FutureFlow

Ref. Ares(2016)3842599 - 22/07/2016

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 691777

Document Information

Programme	Horizon 2020 – Cooperation / Electricity
Project acronym	FutureFlow
Grant agreement n°	691777
N° of the Deliverable	D1.1
WP/Task related	[W1 / T1.1]
Type	(Report)
Confidental:	Public
Date of delivery	[31.06.2016]
Status and Version	Version 0.9
Number of pages	129 pages
Document Responsible	cyberGRID GmbH
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Version	Date	Author(s)	Notes	Status
0.1	03.05.2016	3E	Template	done
0.2	05.05.2016	All	Draft table of content	done
0.3	10.05.2016	All	Final table of content	done
0.4	17.05.2016	All	Description of content	done
0.5	25.05.2016	All	Review of document	done
0.6	03.06.2016	All and TRANSELECTRICA and MAVIR	Internal review	done
0.7	16.06.2016	All	Draft	done
0.8	23.06.2016	Reviewers, MAVIR	Official review	done
0.9	28.06.2016	Executive Board	Executive board confirms deliverable	pending

Executive summary

This report provides an overview of the current state of aFRR markets for power system balancing and potential new resources in the control zones of APG (Austria), ELES (Slovenia), MAVIR (Hungary), and TRANSELECTRICA (Romania). The investigations have been performed in the scope of the FutureFlow project. The aim of this report is to foster the common understanding about current state of aFRR markets and to point out challenges for the investigated coupling of aFRR markets of the four TSOs. Further on, the requirements and barriers concerning the entrance of potential new market participants, in particular distributed renewable energy sources (RES) and distributed generation (DG) or demand (demand response, DR), are shown and facilitating measures are discussed. In a second step initial recommendations for aFRR market design and technical implementation are developed in order to facilitate participation of portfolios of various units in aFRR systems. Finally this report should provide the gathered knowledge as a basis for the ensuing work packages of the FutureFlow project.

Past and current practice for procuring aFRR reserve by many TSOs is mainly to use conventional generation units, such as big hydro and thermal power plants which are able to decrease or increase its generation to provide requested change from the TSOs. In many control areas there is only a limited number of suitable conventional providers available which may result in low market liquidity in some cases. Therefore, many TSOs aim to facilitate aFRR market access for innovative providers like Demand Response (DR) and Distributed Generators (DG), not only within their control area, but also neighboring aiming for the increased competition and lower balancing cost.

aFRR markets and participation of RES

In the first chapter the current state of aFRR markets is explained, focusing on the participating TSOs. Based on the findings about different technical aFRR market rules, such as: procurement cycle and product resolution of balancing reserve power, it is discussed how to optimize current market rules in order to allow RES to participate in the aFRR markets.

A Monte-Carlo study of the main market design or orchestration parameters indicate a clear potential of renewable energy sources (RES) to be applied in the automated frequency restoration reserve (aFRR) market if the aFRR market is adapted towards RES.

To cope with the variability and the ability of forecasting RES, an aFRR market closer to real-time orchestration is needed before potential balancing energy from RES can be exploited. A Monte Carlo analysis of 840 combinations show that (a) a daily procurement cycle and (b) a one-hour product length are desired to stimulate potential RES market participation.

Further, the study shows that a mixed portfolio of units of different types (RES and DR or DG) is the best practice when RES are included in the market.

Potential volume of new market participants

In evaluating the existing potential of flexible power that is available in the four control zones of this project the bottom-up approach was used, where extensive effort has been put into the investigation of potential providers of flexibility at the field level. To obtain relevant results, a list of most promising candidates with flexibility resources (companies) from different sectors has been prepared (industrial resources with own generation, industrial resources with load flexibility, business or public resources with energy management system, small and large RES, CHP) - forming a representative sample of the entire C&I flexibility potential. Due to the observed differences in the knowledge of consumers in self-estimating their flexibility potentials, the acquired results (from questionnaires prepared specifically for DR/DG customers) needed to be validated. Thus, the "door-to-door" applicative survey approach has been complemented by an investigation of the theoretical flexibility potential to enable the analysis to gain a relative perspective of the identified potential. Finally, in order to be able to compare results and draw relevant conclusions the two approaches have been validated against each other by the two case studies. Two potential flexibility providers' –"industrial" and "commercial" - actual data have been used to calculate theoretical flexibility potential. The results were compared and evaluated against the actually surveyed flexibility potential. Both approaches have shown to be relevant, since they provided similar conclusions.

Shiftable loads typically feature one of the following characteristics: heat or cold storage (e.g. space heating, refrigerators), demand flexibility (e.g. washing, ventilation) or physical storages (e.g. cement industry, fresh water supply). Industrial load shifting may be limited by technical constraints, process requirements and availability of unutilized plant or machine capacity. For processes with very high utilization rates - as they are found in energy-intensive industries - only load shedding without previous or subsequent balancing can be implemented. In residential and commercial sector, typically both load shifting and shedding can be realized.

Estimating available flexible capacity is a complex process, since the actual potential depends on numerous factors, including: accounting for different sectors - industrial, tertiary and households sector, temporal availability of flexible loads, the duration of load interventions, the shifting time and the frequency of DR actions, distinction between the theoretical, technical, economic and practical potential, considering load shedding, load shifting to an earlier time, load shifting to a later time and distributed generation, willingness to participate in flexibility programs, especially within the house chores (washing, dishwashing, cooling, etc.), industrial production activity, business hours and electricity grid load (e.g. when the economy is booming the flexibility potential is lower), household activity level and occupancy variance etc. A single research effort, which would attempt to assess the flexibility potential, while considering all the above influences is a very challenging task, which has not yet been performed. Attempting to estimate the true market potential within this project, due to the above stated constraints, has exposed the need for an intensive individual approach to each DR & DG customer. Nevertheless, the theoretical flexible capacity potential in the four control zone has been estimated to:

