project. The purpose and geographical scope of the case studies can be found in the synthesis report[57].

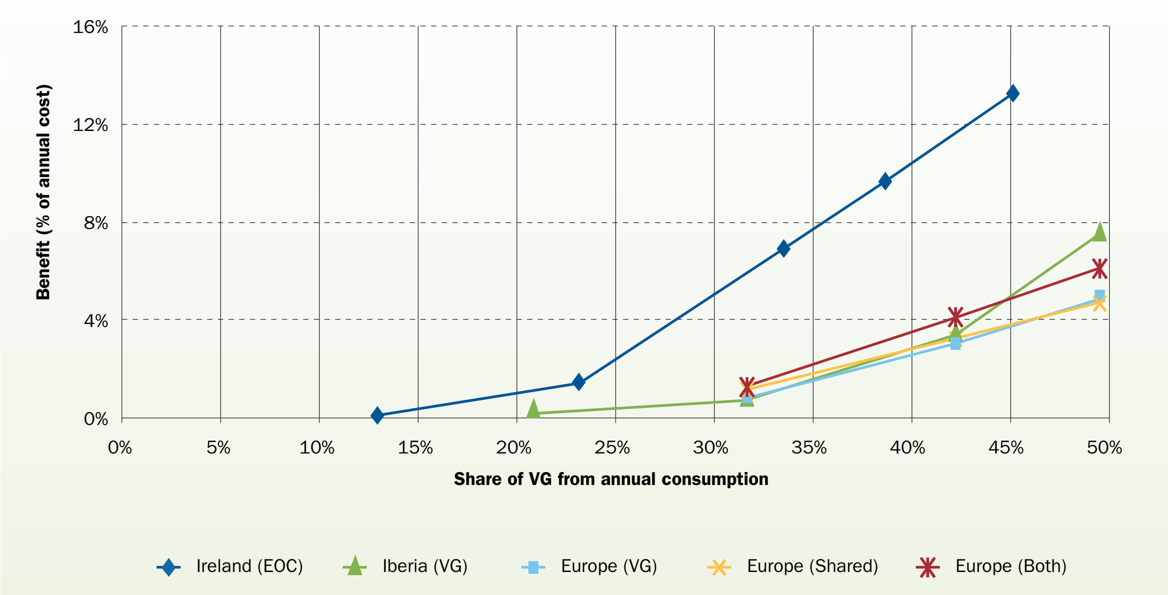
The benefits are calculated by comparing annual power system operation costs[58] in cases both with and without GSS provision by VAR-RES. These annualised benefits are then compared to the annualised investments needed to create the capability in VAR-RES plants to achieve those operational cost reductions. Hence, the cost-benefit comparisons in this section are between the capability costs and operational benefits (cost reductions).

6.2 VAR-RES in frequency support

6.2.1 Cost-benefit of using VAR-RES in frequency support

The Irish, Iberian and European case studies all showed clear benefits from wind/solar PV system services in the scenarios with higher shares of wind/solar PV. Figure 2 shows the annual benefits (reduction of total operating costs) from these studies. While the results from the different case studies are not directly comparable, the figure demonstrates clear benefits at higher penetration levels. In the Irish base case wind power is curtailed to stay below SNSP of 50% at all times and in the Irish enhanced case (EOC) to stay below 75%[59]. This difference yields considerable benefits at higher penetration levels. The Iberian and European case studies have lower benefits, but they do not contain a limit to SNSP like the Irish case. The benefits are only due to VAR-RES replacing conventional generation in the frequency reserves FCR and automatic FRR. The European case study also demonstrated that the benefits of VAR-RES participation were similar to the benefits of sharing frequency support across borders. Combining VAR-RES participation and cross-border sharing increased the benefits to some extent.

FIGURE 2: THE BENEFIT (OPERATIONAL COST REDUCTION) OF VAR-RES IN FREQUENCY SUPPORT IN THE DIFFERENT CASE STUDIES. FOR EUROPE THE BENEFIT OF CROSS-BORDER SHARING OF FREQUENCY SUPPORT IS PRESENTED



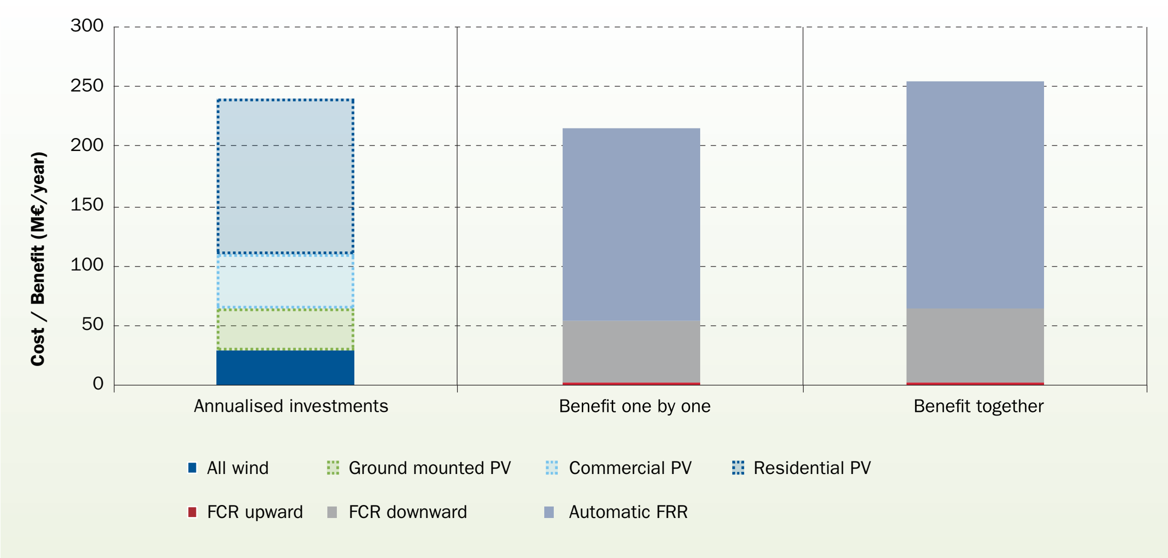
Source: Ireland: EOC Enhanced Operating Capability has all variable generation with enhanced AS

57 REserviceS D7.1

58 Operational costs include fuel costs and other variable operation and maintenance costs. Unit start-up costs and restrictions, piecewise linear part-load efficiencies as well as wear and tear costs due to cycling are included. At transmission level losses are estimated endogenously and at distribution level the losses are included in the electricity demand.