Table 1: The theoretical flexible capacity potential in the four control zones

	SI (MW)	AT (MW)	HU (MW)	RO (MW)
DR Industry	+119/-16	+315/-103	+156/-37	+677/-87
DR Tertiary	+91/-79	+363/-321	+349/-295	+231/-198
DR Residential	+128/-789	+602/-3.546	+530/-2.938	+755/-4.896
Distributed generation	+581/-581	+6.086/-6.086	+882/-882	+6.408/-6.408
Total	+894/1.440	+6.965/-9.828	+1.845/-4.080	+7.966/-11.485

Identifying the flexibility potential the market research-survey began with creating the list of customers. Both traders (EE and GEN-I) focus on their biggest, key customers in participating TSO's region. Existing customers, who are participating in established balancing service markets, e.g. mFRR (Slovenia, Austria), constituted the priority list. In general, the results confirm the complexity of new services: smaller customers express less interest, while the large industrial customers can be assumed as strong holders of flexible capacity. The percentage of successfully contacted customers with positive answers for the participation in such innovative solution confirms that the research was successful. Commercial sector provided good information about the flexible capability and willingness to participate. The results for the manufacturing sectors are more or less as expected. Industrial customers reported considerable potential to provide flexible capacities.

First intermediate results shows that 318 MW of theoretical flexible capacity could be provided. Real potential on the executive level, will be confirmed only by signed contracts later in the project.

Analyzing the units with the capability of flexibility and inviting customers to participate is not a onetime process, but requires an ongoing approach. Customers are expecting additional contacts with more information before confirming the final participation and signing contracts.

Harnessing the identified flexibility potential using DR and DG requires the coordinated participation of the full energy value chain, including the Transmission System Operator (TSO) in balancing markets, the Distribution Systems Operator (DSO), the supplier, the Balance Responsible Party (BRP) and the aggregation service provider as Balancing Service Provider (BSP). Most consumers do not have the means to trade directly into the energy markets. To engage them in market participation, therefore requires a clearly defined offer, which is both simple to use and contains clear benefits. They require a party with expertise in selling and providing this offer through aggregation. Aggregation service providers (who may or may not be electricity suppliers) are therefore central players in creating vibrant demand-side participation. An aggregator's success is entirely dependent upon the successful participation of the consumer in DR & DG programs. The introduction of the role of aggregator into a market creates critical momentum around the growth of DR & DG, attracts private investment and spurs competition between service providers.

To enable the participation of independent aggregation service providers in a safe manner, the relationship between the supplier, Balancing Responsible Party (BRP) and the aggregator must be defined. Standardized processes for information exchange, transfer of energy, and financial settlement between these parties are a critical requirement in order to facilitate the smooth functioning of the market to ensure consumers the right to choose providers freely, while at the same time ensuring that market functions remain stable, in particular the one of the BRP.

To enable conditions for fair competition between the different market actors, traditional and new, the regulatory environment should create a level playing field for all competitors, where not only the very largest industrial consumers, with their own bilateral power purchasing agreements can participate in Demand Response programs. To enable consumer participation, a set of regulatory steps should be fulfilled:

- Participation of demand-side resources and their aggregation in electricity markets should be authorized
- Shifting the attention from the resource towards the aggregator, which should be solely responsible for providing the aFRR services within the regulatory requirements (chooses at his discretion the electricity generation technology and limitations of its technical performance, communication standards towards flexibility units and type of their activation etc.)
- Fair treatment based on risk for the system should be implemented and regulation should not favor one resource over the other. For example, the same measurement and communication requirements should not be used for a 500 MW power plant and a household. Unnecessary and unleveled requirements might be a major cost driver for smaller participants and a major consideration in what type of facilities may be able to participate in the market or program.
- Cross-border activation of resources should be enabled. Opening the market would increase the number of potential resources, thus increasing competition that should lower the prices on the competing market.

In order to enable the inclusion of new sources of flexibility to the aFRR market, the products should be designed by considering their characteristics and limitations these sources are facing:

- Full Activation Time (call time) should be as long as possible
- Minimum bid quantity should be as low as possible
- Symmetrical products should not be obligatory
- Prices (e.g. for reserved capacity and activated energy) should be more transparent and be defined in the same way for all market players - presumably auction based with publicly cleared prices and clearly defined type of settlement.

Measurement and verification of aFRR provision

In general, if the TSO-TSO-model is applied, the measurement and verification of aFRR provision should be the task of the connecting TSO. Nevertheless it turned out to be a challenging topic since there are a lot of individual rules in each control zone and in the current state there is no common standardized procedure of the four TSO. In order to deal with the existing heterogeneity, it was chosen to point out common approaches and general issues relevant for most control zones as well as good practices to verify the provided aFRR. It seems to be a promising approach of many TSO to allow any source of flexible capacity as long as the main requirements for aFRR provision are fulfilled. If a TSO wants to increase the number of aFRR providers and the market liquidity it could be helpful to re-interpret certain historically grown requirements in order to promote new sources of flexibilities like RES and industrial loads organized in pools and managed by VPPs. In the past many rules have been defined to deal with large generators only, some of these rules may become a barrier for smaller flexibilities managed by VPPs.

The definition of suitable algorithms for baseline calculation are crucial for participation of VPPs in aFRR markets. The investigation showed that there is no common procedure for baseline calculation which could meet all the requirements related to different characteristics of various resources of flexibilities, the TSOs approach for P/f-control and verification and in some cases even the national power market clearing rules. Therefore, it is important for TSO not to insist on too strict rules but rather to allow different verification approaches as long as the fundamental requirements are fulfilled. The report explains six different baseline methodologies, of which four fulfil aFRR requirements for sure and are proven practice in some control zones. These methods are (corrected) power market schedule, baseline submitted with short lead time (min. equal to full activation time), continuation of the current measurements, and available active power (of renewable generators). Further methods may also be applicable but are not approved by sufficient practical experience yet. In case that the real-time calculation of provided aFRR power requires a short-term baseline correction it is preferable that the provider performs the correction, which of course requires transparent rules to support ex-port verification by the TSO.

Some TSO accept new proposals for verification methods developed by the providers of flexibility as long as reliability and transparency fulfil the requirements for aFRR provision. This approach proved to be good practice to facilitate the participation of RES and VPPs in balancing markets. Alternatively, the provider could choose a baseline method from a catalogue of methods already verified by the TSO.

Currently at many of TSOs the aFRR prequalification procedure has to be performed for each participating unit individually. If a portfolio based prequalification procedure would be introduced, this could facilitate the participation of portfolios of smaller units like DG and DR.

Communication requirements

Considering the current aFRR market and real-time control system, multiple actors interact with each other and exchange information between them.

A survey of existing and foreseen communication protocols and standardization frameworks has shown a very diverse picture of solutions, focused per field and type of use. The analysis of presently used communication protocols within TSO environments has shown that proven solutions are preferred, i.e. IEC 60870-5-104 and IEC 60870-6-503 are the most used protocols. ENTSO-E EDI models are in full use, though versioning differs, but this is not critical for effective information exchange.

Although IEC, CEN/CENELEC specified protocols and common information models (CIM) can offer almost the complete solution set, recently a fast take up of DR specific protocols has been observed, most notably OpenADR. Another trend is the expansion of OPC UA, which offers multiple communication profiles. IoT and Web communities are successfully offering queuing based messaging protocols, which have been proven already in fast transaction oriented financial markets. PLC/SCADA vendors have acknowledged the trends and are offering these protocols in their products. Note that IoT/Web protocols offer straightforward, fast integration with TSO cloud based services (e.g. common across region activation of capacities for balancing markets).

A multi-step approach for the implementation of communication solutions is proposed. TSO must stipulate the protocols used for the pilot implementation to realize fast time to market. Such a solution will have limited scalability, though. In the next steps one can investigate and implement messaging protocols oriented communication and demonstrate its operations in a controlled environment. Information security design builds upon known approaches and standards, emphasizing that there is no secure perimeter taken for granted, rather it must be assured with rigorous multi-layer security implementations.

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Table of acronyms

Acronym	Meaning
ACE	Area Control Error
AT	Austria
aFRR	Automatic Frequency Restoration Reserve
ARIMA	Autoregressive integrated moving average
BLP	Baseline load profile
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CAF	Common Activation Function
C&I	Commercial and Industrial consumers
CCGT	Combined cycle gas turbine
CHP	Combined Heat and Power
CZC	Cross Zonal Capacity
D-1	Day a-head
DAFC	Day-ahead forecast
DER	Distributed electricity resources
DG	Distributed generation
DR	Demand response
DSO	Distribution System Operator
EC-GSM	Extended Coverage Global System for Mobile communication
EDI	Electronic data interchange

ENTSO-E	European Network of Transmission System Operators for Electricity
EMS	Electricity management system
eUICC	Embedded universal integrated circuit card
FAT	Full Activation Time
FCR	Frequency Containment Reserve
FF	Future Flow
FRCE	Frequency Restoration Control Error
FRR	Frequency Restoration Reserves
GCT	Balancing Electricity Gate Closure Time
GPRS	General packet radio service, 2G cellular networks
GSM	Global System for Mobile communication
DLC	High level data link control
HU	Hungary
IDCF	Intraday congestion forecast
IDFC	Intraday forecast
IoT	Internet of things
IEC	International Electrotechnical Commission
IP	Internet protocol
IS	Imbalance Settlement
ISP	Imbalance Settlement Period
IT	Information Technology
LF Controller	Load-Frequency Controller

LFC	Load frequency control
LFC area	Load-frequency control area
LTE	Long term evolution, 4G cellular networks
MAC	Medium access control layer of communication
mFRR	Manual Frequency Restoration Reserves
MO	Merit order
MOL	Merit order list
MPLS	Multi-protocol label switching
NTC	Net Transfer Capacity
P/f	Power Frequnecy
PHY	Physical layer of communication
PLC	Power line carrier or Programmable logic controller
PMU	Phasor measurement unit
Prosumer	producer and consumer type of customer
PTDF	Power transfer distribution factor
PV	Photovoltaic
QoS	Quality of service
RES	Renewable energy sources
RO	Romania
RR	Replacement Reserves
SCADA	Supervisory control and data acquisition
SETSO	South-East Europe Transmission System Operators

SI	Slovenia
SLA	Service level agreement
TSO	Transmission system operator
TSP	Trust service provider
UCTE	Union for the coordination of transmission of electricity
UMTS	Universal mobile telecommunications system, 3G cellular networks
VEN	Virtual end node
VPN	Virtual private network
VTN	Virtual top node
WAFC	Week-ahead forecast
WAN	Wide area network
xDSL	x digital subscriber line (x = A/asymmetrical, S/symmetrical, V/very high speed)

Glossary

Glossary can be found in Annex A.

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The aim of the FutureFlow Project

Four European TSOs of Central-Eastern Europe (Austria, Hungary, Romania, Slovenia), associated with power system experts, electricity retailers, IT providers and aggregators, propose to design a unique regional cooperation scheme: it aims at opening Balancing and Redispatching markets to new sources of flexibility and supporting such sources to act on such markets competitively. By means of a prototype aggregation solution and renewable generation forecasting techniques, flexibility providers – distributed generation (DG) and commercial and industrial consumers (C&I) providing demand response (DR) – are enabled, to participate on the aFRR market with participation in the portfolio for Frequency Restoration Reserve (including secondary control activated with a response time between 30 seconds and 15 minutes). Retailers act as flexibility aggregators and pool the resource in order to provide the products required by the TSO. A comprehensive techno-economic model for the cross border integration of such services involves a common activation function (CAF) tailored to deal with congested borders and optimized to overcome critical intra-regional barriers. The resulting CAF is implemented into a prototype Regional Balancing and Redispatching Platform, securely integrated within the four TSOs' IT systems: this makes research activities about cross-border integration flexible while linking with the aggregation solution. Use cases of growing complexity are pilot-tested, going from the involvement of DR and DG into national balancing markets to cross-border competition between flexibility providers. Based on past experience with mFRR, participating C&I consumers and DG are expected to provide between 30MW and 45MWof aFRR. Impact analyses of the pilot tests together with dissemination activities towards all the stakeholders of the electricity value chain will recommend business models and deployment roadmaps for the most promising use cases, which, in turn, contribute to the practical implementation of the European Balancing Target Model by 2020.