59 Eirgrid, SONI and SEMO, 2012

FIGURE 3: ANNUALISED INVESTMENT COST TO PROVIDE FREQUENCY RESERVES VS. ANNUAL OPERATIONAL COST REDUCTIONS (BENEFITS) FROM RESERVES IN THE VAR-RES42 SCENARIO



In Figure 3 the annual operational cost reductions are compared to the annualised investments required to make all new variable generators capable of frequency support. The scenario is from the Iberian case with variable generation producing 42% of the total generation. The left bar shows the estimated investment costs to enable the participation of all VAR-RES assets in the reserves provision. The middle bar shows the benefits when each of the reserve categories are assessed separately and added together afterwards. The far right bar shows a case where VAR-RES has been able to participate in all reserves in the same model run. The difference between the middle and far right bars indicates that there are co-benefits when VAR-RES is participating in all frequency support services at once. In both cases, the benefits outweigh the annualised investment costs of wind power and lower cost PV categories. Due to small unit size, residential PV currently costs more, especially per installed MW. This is not a cost effective source of frequency reserves.

6.2.2 Cross-border sharing vs. VAR-RES in frequency support

The REserviceS European transmission case study also investigated the benefits of sharing frequency support services across country borders. The results showed that the benefits of VAR-RES in frequency support are similar to the benefits of cross-border sharing of frequency support (Figure 2). Sharing was allowed to the extent proposed in the new ENTSO-E Network Code for load frequency control (ENTSO-E 2013). The benefits of VAR-RES were slightly better than the benefits of sharing, as the VAR-RES penetration increased. Utilising both at the same time created some additional benefits — especially at higher penetration levels.

6.2.3 Other options for frequency support

Frequency can be supported by means other than power plants. Some of these options may be more cost effective than utilising VAR-RES, overall or in specific circumstances, but they were not studied in the REserviceS project. Other options include:

- Demand response;
- Lowering the minimum load capability of thermal plants;
- Storage systems that are quick to respond or have an inertial mass
  - Flywheels: transferring the rotational kinetic energy stored in rotating masses into electricity
  - Batteries: change of charge/discharge.

The cost-benefit of VAR-RES should be compared to all these options and can be a topic for further studies.

6.3 Cost benefit of VAR-RES in voltage support

Voltage control from variable generation requires additional CAPEX cost and results in some operational costs. On the other hand, VAR-RES voltage support may create benefits that outweigh the costs, as shown in some of the case studies. However, many of the items can be currently difficult to amortise for wind power/PV operators, especially when it comes to dynamic voltage or frequency support from VAR-RES for example, the P droop function required to mitigate the '50.2Hz risk'. Furthermore, operational impacts are case specific and require detailed analysis. More information about investment and operational costs as well as possible benefits, can be found in the synthesis report[60].

When a CBA is performed, a system approach must be adopted in order to consider global costs and cost allocation among participants. Moreover, external benefits and costs may be important when assessing the suitability of different solutions. The best solution is not the same everywhere and may change as the system changes. More flexible planning taking different options into account would be beneficial.

6.3.1 Cost-benefit of using VAR-RES to support voltage at high voltage levels

The REserviceS cases studies have shown that current wind turbine technology can provide suitable voltage control services, within its design limits and capability range. However, the literature on cost/benefits of utilising VAR-RES to control transmission level voltage is sparse[61].

Importantly, the Irish case study presented a comparison between 2010 (real) and 2020 (simulated) scenarios of available reactive power within the grid. As a result, 'enhanced operation capability' enabled wind generation to exhibit a favourable, almost 25% lower cost structure when remunerated per capability compared to other providers of the Dynamic Reactive Power service. When remunerated dispatch-dependent it exhibits on-par costs. Annual payments are shown in Table 13 for each €1m spent on GSS, normalised to installed capacity (i.e. € per MW installed).

TABLE 13: ILLUSTRATIVE ANNUAL GSS PAYMENTS (PER MW INSTALLED), FOR DYNAMIC REACTIVE POWER SERVICE BY PROVIDER TYPE

Dynamic Reactive Power	Enhanced wind power plant	CCGT	OCGT	Coal	Pumped storage
Capability (€/MW installed)	15	20	20	20	22
Dispatch-Dependent (€/MW installed)	27	29	2	29	26

Source: Eirgrid 2012

6.3.2 Cost-benefit of using VAR-RES to support voltage at low/medium voltage levels

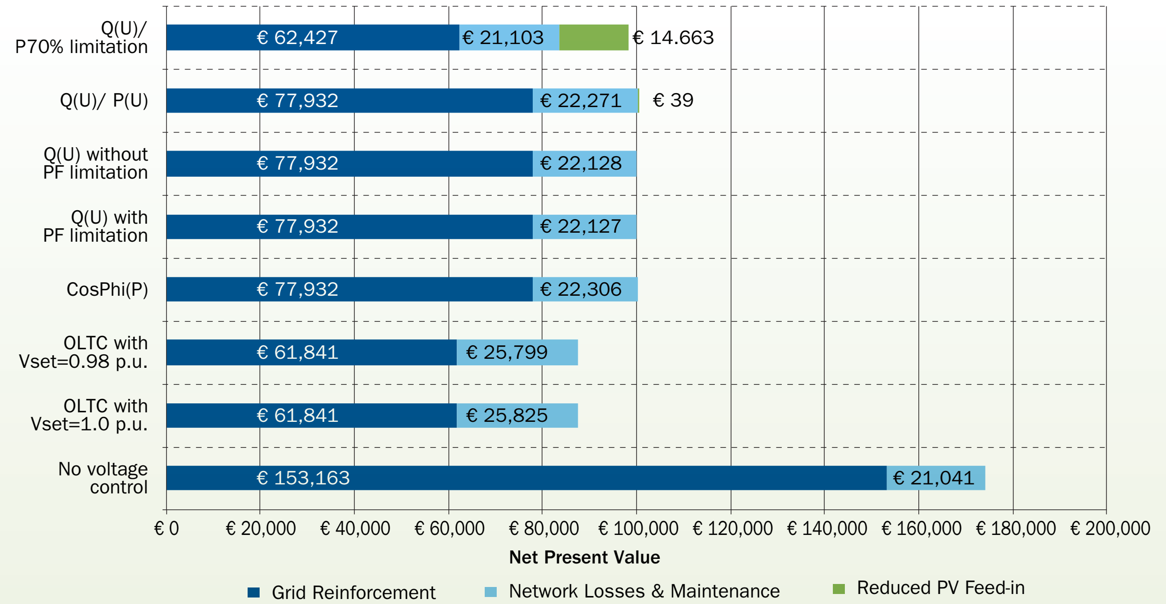
The provision of voltage support by reactive power consumption/production from distributed generation is helpful to maintain the voltage profile within acceptable limits, regardless of how the reactive power is absorbed or generated (e.g. using statcoms, automatic power regulators, etc.). Consequently, the hosting capacity of the distribution network can be increased without jeopardising the security and quality of the system.

Applying autonomous voltage control strategies at LV level by setting the operation points of solar PV inverters as well as the OLTC of MV/LV transformer could significantly mitigate the voltage raises caused by high solar PV feed-in and hence improve the steady state voltage stability. The investment costs for grid reinforcements can be substantially decreased by using such solar PV based GSS. This local control approach does not require any ICT infrastructure, which makes it more suitable for the application in LV grids with numerous solar PV systems. The operational costs for the DSO, however, might be slightly increased by applying these control approaches (grid losses, maintenance). Exemplary results confirming the above are shown in Figure 4.