Project Partners

No	Name	Short name	Country
1	ELES DOO SISTEMSKI OPERATOR PRENOSNEGA ELEKTROENERGETSKEGA OMREZJA	ELES, d.o.o.	Slovenia
2	AUSTRIAN POWER GRID AG	APG	Austria
3	MAVIR MAGYAR VILLAMOSENERGIA-IPARI ATVITELI RENDSZERIRANYITO ZARTKORUEN MUKODO RESZVENYTARSASAG	MAVIR ZRT	Hungary
4	COMPANIA NATIONALA DE TRANSPORT ALENERGIEI ELECTRICE TRANSELECTRICA SA	TRANS	Romania
5	ELEKTROINSTITUT MILAN VIDMAR	EIMV	Slovenia
6	ELEKTROENERGETSKI KOORDINACIONI CENTAR DOO	EKC	Serbia
7	ELEKTRO ENERGIJA, PODJETJE ZA PRODAJO ELEKTRIKE IN DRUGIH ENERGENTOV, SVETOVANJE IN STORITVE, D.O.O.	EE	Slovenia
8	GEN-I, TRGOVANJE IN PRODAJA ELEKTRICNE ENERGIJE, D.O.O.	GEN-I,d.o.o.	Slovenia
9	SAP SE	SAP SE	Germany
10	CYBERGRID GMBH	CYBERGRID	Austria
11	GEMALTO SA	GTO	France
12	3E NV	3E	Belgium

1 Introduction

1.1 Outline

This deliverable (D1.1) covers two subtasks.

Subtask 1.1.1 "Requirements for DR and DG participation in aFRR markets" deals with market and technical conditions to allow such units to participate in aFRR markets. Subtask 1.1.1 starts with the market analysis of the downward and upward reserve potential by the DR and DG located in industry as well as based on RES like photovoltaic and wind. Further, current balancing electricity market rules are researched. Finally, this Subtask discusses how to combine DR and DG units to provide reliable aFRR reserve to the TSOs.

Subtask 1.1.2 "Selection of DR & DG units for participation in aFRR markets" gathers potential DR and DG units by means of a market survey. Technical information and characteristics are combined in a detailed questionnaire which was redistributed between potential DR and DG customers in the four different counties. The "door-to-door" applicative survey approach has been complemented by an investigation of the theoretical flexibility potential to enable the analysis to gain a relative perspective of the identified potential. Finally, in order to be able to compare results and draw relevant conclusions the two approaches have been validated against each other by the two case studies.

Deliverable 1.1. also researches current and proposes new verification methodologies which enable transparent rules for DR and DG units and investigate data exchange between different actors in aFRR market.

1.2 Objective

The aim of this deliverable is to inform the reader about the possibilities of providing aFRR using DR and DG units. This report is supported by the market survey of such DR and DG units in four countries together with extended questionnaire providing information about dispatching and aFRR market for participating TSOs.

1.3 Relation to other work packages

Work package 1 (WP1) with title "Cross-border integration of aFRR markets with DR and DG" is the basis for further work packages. It provides basic information and current analyses of the status of aFRR markets. Outputs of this work package bring key knowledge and information for the following work packages.

Task 1.1, which results in deliverable D1.1. is providing initial information about DR and DG units and will be used as a basic document for following tasks and work packages.

2 Review of current reserve market with respect to market participation

To allow a level playing field for renewable energy resources (RES) in the automatic frequency restoration reserves (aFRR) market, the market design needs to be improved. We start by reviewing the current aFRR market design, focusing on the participating transmission system operators (TSOs). Based on this, we can identify key parameters that influence or limit the potential of RES in aFRR and are subject of optimization.

The review of the structuring of the aFRR markets is based on two main sources of information:

- On the one hand, an extensive questionnaire has been prepared as part of this Task in which all participating TSOs have shared information on their current aFRR market organization and key figures on the trading results of this market.
- On the other hand, the *"Current State of Balance Management in South East Europe"* report [ETSO, 2006] presented at SETSO Sub Group Balance Management on June 22-23 (Athens) is used as a reference source for the none-participating TSOs.

As such, we'll start with the general review.

2.1 The aFRR market

Transmission system operators (TSOs) are responsible for transmission of electric power on the high voltage transmission networks. Although some functions have been added such as the provision of open access to all market participants and the facilitation of the electricity balancing market, this basic role has not changed since the liberalization of the electricity balancing markets. To fulfill its basic responsibility of operating the transmission system, the TSO independently procures the different system services for power-frequency control services, congestion management, voltage control, loss reduction and black start. These services are procured from various sources through commercial arrangements. In order to put the TSO's role into context, it is necessary to understand the manner in which the system services can be procured and paid.

Market participants aim to cover their physical positions by forward contracts for physical delivery, futures contracts that are financially settled against a reference price, or option contracts. Therefore the highest volume of power is traded already before the day-ahead (D-1) market opens. After gate closure time (GCT) of the day-ahead (D-1) electricity balancing market and after intraday (ID) trading, participants have generally covered their positions and fine-tuning of the portfolio commences, based on new information of the physical demand and supply balance, and the latest forecasts.

At GCT, trading stops and the TSO takes control of the system. At GCT, all participants submit their data regarding: intended consumption and production schedules for the next period by location to the TSO. After gate closure and in real time, the TSO will vary the generation (or demand) points in order to balance the system or manage congestion. The TSO must therefore have control over production and demand assets, which are typically procured in different types of reserve: fast reserve to cope with short-term imbalances, and longer-term reserve to replace the fast reserve activation once the short-term imbalance has been resolved. To maintain this balance, the TSO generally procures three types of reserves:

- **Primary control** or **frequency containment reserve (FCR)**, a decentralized and automatic reaction to a frequency deviation *e.g.* caused by small variations in production and consumption (frequency variation).
- **Secondary control** or **automatic frequency restoration reserve (aFRR)**, a set of actions of generation or demand assets, centrally orchestrated per control area as part of a frequency control loop.
- **Tertiary control** or **manual frequency restoration reserve (mFRR) and replacement reserve (RR)**, non-automated services for cope for plant loss or significant forecast errors.

It's the secondary control or aFRR that will be subject of the main review and study here.

2.2 aFRR market design

Both the European Network of Transmission System Operators for Electricity (ENTSO-E) as well as the local transmission system operator (TSO) set requirements for aFRR, and both are reviewed here. We will focus on the participating TSO regions, but to be general we will include some information on other existing product designs if applicable. This also supports the chosen parameters in the study if these do not directly appear in the participating TSO regions but do exist in others.

The ENTSO-E posits that secondary control is used after a system disturbance, whereby system frequency and power exchanges must begin to return to their set point values after 30 seconds, and must be completed within 15 minutes of the incident.

The TSO operates the balancing markets and has the freedom to add requirements to the aFRR market. Generally, generators and loads submit adjustment bids to increase/decrease their output or consumption at fixed intervals. In real time, the TSO accepts some bids in a price based merit order and the accepted and/or activated bids are paid either by their bid price or the marginal bid price.

We'll review this balancing market for the participating TSOs.

2.2.1 APG, Austria

The market model applied in Austria for automated frequency restoration reserve (aFRR) combines bilateral contracts with a balancing market. Both generators and consumers can submit bids and offers to the balancing market at a minimum of 5 MW bids.

Secondary control power is offered mainly as a week product: The bidding period is on Tuesday from 9:00 am and 2:00 pm and daily reserves are contracted at 10:30 am. Suppliers who are accepted for weekly or daily aFRR capacity can adjust their reserve electricity prices for the following day on each working day up to 15:00. The original price may, however, not be exceeded in the case of positive secondary control power or undercut in the case of negative secondary control power. The product length of a week is additionally broken down in twelve product time slots, i.e. daily 'peak week' slots from 8:00 to 12:00 from Monday to Friday, daily 'off-peak week' slots from 0:00 to 8:00 and from 20:00 to 24:00 on Monday to Friday, and a 'weekend' slot for Saturday and Sunday. This results in an effective product resolution of 12 hours.

In contrast to the ENTSO-E, APG demands a full activation time (FAT) of 5 minutes and allows a tolerance limit of 3% relative to the control signal.

The balance groups strive to balance electricity supply and demand on a 15-minute basis. Based on the measured imbalances and the activated reserves, the volume and price of the resulting balancing power during every 15 minute period are computed by the settlement agency at the end of each month, and charged or credited to the various balance groups. Power injection is credited and withdrawals are debited (or vice versa at moments of negative prices due to too much feed-in).The balance groups strive to balance electricity supply and demand on a quarter-hourly basis. The volume and price of the resulting balancing power during every 15 minute period are computed by the settlement agency at the end of each month, and charged or credited to the various balance groups. Power injection is credited and withdrawals are debited.

Balance groups are confined to given control areas. However, it is immaterial which grid area or grid level balance-group members are physically connected to within the control area. All generators, suppliers and consumers connected to the public network are obliged to join a balance group or form one themselves. The same applies to electricity traders if they only trade electricity but do not supply final consumers.

Electricity procurement from or supply to other balance groups must be electronically notified to the balance-group coordinator by way of schedules for the next day. These schedules contain details as to the amount, period, direction of flow, and balance groups concerned.

The settlement prices paid for the balancing power are determined on the basis of the activated bids. The settlement-price determination procedure is based on the marginal price as established by an appendix to the general terms and conditions of the balance group coordinators. There are capacity payments for the secondary control (approximately 200MW) with an option of shift to 400 MW (largest Austrian generation unit) and for the tertiary control, whereas in the balancing market an average of approximately 100 MW market maker exists.

2.2.2 MAVIR, Hungary

On the result of long term procurement procedures (mainly quarter-yearly), MAVIR concludes contracts (framework agreements) with the Balancing Service Providers (BSPs). This contract allows and obliges the BSPs to bid on day ahead (D-1) timeframe for each balancing service they are prequalified for, such as primary control, secondary control and tertiary control. The daily bidding on secondary control market or aFRR has a minimum of 1 MW bids and the product length of a bid is 1 hour which can be settled at a 15 minute resolution.

For all technically capable (and prequalified) service provider it is mandatory to offer the available balancing reserve and balancing energy bids. Based on the transparently predefined conditions, those BSPs, which have reservation during the day-ahead procedure, receive reservation fee, and those, which are activated during real-time operation can receive energy fee or activation fee. The settlement is based on pay-as-bid systemIn addition to the FAT of 15 minutes as demanded by the ENTSO-E, MAVIR requires a minimum ramp rate of 2 MW/min and allows a tolerance limit of 1% with a maximum of 2 MW.