60 REserviceS D7.1

61 See REserviceS D7.1 for examples related to the case studies

FIGURE 4: TOTAL NET PRESENT VALUE OF INVESTIGATED LOCAL CONTROL STRATEGIES FOR AN LV FEEDER IN SOUTH OF GERMANY



Source: D6.2

Another strategy would be to provide reactive power compensation with VAR-RES in order to decrease the line losses, by keeping the load power factor as close as possible to one. However, in that case the increase of hosting capacity would be limited. Thus the DSO has to make a choice between increasing the hosting capacity and optimising losses.

Because of its strong dependency on the case characteristics, the effectiveness of voltage control from wind and solar energy must be assessed on a case-by-case basis. Numerical results depend on characteristic impedance, network topology, and load/generation distribution and location. The CBAs in REserviceS case studies show that the implementation of advanced voltage control techniques provided by VAR-RES can benefit the electrical system by:

- Increasing the grid hosting capacity for higher shares of VAR-RES;
- Reducing the risk of VAR-RES curtailment;
- Reducing the operation costs and grid reinforcement costs;
- Reducing network losses and reverse power flows as well as improving quality of power supply;
- Enabling further applications linked to the implementation of a bi-directional communication network and enabling the participation of VAR-RES in ensuring grid stability and reliability and power supply, by providing GSS like voltage and frequency control.

6.3.3 Other options for voltage management

This section compares the costs and benefits of voltage management by VAR-RES with other, mainly network-based, options.

The Irish DS3 programme (Eirgrid 2012, REservices D5.1) evaluated two alternatives to enable the operation of the system at 75% SNSP instead of 50% SNSP. Both scenarios were designed to resolve the four fundamental challenges identified: inertia/RoCoF, ramping, reactive power and transient stability. The investigation focused on a scenario with enhanced capabilities from generators including wind power, but also contained an alternative network investment scenario. The network investment scenario was deemed to be a more costly alternative (€1206 m) in comparison to the enhanced generator capabilities scenario (€535 m). The cost assumptions for this analysis are given in Table 14 and Figure 5.

TABLE 14: TOTAL CAPITAL COSTS FOR ENHANCED GENERATION AND NETWORK INVESTMENT SCENARIOS

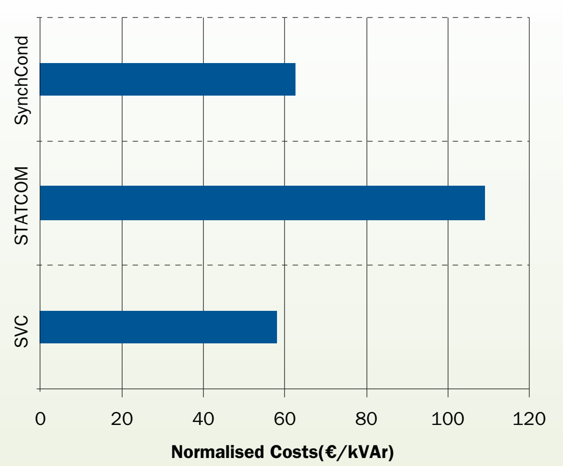
Enhanced generation scenario	Capital Cost (€/MW or €/MVAr)	Volume (MW or MVAr)	Total cost
Enhanced Wind (inremental cost)	€139,000	1300	€181m
Enhanced New CCGT	€30,000	450	€14m
Improve Existing CCGTs	€122,000	2000	€244m
Enhanced OCGT (incremental cost)	€74,000	400	€30m
Sync Comp conversion	€63,000	200	€13m
STATCOM (total cost)	€109,000	500	€55m
TOTAL			€535m

Network investment scenario	Capital Cost (€/MW or €/MVAr)	Volume (MW or MVAr)	Total cost
Synch Comp/Flywheel	€766,000	840	€643m
Enhanced OCGTs - Strategic Reserve	€724,000	400	€320m
Batteries	€829,000	0	
STATCOM	€109,000	2,500	€303m
TOTAL			€1.206m

Source: DNV KEMA 2012

Table 14 demonstrates how the extent of availability of different options can be case specific (e.g. upgradable existing CCGTs, possibilities for converting retiring units to synchronous compensators). Furthermore, the need for steady state voltage control (SSVC) and fast reactive current injection (FRCI) is localised as the penetration levels of VAR-RES develop unevenly and the strength of the existing grid varies.

FIGURE 5: NORMALISED COSTS OF ALTERNATIVE VOLTAGE MANAGEMENT SCHEMES[62,63]



6.4 Cost-benefit of using VAR-RES for system restoration

The cost-effectiveness of services by VAR-RES for participating in system restoration has not been investigated in REserviceS. Irrespective of the technical capabilities to be developed and functionalities to be deployed during a system restoration event, the issue of unavailability of the primary resource for VAR-RES dominates the technical and economic discussion. A key issue for further research is how to design cost-effective system restoration strategies for scenarios with very high shares of VAR-RES.

- Large-scale participation of VAR-RES in system restoration is unlikely without involvement of energy storage installed in/nearby the participating VAR-RES plants;
- During the restoration sequence, different small island 'local' networks need to re-synchronise and for this purpose the appropriate system stabilising capability needs to be present in the participating VAR-RES plant.

[62] Willem, 2013
[63] Miroslav, 2013

Both aspects involve additional CAPEX to VAR-RES plants. These costs as well as potential benefits for system operators and plant operators are likely to be case specific. Ongoing research projects will provide more insights into this.

6.5 The excessive cost of requiring capabilities from all generators

The capability to provide either frequency or voltage support from variable generation comes at a cost. Therefore, it is important to assess whether the expenditure is justifiable in all cases. In the end, electricity consumers will pay the bill and a reasonable balance has to be struck between adequacy, stability, power quality and costs.

In the Iberian case with 42% of annual energy from VAR-RES (scenario VAR-RES42) the frequency response remained adequate when only 25% of wind power participated in the frequency reserve. At the same time the economic benefits were unchanged. The current cost of equipping all wind generation with frequency response capabilities is shown in Figure 3. According to the model results, only a fraction of those investments would be needed. The cost of equipping solar PV is even higher mainly due to the smaller size of the systems. There is a large difference in equipping PV with frequency response capabilities depending on the size category (roof-top, commercial and utility-scale). According to the model results, while the frequency response when solar PV is participating in the FCR is somewhat better (smaller frequency excursion), solar PV is not needed to maintain frequency. These results are current estimates and they are bound to change as experience and technology matures. The frequency response model was simple and as such not capable of capturing all aspects related to frequency and no aspects related to voltage.

It is more difficult to assess whether uniform voltage support capabilities should be required from all VAR-RES. As the REserviceS case studies analysing voltage control demonstrated, the costs and benefits are case specific. The case studies demonstrate that voltage control capabilities from all VAR-RES generators are unlikely to always be the best choice. An across the board requirement may lead to excessive costs.

6.6 Conclusions – economic benefits

The REserviceS simulations of power systems of various sizes across Europe and increasing share of VAR-RES (up to 50%) show that it is beneficial to use variable generation in frequency reserves and that these system benefits increase with the share of variable generation. The benefits were calculated by comparing the overall operational costs of power generation with and without using VAR-RES for frequency support. The greatest benefits are observed in the downward FCR and in the automatic FRR. In the simulations the benefits for the system operator are higher than the cost of equipping all VAR-RES with the capability to participate in frequency support, especially for wind power plants with their lower CAPEX costs (per MW) than residential PV. In the system simulations not all VAR-RES needed to participate in frequency support in order to achieve the economic benefits. In a sensitivity analysis the frequency response and its corresponding economic benefits remain adequate with 25% of the VAR-RES participating in frequency support services. Thus it should be sufficient to only equip part of VAR-RES with capability for FCR and automatic FRR services. 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 utilised.

The REserviceS case studies analysing different MV/LV networks with different VAR-RES shares conclude that the cost/benefit ratio of voltage support from VAR-RES is case specific and that provision of voltage support by VAR-RES should be compared with alternatives. Since there will be many locations where individual decisions need to be made about the source of voltage support, universal and robust methods are needed, to make the assessment with reproducible and comparable results.

7 MARKET CONCEPTS (COMMERCIAL FRAMEWORKS)

7.1 Introduction

This chapter addresses possible market concepts and other commercial frameworks for an efficient deployment of GSS in systems with high shares of VAR-RES. It assumes that the roll-out of GSS markets is acknowledged by policy makers as a building block of a truly integrated Internal Energy Market in the EU, going beyond the present integration approach of merely day-ahead power trading and, instead, capturing a larger portion of electricity-related commodities. Consequently, the discussion aims to provide answers to the following questions:

- Is a market based system to be preferred or are there other options that allow for a least cost service provision?
- What general market designs are possible?
- Are solar PV and wind already offering services in some markets and how was this realised?
- What are the main barriers for VAR-RES to offer their services? Can simple changes be made to surmount these or are more complex design adaptations necessary?
- Are market based mechanisms a possible option for services provided for distribution system operation?

7.2 The electricity market – interface to reservices

In this chapter the term electricity market is used whenever markets are used for the procurement of electricity services (reactive and active power both upward and downward) irrespective of whether they are traded on the spot market as a standard product, over the counter in bilateral agreements or as balancing power to the system operator. A detailed description of main market design features across the EU including different products and timeframes can be found in the synthesis report.

Generally, self and central dispatch electricity markets can be distinguished as the two major categories for power market design in the EU Member States[64]. Most markets in Europe are self-dispatch markets. Central dispatch can be found in Ireland, Italy, Slovakia, Latvia, Poland and Greece. Since the choice between self-dispatch or central dispatch models are closely linked to the level of intervention by a TSO needed to guarantee system stability, it has important consequences for balancing and related GSS market design. However, this chapter focuses on self-dispatch electricity markets as this is the predominant market model in the EU. The target model is also based on this principle.

7.2.1 Differences in self-dispatch market types

Balancing market arrangements differ substantially on self-dispatch markets as TSOs have different approaches to leaving balancing responsibility to market mechanisms[65]. In general, the more TSOs incentivise market players to take part in the overall balancing processes (which is more the case where a resilient grid is in place), the better VAR-RES can participate in this kind of market. Balancing actions undertaken by TSOs consist mostly in the activation of fast reserves, with short activation periods that are closer to real-time, so that renewables can still react to potential forecast errors. By this means, TSOs aim to incentivise market players to restore the balance of their perimeter even in real-time.

In contrast, where TSOs take over the balancing responsibility from the market in an early stage (e.g. one hour before delivery time), reserves are often contracted further ahead by the TSO and are held available for any moment. Under this approach, TSOs are performing imbalance forecasts and try to anticipate important imbalances by activating slow balancing energy products, which by definition are less suitable for VAR-RES participation.

7.2.2 Markets for reactive power for voltage support

In view of appropriate market designs for reactive power procurement, the following differences between active and reactive power should be highlighted:

- Reactive power should be supplied close to the point of demand. Otherwise the effect is limited and on the way to the point of demand, reactive power congests the power lines limiting the capacity to transport active power. In particular the possibilities to provide reactive power from lower voltage level to higher voltage levels are limited;
- The demand for reactive power is relatively low

---

[64] See REserviceS D7.1 for more detail on these market forms

[65] See REserviceS D7.1 for more information

compared to the demand for active power in a power system. Some generators can offer reactive power at very low cost.

These factors limit the number of possible offers for reactive power demand. Also, the costs of implementing trading platforms of standard reactive power products and the trading transaction costs might not be justified by the traded volume.

On the other hand, the need for reactive power and the need to diversify reactive power sources grows with the increased penetration of renewables, as the market share of conventional power plants (which traditionally delivered reactive power) steadily decreases. Thus, reactive power is often either required as a mandatory service by the TSO or is tendered longer term by the TSO, typically on an annual basis.

7.2.3 Grid support services market in Europe in monetary terms

GSS represent a small part of today's market for generators in terms of revenue. The international comparison of GSS conducted in Ireland in the context of the DS3 programme estimated that in today's European markets on average GSS payments represent less than 5% — often between 2-3% — of the total revenues earned by electricity producers from energy-only markets. An exception is Spain where the annual cost of system services in 2010 was €593.8m, representing 10.8% of total revenues in the national electricity market.

A more detailed overview of different GSS market revenue is presented in the synthesis report. Overall, the comparison shows that commercial provision of GSS could play an increasing role as alternative market-based revenue streams for all generators, in particular in view of lower average spot market prices on energy-only markets (due to increasing penetration levels of low marginal cost VAR-RES). GSS revenues could help ensure investors' interest in power generation assets and help tackle any potential generation gap in power systems in a more market-based fashion. This is in contrast to the increasing number of capacity remuneration mechanisms across the EU.

7.3 Identification of best practices in different countries

REserviceS case studies and research identified good practice and market rules that facilitate the provision of GSS from wind and solar PV[66].