2.2.3 TRANSELECTRICA, Romania

All dispatchable units must offer their non-contracted electricity into the ancillary services market. Consumers are allowed to offer load reduction service on a voluntary basis. The balancing market is comprised of three services: Secondary regulation (aFRR), fast tertiary regulation (mFRR) and slow tertiary regulation (RR), *i.e.* based on activation time less or more than 15 minutes. To solve the problem of allocation of the different services in the context of a mandatory market, the rules require that participants make only one offer with several price–quantity pairs for the entire capacity of the generation unit. For generation companies, all quantities below the scheduled production are automatically considered for downward regulation and the quantities above for upward regulation. In case of aFRR there is continuous (pro-rata) automatic activation of upward and downward regulation. In case of mFRR and RR, there is manual merit order activation, for upward and downward regulation. The approach allows to always consider the maximum amount of each ancillary service that can be made available at any point in time and there is thus no ex-ante allocation of capacity to a particular service. In case of aFRR, the total necessary reserve (aFRR) is establish in D-1, including all dispatchable units which will provide this services, based on merit order and the existing contracts or available energy.

The regulating bands of all participating dispatchable units are implicitly reset every hour. It is thus possible to rearrange the contribution of each generating unit to secondary regulation for each hour, based on the remaining bids. If necessary, secondary regulation can be replaced by fast tertiary within 15 minutes.

In addition to the FAT of 15 minutes as demanded by the ENTSO-E, TRANSELECTRICA demands a minimum ramp rate of 2 MW/min and allows a tolerance limit of 1%.

2.2.4 ELES, Slovenia

The market model applied in Slovenia for automated frequency restoration reserve (aFRR) combines bilateral contracts with a balancing market. Both generators and consumers can submit bids and offers to the balancing market at a minimum of symmetrical 5 MW bids.

In addition to the ancillary services that are contracted on a yearly basis (generally in November), the TSO is balancing the system also with non-reserved balancing products. This kind of balancing electricity is purchased by the TSO with a simple market based procedure, from internal Slovenian generation resources and the control areas outside Slovenia. Costs for the non-reserved balancing electricity are covered through the imbalance settlement procedure, similarly to the ancillary service reserve usage costs.

2.2.5 To summarize

To grasp the differences between the different participating TSOs, we could make following summarizing table, Table 2.

Table 2: Overview of the main market parameters and requirements of the respective automatic frequency restoration reserve (aFRR) market designs of ELES, APG, TRANSELECTRICA and MAVIR

	APG *Austria*	**ELES** *Slovenia*	**MAVIR** *Hungary*	**TEL** *Romania*
Minimum bid to the balancing market, *i.e.* product resolution (in size) at each product bin (in time).	5 MW	1 MW	1 MW	10 MWh
Is aggregating generators allowed to reach the necessary product resolution (in size) **?**	Yes	Yes	Yes	No
Are demand response aggregators participating in the aFRR market?	Yes	Yes	No	No
At which timeframe must bids be submitted, *i.e.* what's the procurement cycle (distance to realtime)**?**	On Tuesday, weekly	In November, annually	D-1	D-1
Is submitting a symmetrical bid a necessity?	No	Yes	No	Yes
At which resolution is the balancing capacity procured, *i.e.* what's the product resolution (in time)**?**	12h in week, 48h weekend	1 yr bid, 1h activation	1h bid, 15min act	1h
What is the asked full activation time?	5 min		15 min Min 2 MW/min	15 min Min 2 MW/min
What is the allowed tolerance limit?	3%		Min(1%, 2 MW)	1%

3 Current redispatching mechanisms and perspective developments

While the substantial part of Future Flow project is related to the design of the mechanism for the exchange of electricity within aFRR, project also deals with practices of redispatching and innovations in cross-border cooperation in this respect, and potential co-existence of aFRR exchange and redispatching over the common platform.

After the analysis of relevant European target models, and the extensive questionnaire filled by the concerned TSOs, two facts streamlined the redispatching design within Future Flow project from the very beginning:

- Electricity Balancing Network Code, at Chapter "Activation of balancing Electricity bids" states that "Balancing Electricity bids for Frequency Restoration Reserves with automatic activation shall be exclusively available for the purpose of maintaining the active power balance."
- all four TSOs are members of TSC cooperation(Transelectrica joined recently), and share the principles of cooperation of the cross-border redispatching to be applied

The first bullet provides no space for the co-usage of the same bids for both aFRR electricity exchange and for redispatching purposes. Therefore, redispatching process should be developed in a way parallel to the aFRR process.

The fact that all four TSOs are members of TSC regional security cooperation process provides the space to seek for the harmonized potentials for innovations in the field of balancing. TSOs intend to seek for the needed further developments that could support the so far achieved level of cooperation within TSC.

The initial considerations go towards:

- the co-optimization of technical (sensitivity factors based on network locations) and economic criteria (cost of dispatch) for the selection and application of redispatching actions to solve the network congestions
- seeking for the potential of DR/DG units to participate at redispatching (and required additional information, such as network locations of DR/DG)
- cost allocation and cost sharing principles of redispatching among the TSOs, including the determination of the amounts and the origins of loop flows and export/import flows

These will be mainly the subject to the Task 1.2. of FutureFlow Work Package 1 ("Cross-border balancing and redispatching mechanisms tailored to congested borders situation").

4 Environment enabling RES participation in aFRR markets

This chapter focuses on integrating renewable energy sources (RES) in the automatic frequency restoration reserve (aFRR) market. The chapter is structured as following:

- The first two sections focus on the potential of organizing the aFRR market in a more appropriate way towards RES.
- The third and last section addresses the optimization potential for aggregators as an actor within this aFRR market.

4.1 Product design restrictions for RES

The very nature of renewable electricity sources (RES) such as solar and wind power makes it hard to join the aFRR market. Both wind and solar generation is a direct outcome of the instantaneous irradiation level, the wind speed, wind directions and the inertia of configurations, and is thus - in contrast to conventional generation systems - not easily predictable and dispatchable; as shown in Figure 1 and Figure 2. First, both wind and solar generation are subject to seasonal variations. Second, daily cycles are substantial, mainly due to daily irradiation and temperature changes. Finally, (intra-)minute fluctuations are observed. Managing the variability of wind generation is the key aspect associated to the optimal integration of that renewable power into power grids. The limitations of the nature of RES for aFRR can thus be reduced to two distinct characteristics. The very nature of renewable electricity sources (RES) makes it hard for RES to join in the aFRR market, *i.e.* focusing on solar and wind power. Both wind and solar generation is a direct outcome of the instantaneous irradiation level, the wind speed, wind directions and the inertia of configurations, and is thus - in contrast to conventional generation systems - not easily predictable and dispatchable; as shown in Figure 1 and Figure 2. First, both wind and solar generation are subject to seasonal variations. Second, daily cycles are substantial, mainly due to daily irradiation and temperature changes.

- **The predictability**. The strong dependency of RES generation on instantaneous weather conditions make them hard to forecast. Similar to weather forecasting, the forecast worsens when the forecast time horizon increases. As such, the time horizon over which aFRR bids must be submitted, i.e., the **procurement cycle**, becomes a critical market parameter. If this cycle is too long, i.e., too far from real time, only small fractions of the forecasted generation can be offered reliably due to increasing forecasting uncertainties.

The variability. Variations are inherent to RES causing low availability. Variability increases with the length of the considered time window. Hence, in the aFRR market, the **product length** is critical. As it increases, the variability of RES increases and only small fractions of the forecasted generation can be offered reliably. This is the main reason why managing RES variability is key in grid integration and aggregation of individual sources is important. Compared to the procurement cycle and product length, the other aFRR market parameters are less critical to offer RES to the aFRR market:

- Renewable energy plants and/or portfolios are generally smaller than centralized conventional generation units. The required minimum bid size may thus form a potential limitation if aggregation of generation within a bid is not allowed.

- Renewable energy plants and/or portfolios would first need to be curtailed to a sub-optimal level of generation in order to offer upward reserve, making symmetrical bids a limiting factor from an economic perspective.
- Renewable energy plants and/or portfolios generally have a system inertia below the stated full activation time (FAT) and controlling the plants within the tolerance limits is technically feasible, especially when aggregation of loads is allowed.

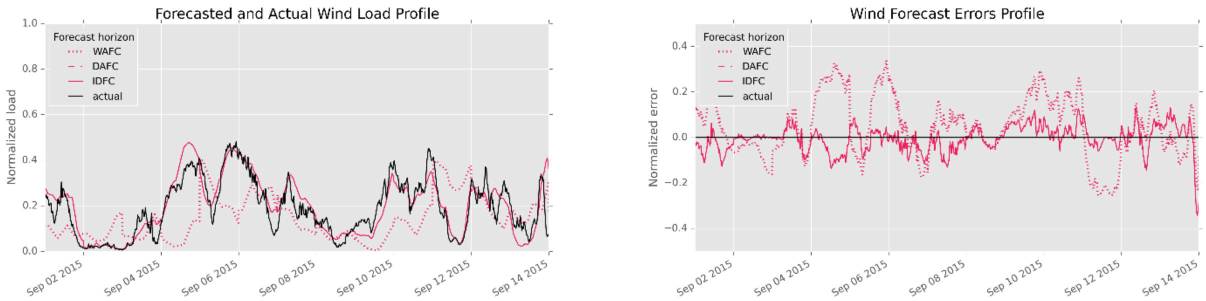


Figure 1: Example P50[1] week-ahead (WAFC), day-ahead (DAFC) and intraday (IDFC) forecast and actual measured load profile of a portfolio of wind parks, and the corresponding forecasting errors (standardized as a fraction of the wind plant installed capacity).[2]

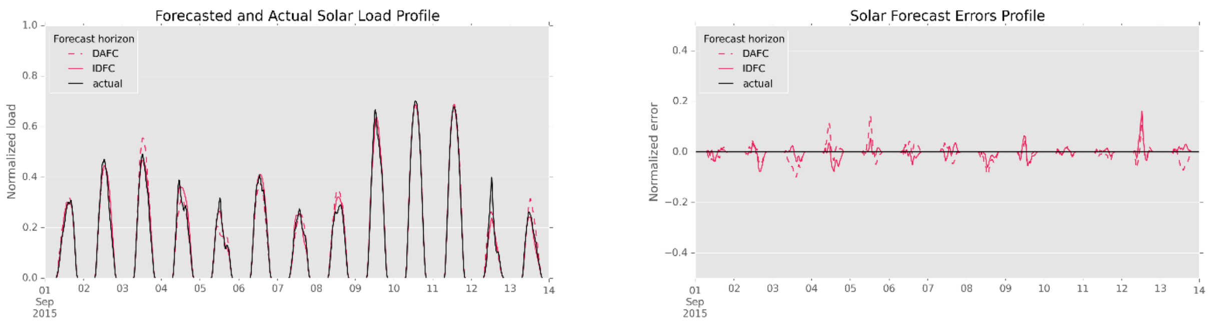


Figure 2: Example P50 day-ahead (DAFC) and intraday (IDFC) forecast and actual measured load profile of an aggregated portfolio of solar parks; and the corresponding forecasting errors (standardized as a fraction of the installed photovoltaic capacity).

[1] The stated P50 or P5 forecasts denote a probabilistic forecast. In contrast to single-valued forecasts, probabilistic forecasts assign a probability to each of a number of different outcomes, and the resulting set of probabilities represents the probability forecast. It is a type of probabilistic classification. The notation of P50 reflects the forecast which has a 50% probability to be under- or over performed, while P5 means there is only a 5% chance that the resulting observation will be lower than the forecast and a 95% chance that the observation will exceed the forecast. As such, to reach a 98.5% certainty for the forecast, the P1.5 is of main importance.

[2] We use the forecasting data from ELIA as available on e.g. http://www.elia.be/en/grid-data/power-generation/wind-power for a large portfolio of wind and solar. Additionally, we create a combined portfolio of 65% capacity solar and 35% wind so that both resources generate the same amount of electricity.