7.3.1 Frequency support services

Based on REserviceS analysis, market design mechanisms for frequency support services should allow for the following:

- Market-based remunerated provision: Present TSO requirements for different frequency support services, differing in activation time, length of provision, accuracy, etc. indicate the need for arrangements that ensure that services are provided cost-efficiently. A mandatory provision across all generators would mean that all assets may not be utilised efficiently at all times;
- Clear technical requirements, prequalification procedures and procurement rules: Detailed and clear specifications are crucial for the participation of wind and solar PV in GSS provision;
- Procurement gate closure times close to delivery: A short time lapse between the gate closure and the delivery of frequency support is crucial to allow for cost-effective participation by wind and solar PV. The longer the time between procurement and delivery, the more room for forecast errors;
- Split of bids between upward and downward frequency support provision: Symmetrical products require both upward and downward power bids to be provided simultaneously. Asymmetrical products allow upward and downward bids to be offered separately. For VAR-RES, demand response, but also CHPs, it is often crucial to have the choice to either offer upward or downward demand. Having this option would allow participation of VAR-RES in reserves which in turn can reduce the overall need to curtail VAR-RES;
- Aggregation of bids and offers: Some balancing products in some markets can only be offered with single unit commitment. Allowing offers from a portfolio of aggregated units not only delivers more flexibility to the providing parties, but also allows for the aggregation of very small units for relatively large offers. Aggregated offers also reduce variability and forecast

[66] See REserviceS D7.1 for a more detailed overview of the country specific examples.

errors from VAR-RES, hence increase firmness of products;
- Cross-border exchange of services: There is already experience of cross border trade of services in the balancing market (FRR manual) from the Nordic Regulating Power market. This exchange of services allows for greater geographical areas to be clustered, reducing the need for frequency support services by sharing resources across borders.

7.3.2 Voltage support services

In terms of market arrangements voltage support services differ fundamentally from frequency support services. The only market based arrangements for reactive power service considered so far are auction systems in which the long-term provision of reactive power is tendered. Sometimes there are fixed reimbursements for reactive power provision for all generators. Often, however, reactive power support is a mandatory and non-reimbursed service, irrespective of the location where the support is needed, and within certain reactive power set-points[67]. This causes investment costs potentially to be stranded, as the power system might not need that amount of reactive power. The main reasons for these differences are:

- Voltage support services are needed locally and the quality of the service depends on the (grid-) distance of the providing power plant. Therefore the number of potential bidders would be limited and the creation of standard products is difficult;
- The costs for voltage support services are significantly lower than the costs for flexible active power provision, which reduces the interest for both the providing and the requesting party to integrate the provision in a market-base process.

REserviceS identified the following as best practices for voltage support services:

- Remunerated service provision: In only a few countries analysed this practice is applied through a combination of full market-based tender processes and bilateral arrangements between generators, especially above certain capacity threshold (e.g. >100MW in GB), and TSOs. In most countries this service is mandatory without remuneration;
- Remuneration based on capability and utilisation: In order to get the most cost-efficient services from VAR-RES, TSOs should recognise that the provision of voltage support is a combination of capability and utilisation[68,69];
- Absorption or injection of reactive power differentiation: Voltage support from generators is location specific, hence their capability and provision of voltage support either through injection or absorption of reactive power shall be distinguished (e.g. France);
- DSO participation in the provision of services: In France, the TSO operates compensation devices and in some cases reactors on its own network. Compensation devices are connected on the MV bus bars of primary substations. They are operated by the DSO within an agreement with the TSO with only the first one considered a GSS and subject to payment. In the case studies analysed by REserviceS at distribution level in Spain and Germany, active participation of DSOs in managing voltage services in coordination with TSOs resulted in more efficient and less costly power system operation;
- Aggregation and coordination of units for voltage support services: Power systems allowing for aggregation of VAR-RES and coordinated approaches for voltage support by reactive power consumption or absorption, yield clear benefits to system operation (such as reducing power losses or increasing DG hosting capacity). Control can be coordinated locally by the DSO up to a certain penetration rate.

7.4 Key market design/product adaptations to offer on GSS markets

7.4.1 Suitable product characteristics for frequency support services

The main aspects for a frequency support product provided by VAR-RES are the following.

7.4.1.1 Contracting time

The contracting time before delivery of reserved products for frequency support needs to be shortened: tenders on daily or even shorter basis.

[67] Strbac et al, 2005
[68] See REserviceS D7.1 for country specific remuneration examples
[69] http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=28894

As there is a gate closure time for day-ahead and intraday trading, the procurement of reserve power products needs to be fixed at a certain point in time before delivery. The TSO needs this time buffer as a safety margin if the offer for reserve products is not sufficiently high and to allow for planning the operation of the reserve products once these are contracted. This time buffer is very different for the different "standard" products of FFR, FCR, FRR and in the different balancing zones depending on the technical situation, the need for demand, the communication hardware in place etc. Often the FCR is contracted with a far longer lead time as the technical pre-qualification requirements are significantly higher (often annual tendering), while in some regions manual FRR/RR is procured on a daily or even more regular basis.

For the participation of VAR-RES in frequency support, smaller portfolios and a frequent tendering for shorter time frames is favourable. The uncertainty of VAR-RES influences how much can be offered and uncertainty decreases with shorter time horizons. Therefore tenders on a daily or even shorter basis are a prerequisite for their participation.

7.4.1.2 Time for service provision availability

The time for service provision availability should be small: preferably one hour or less.

Frequency support products are often requested in the form of a fixed band for relatively long time periods. In some markets and for some products (typically FFR) the products need to be kept ready for delivery during one year at any time. As output from VAR-RES varies, it can offer bids only when the time frame is sufficiently short.

The general recommendation is to reduce the product length significantly. For the automatically activated reserves, FCR and FRR, procuring part of the services with shorter markets, as in Nordic countries today, is one option to open up the possibility for VAR-RES.

7.4.1.3 Separate upward and downward reserve products

For technical or economic reasons some plants and loads are either operated at maximum available power/load or are switched off/disconnected. This is also the case for most renewable energy sources. As CAPEX intensive technologies, plants are operated at the maximum available power.

Other plants are either switched off or operated at full power and can therefore only provide upward or downward but not both services. For example, a heat driven CHP plant usually runs at full power for heat production or is maintained at minimum load in order to avoid shutting down for a short period. During certain hours it can therefore only provide downward reserve and during others only upward reserve.

While some plants can be flexibly operated upward and downward as they can be run economically at partial load, other plants and consumption only can provide flexibility in one direction — either upward or downward — e.g. as technical requirements or other connected processes request operation at full load or zero load operation.

7.4.1.4 Allowing portfolio offers

Allowing offers by portfolios of wind and PV (and/or other generation and demand) facilitates offers by PV and wind for the following reasons:

- Single PV systems and wind farms are often too small to allow offers above the minimum bid size;
- The forecast accuracy for larger and wide spread portfolios can be significantly higher and both the bidder and the contracting TSO would benefit;
- Larger portfolios allow benefits from economy of scale.

7.4.1.5 Reducing the minimum bid size

For various products on the different national balancing markets the minimum bid size was historically designed for large central generation in order to limit the market settlement effort, the contracting effort, the control effort, etc. At the same time high minimum bid sizes often exclude renewables but also demand flexibility from those participating in these markets.

7.4.1.6 Confidence intervals for availability considerations

Reserve power contracting is often based on the idea that the reserve power needs to be available with 100% probability. This ignores the fact that conventional power plants have unplanned outage probability and therefore conventional power cannot offer reserve power with 100% certainty. For weather dependent renewables it is evident that future production has to be based on weather predictions and that the actual production might divert from the forecast.

If renewables are supposed to participate in balancing markets, the balancing products must be contracted taking into account potential unavailability. TSOs therefore should investigate how far e.g. the concept of confidence intervals for future production can be integrated into reserve power contracting.

7.4.1.7 Implementing a reactive market design

As described above, it might be valuable to evaluate implementing a reactive market approach that allows real-time balancing of the BRPs perimeters. Flexibilities of VAR-RES can then be used by the BRP manager if they prove to be most cost-efficient. This would also reduce the need for reserve power for balancing by the TSO.

7.4.2 Suitable product characteristics for voltage support services

Voltage support services are, like any other GSS, valuable to the power system operator and incur costs for the power plant operator. They should ideally be reimbursed with a fee fixed by a competitive process, irrespective of whether this is organised in a regular bidding process or an auctioning arrangement, whether the contracting is for short time horizons like days to months, or for longer time horizons up to several years.

A non-remunerated mandatory band as part of the grid code requirements could be complemented with payment for additional support to grid operation, provided such costs are recognised by the regulator and recoverable by the DSO.

A tendering or auctioning process could be an option for remunerating voltage support services when:

- The need for reactive power is analysed and studied by system operators and a forecast for future locational needs is established;
- Based on the investigation, a tender for reactive power within a certain perimeter is published or an auctioning system is started to receive the lowest cost reactive power provision;
- The best offer (or best offers) is awarded with a fixed reimbursement for the reactive power provided to the system and a minimum off-take guarantee to ensure investment security.

As VAR-RES development is supported by policies that are increasingly incentivising power systems' integration, an alternative could be to require voltage support by the grid code and to compensate the cost directly through support policies. To avoid tendering or an auctioning process with just a few market participants, a flexible regulatory framework should be established allowing DSOs to compensate VAR-RES systems directly through a fee or indirectly through lower connection or network tariffs. This would cover the additional capital costs and additional losses due to the reactive power provision.

7.4.3 Procurement models enabling TSO/DSO coordination of GSS

To enable the provision of GSS by VAR-RES, a multi-level procurement process should be defined involving TSOs and DSOs, and generators connected to their networks. On the one hand, the participation of VAR-RES in a GSS market — run by the TSO — could violate constraints in the distribution grid. On the other hand, by solving local issues (congestion or voltage management) with GSS provided by VAR-RES, DSOs' actions could affect the transmission grid operation. Given the complexity of coordinating each task, a definition of the supervision and control actions is necessary and a clear hierarchy of functions between TSO and DSOs has to be established[70].

7.5 Conclusions – market concepts

In today's energy-only market, dominated by synchronous generation, the contribution of GSS in the system costs and revenues to generators is very low compared to energy and capacity payments. Incentives designed to encourage VAR-RES to provide GSS should be put in place since it is clear that VAR-RES can provide GSS and decrease the operational costs of the power system. Currently, only a few markets (e.g. Ireland, Great Britain)

[70] Delfanti et al, 2014

provide arrangements for enhanced services where VAR-RES are incentivised to participate. In future systems with high shares of VAR-RES GSS will increase, even if it remains a small part of total system costs and revenues.

Not all generators in a system need to provide GSS to ensure safe system operation. Thus a mandatory request for GSS may not be cost-efficient. Market based remuneration on the other hand stimulates cost reduction and incentivises the provision by plants offering the cheapest services, irrespective of whether these are renewable or conventional plants.

Detailed and clear specifications are crucial for the participation of wind and solar PV in GSS provision. Without these, market participation and procurement of such services is limited to incumbent generators with long term contracts already in place. Requirements should be defined in close cooperation between the network operators and VAR-RES industry via consultation, as in Ireland.

To enable the provision of GSS by VG, a multi-level procurement process should be defined involving TSOs and DSOs, and generators connected to their networks. On the one hand, the participation of VG in a grid support services market - run by the TSO - could lead to violate constraints in the distribution grid. On the other hand, by solving local issues (congestion or voltage management) with GSS provided by VG, DSOs' actions could have repercussive effects on the transmission grid operation. Given the complexity of coordinating each tasks, a hierarchical definition of the supervision and control actions is necessary and a clear hierarchy of functions between TSO and DSOs has to be established.

In order to enable full utilisation of the capabilities of VG for the provision of GSS, the design of markets and products should be adapted to take into account the characteristics of VG. Characteristics of 'service' products such as separation of bids up from downwards, inclusion of confidence intervals and aggregated bids and offers are fundamental for allowing wind and solar PV to participate cost-effectively in grid support services provision.

- As a first step, TSOs should allow a certain amount of balancing power to be offered with a confidence tag stating the probability of the offered power;
- For small systems or for small portfolios of VAR-RES, the minimum bid size is key to a decision to enter the market. Although low minimum bid sizes have the downside for the TSO that non-automated management of the portfolio of small bids can be highly complex, their advantage is that the increased competition may reduce procurement costs;
- The time elapsed between the gate closure and the delivery of frequency support is critical to allow for wind and PV cost-effective participation, and should be as short as possible. The longer the time between procurement and delivery the more scope for forecast errors and the less opportunity for VAR-RES to take part in the provision of services at reasonable costs;
- The 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, as VAR-RES are constrained in offering to the reserve market due to weather dependency, for example at night and/or at too low or too high wind. Future production can only be predicted with an accuracy that decreases with increasing forecast horizon, resulting in actual production deviating from forecast;
- All products should be split into upward and downward products. PV and wind would be able to offer downward reserves at relatively low costs. Other flexible resources and demand in the power system would benefit from such product design;
- In order to enable cost-efficient offers with high certainty, solar PV and wind need to be allowed to offer reserve products from aggregated portfolios of several PV and wind plants spread across wider areas. The general allowance to offer reserve products with portfolios would significantly facilitate the participation of renewables and reduce system costs;
- It might be useful to evaluate a reactive market approach that allows 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 most cost-efficient. This would also reduce the need for reserve power for balancing by the TSO.

Provision of voltage support services creates costs for the VAR-RES. Therefore these services should be remunerated. There are several possibilities for doing so, e.g. a regular bidding process, auctioning arrangement or contracting for short or long time horizons. An alternative is to require voltage support in grid connection arrangements and to compensate the cost directly through support policies.


© EWEA

8 KNOWLEDGE GAPS AND FURTHER RESEARCH

8.1 Introduction

This chapter identifies knowledge gaps and future R&D needs based on the issues presented in the previous chapters, supplemented by literature sources[71]. Identified knowledge gaps were compared to a survey amongst project partners and the REserviceS Advisory Board.

8.2 Knowledge gaps

8.2.1 System needs for GSS

TSOs regularly assess the system needs for GSS. With power systems shifting towards high penetration levels of VAR-RES, the tools and methodologies used in assessing the system (operator) needs for services require adaptation. Methodologies need to be devised to account for the impact of uncertainty associated with VAR-RES relating to system needs, as well as development of new tools and strategies for the operation of systems with such uncertainties.

The combined effects of wind and solar PV in terms of GSS needs more investigation. Possible new services (see synthesis report) and their impact on the power system need to be investigated in order to develop methods and models that can capture different operational time scales. For example, models focusing on electromechanical dynamics (20 ms to 30s), focusing on system balancing (5 min to 24h), focusing on frequency quality for services such as FCR and FRR (seconds to minutes), for power systems with high variability. This requirement is highlighted in the ENTSO-E R&D Roadmap (R&D roadmap milestones 7 and 8).

Another area where gaps were identified is in enhancing the TSO/DSO interaction. Several issues stand out:

- Increased observability of the distribution systems for transmission network management;
- Grid support services provided through DSO and aggregators;
- Demonstration of power load control mechanisms at TSO and DSO levels;
- Improved defence and restoration plans;
- Integration of demand side management at DSO level into TSO operation;
- Mandatory requirements versus remunerated services? R&D is needed to determine suitable assessment methods at DSO level.

8.2.2 Technology

8.2.2.1 Wind

Wind turbines are designed for specific load cases, as prescribed in international standards (e.g. IEC 61400-1 for onshore wind turbines and IEC 61400-3 for offshore wind turbines). Some of the proposed GSS would require wind turbines to operate in dynamic regimes not accounted for in the design. Therefore, there is a need to improve understanding of the potential impact that GSS operation modes could have on wind turbine design (structural, mechanical, electrical, control and protection).

Control plays a crucial role in the capability of wind power to deliver GSS with the required performances, i.e. response time, firmness of response, etc. There is a need for further development of advanced control strategies focused on GSS delivery, especially at wind farm/cluster level.

Fast and reliable communication is crucial in delivering fast services like FCR and FFR especially at wind farm/cluster level, necessary for delivering a coordinated, optimised and centralised response. Requirements and standards for communication systems are not established, and further work is needed to define them.

From an operational point of view, an improvement in accurately estimating the possible (available) power when operating in de-rated mode is needed.

The development of offshore wind power, especially in Northern Europe, implies connecting wind power using HVDC technology. This could lead to the development of a full scale offshore grid with DC that would connect to (and operate in-between) the onshore AC grids. To this end, there is a clear need to improve understanding of the technical requirements and the control strategies for wind power operating in hybrid AC and DC multi-terminal networks.

[71] ENTSO-E, 2013

8.2.2.2 Solar PV

Any type of frequency support provided by PV technology requires active power derailment or additional dispatchable power, meaning storage, or operating PV systems below the MPP (a type of fixed curtailment). In all cases there is still a lack of knowledge and experience. The economic impact of applying the different options for PV based frequency support needs further investigation (also considering the extra devices and respective OPEX). The subject has been studied mostly with help of simulations, but there have been no case studies on a wider scale that can provide a secure benchmark for replicating the results.

Considering the complexity of the subject (dynamics of the PV technology, the local specificities and the different related costs and their volatility), further in-depth investigation is a huge task. However, with continuously increasing PV and VAR-RES penetration, R&D efforts with a TSO perspective (besides the DSO) are more than justified. This would involve feasibility studies for storage solutions, aggregation techniques, optimum spread of DG and complementarities of wind and PV. The annual impact on the profitability of PV when down regulated should take place at local level and on a wider scale.

Although different methods and technical capabilities have already been assessed in different countries, information is still needed about the costs and benefits of real system operation.

Static voltage support by reactive power provision is already a technical requirement in different grid codes, but the effects of reactive power provision on the grid voltage depend on the specifics of the feeder and the load pattern. Furthermore, depending on the system size, other solutions (such as STATCOM) have shown more benefits, which means that further analysis is needed to provide more insight into cost-effective control strategies.

A more detailed economic assessment for optimally dimensioning the inverter to increase reactive power availability (CAPEX and losses) is also needed.

Just like for wind power, research is needed into possible contributions of solar PV in system restoration, especially for scenarios with high VG penetration. In addition to ongoing research on the technical feasibility of black start service with high shares of PV (storage and other VG), the economical aspect needs more in-depth investigation. Regarding islanding in particular, the behaviour of the inverter (especially the self-commutated) during the fault and the current detection methods of islanding used by the inverters (introducing disturbances) are issues to be further examined.

8.2.3 Markets/costs/economics

In order to achieve higher deployment rates of wind and solar PV, well-functioning GSS markets are necessary. This is highlighted in the ENTSO-E R&D roadmap that includes a dedicated cluster on market designs. In the REserviceS project, several knowledge gaps about market design and cost reductions were identified:

- Studies on coupling energy and grid support service procurement at European level including large scale market models that can capture the complex market interactions across Europe, including cross-border interactions;
- Bottom-up engineering assessment is needed to improve the estimates of current costs and cost reduction potential;
- Design of markets and products that take into account both the characteristics of VAR-RES and the power system in question, including optimisation of gate closure times in relation to the service providing assets and the power system needs (e.g. uncertainty of VAR-RES, start-up times of thermal power plants, inertia of the power system);
- Need for detailed and clear specifications for the participation of wind and solar PV in grid support service provision;
- Interplay between grid support service markets, energy markets and possible capacity markets. How to mitigate issues in different time scales without causing unintended consequences in other time scales.

8.3 R&D needs

8.3.1 System needs

Several research subjects were identified:

- Development of methods and tools for power system (transmission and distribution level) planning that can include the stochastic nature of VAR-RES using probabilistic approaches. This is in line with current research agendas and included in the ENTSO-E R&D Roadmap. It is also included to some extent in research initiatives such as the GARPUR project[72], but the subject is extensive and should be included in future R&D;
- Role of VAR-RES in system restoration services. This is partially investigated in research initiatives such as the iTESLA project[73], however since investigation is in its early stages, the topic requires further research;
- Definition (technical and economic) of new system services and their impact on the system. The need to investigate new services should be an R&D priority;
- Common methodology for system needs of GSS with large amounts of VAR-RES.

8.3.2 Technology

As wind and solar PV technologies are able to provide frequency and voltage support today, research should focus on enhancing those capabilities and/or improving the costs. The synthesis report provides a detailed outline of R&D needs relating to frequency, voltage and system restoration services.

[72] GARPUR Project
[73] ITESLA Project

9 THE RESERVICES PROJECT – A SYNOPSIS

The REserviceS project has assessed the provision of GSS in future power systems with high shares of variable generation (VAR-RES). It focused on service provision by wind and solar PV. The objective was to contribute to creating electricity market mechanisms that enable cost-effective participation of variable generation in frequency and voltage support in European transmission and distribution systems.

An analysis was made of system needs for GSS for frequency and voltage management when shares of renewables become very high. Based on a selected set of frequency and voltage services, existing capabilities in the wind and solar PV technologies have been analysed. An assessment of technical issues as well as challenges for enhanced service provision has also been made. An inventory of the costs (CAPEX and OPEX) has been drawn up for both technologies for estimating deployment costs of enhanced frequency and voltage services when system needs increase due to higher shares of VAR-RES. As the existing information about possible participation of VAR-RES in system restoration is limited, the project has not looked at this in detail, but has made some recommendations for future work.

Case studies involving simulations and economic analysis of different transmission and distribution networks with high shares of VAR-RES have been undertaken, providing insights into technical challenges of massive deployment of services and economic benefits for the power systems. Performing cost benefit analysis in distribution networks is case specific and it was not possible to reach generalised conclusions for voltage services. The project did not address in depth the potential of VAR-RES connected at distribution level to provide flexibility not only for congestion management but also for balancing the system. This should be further investigated in order to set the required coordination among TSOs and DSOs.

An assessment of current electricity market characteristics and trends in Europe, focusing on opportunities for GSS, together with the specific characteristics of large scale deployed VAR-RES, identified suitable market and product characteristics for frequency support services by wind and solar PV. While various pre-conditions and possibilities could be identified for frequency support services by VAR-RES connected at TSO level, the project did not address these aspects in as much detail for voltage services, especially at DS level as well as for TSO/DSO coordination. This issue is highly complex and requires further study.

Finally, based on an internal survey in the consortium as well as in the REserviceS Advisory Board, an inventory has been made of requirements for further R&D into power systems, solar PV and wind technologies and market design.


© Acciona Energía

10 REFERENCES

Chapter 4

- Abele H., Interface TSO-DSO: Reactive Power and Defense Plan, Transnet BW, Mainz, 19.6.2013
- ENTSO-E, 2012. NC RfG: Network Code Requirements for Grid Connection, pg. 31 available at: https://www.entsoe.eu/major-projects/network-code-development/requirements-for-generators/Pages/default.aspx (19.8.2014)
- IEA, 2014. The power of transformation. Paris, February, 2014. Report available from www.iea.org
- Milligan, M., Kirby, B., King, Beuning, S., 2011. The impact of alternative dispatch intervals on operating reserve requirements for variable generation. Proceedings of 10th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms, 25 - 26 October, 2011, Aarhus, Denmark. Energynautics, 2011
- Quitmann, E., Erdmann, E. The power system will need more! How grid codes should look ahead. Proceedings of 13th international Workshop on Wind Integration, London, November 2013
- Twenties, 2013. Market and system security impact of the storm demonstrations in task-forces. TF2 Deliverable D16.6. Available at: http://www.twenties-project.eu/

Chapter 5

- Abele H., Interface TSO-DSO: Reactive Power and Defense Plan, Transnet BW, Mainz, 19.6.2013
- EN50160, European Standard
- ENTSO-E, 2012. NC RfG: Network Code Requirements for Grid Connection, pg. 31 available at: https://www.entsoe.eu/major-projects/network-code-development/requirements-for-generators/Pages/default. (19.8.2014)
- INCREASE EU Project (www.project-increase.eu)
- Marble Bar Project, ABB 2013
- Twenties. Deliverable 9.2: Technical and Economic Impact on Assets of the Services provided by the Wind Farms. 2013 Available at: http://www.twenties-project.eu/

Chapter 6

- Miroslav M. Begovic. Electrical Transmission Systems and Smart Grids. ISBN 978-1-4614-5830-2, Springer, 2013
- Willem Uijlings. System Service Provision: An independent view on the likely costs incurred by potential System Service Providers in delivering additional and enhanced System Services, 2013
- Soni and EirGrid, System Services Consultation – New Products and Contractual Arrangements. 2012

Chapter 7

- Goran Strbac and J Mutale, DISPOWER project Task 5.5: Development of contract structures for ancillary services from distributed generation. University of Manchester, 2005
- Delfanti and al, The new role of DSOs: Ancillary services from RES towards a local dispatch, CIRED Workshop, June 2014

Chapter 8

- ENTSO-E R&D Roadmap 2013 – 2022, The Strategic Research Agenda of the Wind Technology Platform and The European Electricity Grid Initiative Research and Innovation Roadmap 2013 – 2022
- GARPUR EU Project (www.garpur-project.eu)
- ITESLA EU Project (www.itesla-project.eu)

11 LIST OF RESERVICES REPORTS (DELIVERABLES)

All the results of the REserviceS project are available online at www.reservices-project.eu

System needs for ancillary (GSS) services

D2.2 Ancillary services: technical specifications, system needs and costs

D2.1 System needs for ancillary services: table

D2.3 Ancillary services costs for different services and different conventional generators

D2.3 Annex: template for costs table

Wind and PV ancillary services (GSS) capabilities and costs

D3.1 Capabilities and costs for ancillary services provision by wind power plants

D4.1 Capabilities and costs for ancillary services provision by PV systems

D4.2 Annex: overview of costs and cost models

Wind and PV ancillary services (GSS) in future systems – Case Studies

Transmission level: European, Iberia, Ireland, Offshore

D5.1 Onshore wind supporting the Irish grid – Ireland case study

D5.2 Offshore wind providing grid support services – Offshore case study

D5.3 Grid support services at the Iberian Peninsula – Iberia case study

D5.4 European case study – Frequency reserves from wind power and PV in a large footprint

D5.5 Full evaluation and conclusions of the transmission system case studies

Distribution level: Germany, Italy, Spain (2), Portugal

D6.1 Distribution case study scenarios – definition and assessment procedures

D6.2 Provision of ancillary services by wind and solar PV to the Spanish, Italian, Portuguese and German market

Recommendations for a future EU market for ancillary services (GSS)

D7.1 Full Synthesis Report

D7.2 Full Recommendations

Final Publication

D8.9 Final Publication

RE**services**S

ECONOMIC GRID SUPPORT FROM VARIABLE RENEWABLES

PRINTED BY ARTOOS
- ISO 14001
- 100% GREEN POWER
- CLIMATE NEUTRAL COMPANY
- SUSTAINABLE DEVELOPMENT

PRINTED CLIMATE NEUTRALLY
certificate number:53520-1408-1012
www.artoos.be

RECYCLED
Paper made from recycled material
FSC® C007370

www.reservices-project.eu

REserviceS PROJECT

REserviceS was the first project to investigate wind and solar based grid support services at EU level. It provides technical and economic recommendations for the design of a European market for grid support services, as well as for future Network Codes within the Third Liberalisation Package.

REserviceS was funded by the Intelligent Energy Europe programme (April 2012- September 2014, IEE/814/SI2.616374), and coordinated by the European Wind Energy Association. The REserviceS consortium consisted of leading knowledge institutes, renewable power operators, network operators and European wind and solar PV industry associations.