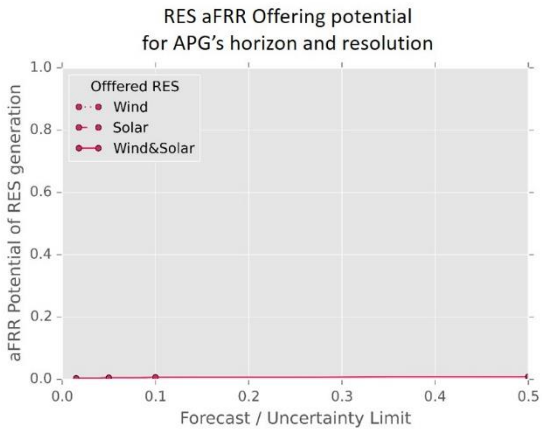
Based on available forecasted and actual power time series of wind and solar portfolios as shown in Figure 1 and Figure 2, the theoretical potential of RES portfolios for aFRR could be determined as the fraction of the total RES generation (without curtailment).

In order to calculate the aFRR potential, the forecasting data first need to be translated from the available P50 forecast (for the commodity market) to a forecast expressing requested 100% availability. Generally, the requested 100% availability is translated in a 98.5% availability to include the general chance of system failure which is always present, making a P1.5 forecast most favorable. This P1.5 forecast indicates the generation profile which is reached (and/or exceeded) with a 98.5% certainty (i.e. the effective availability in comparison to the promised availability on annual basis). However, a higher P10 or even P50 RES forecast could be used as a basis for aFRR bids in case aggregation is allowed with different generation units who enable to cover the forecasting errors to reach a P1.5 with the help of other units. For research purposes, the P1.5 (or in general Pτ) can be obtained ex post based on the P50 forecast and the actual observed load profile by means of a quantile regressions [Koenker & Hallock, 2001]. Quantile regression is obtained by minimizing a sum of asymmetrically weighted absolute residuals of sample y_i, solving the minimization problem

$$min_{\xi \in R} \sum_{i=1}^{n} \rho_\tau (y_i - \mu)^2 \qquad \textit{Eq. 1}$$

where the function $\rho_\tau(\cdot)$ is the tilted absolute value function that yields the τ-th sample quantile as its solution.

Given the P50 forecasted and actual power time series of wind and solar portfolios as shown in Figure 1 and Figure 2 on the one hand, and the description of the aFRR market orchestration of the participating TSOs on the other hand, we can define the theoretical potential of RES portfolios for aFRR in the depicted areas as a function of the considered P-value.



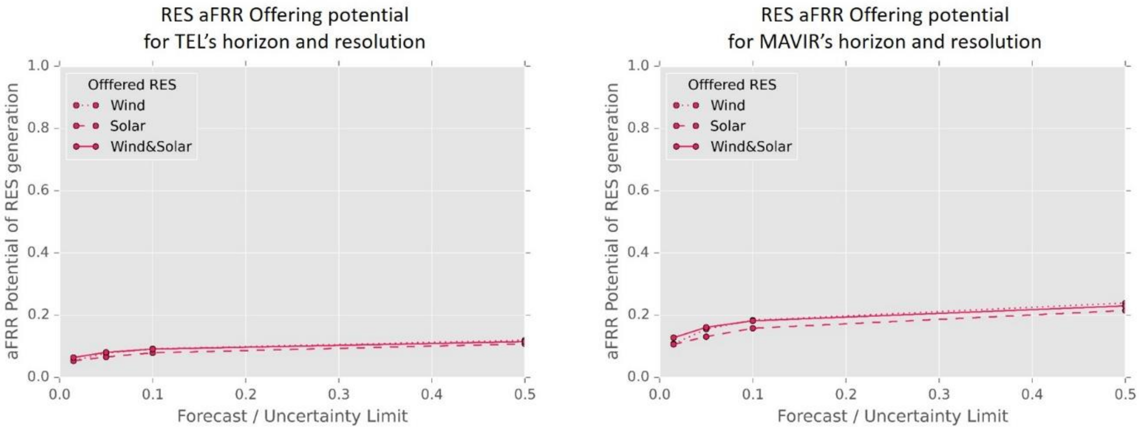


Figure 3: Fraction of the generation of renewable energy resources (RES) that could theoretically be reserved to be offered in the respective automatic frequency restoration reserve (aFRR) market designs of ELES, APG, TRANSELECTRICA and MAVIR as a function of the forecast probability. Here, a forecast probability of e.g. *0.1 denotes the P10 lower-bound forecast.*

The above Figure 3 clearly shows the limited potential of RES offers in the aFRR market of capacity reservation when based on the current combinations of procurement cycles and product lengths in the participating TSO regions. In the current market as organized by ELES and APG, less than 1% of wind and solar generation can be offered to the aFRR market. The main restriction is the annual and weekly procurement cycle of the respective markets. Contrarily, such aFRR market orchestration as organized currently by MAVIR (in fact, there is an obligation for all market participants to offer their services on daily basis on case their position enables it) is more open for RES portfolios. Based on a P1.5 forecast guaranteeing the needed 98.5% availability, the aFRR market orchestration of MAVIR would allow to offer 10.6% of the generated solar power and 10.6% of the generated wind power as balancing reserve if commercial rules would allow and the sources are present. For a portfolio of wind and solar power combined, this may increase to 12.7%.

The main reason of this higher potential is the closer-to-real-time organized market orchestration bids in comparison to the ELES and APG markets.

The range of these numbers, i.e., offering up to 12.7% of the generated electricity at the aFRR market, shows the potential of organizing the market to allow RES in the aFRR market.

4.2 Potential improvement for aFRR market design from a RES perspective

This section defines the requirements of the aFRR market design needed to support the integration of identified potential resources, taking into account their specifics and technical characteristics. The following two topics are addressed: The aFRR procurement process and the characteristics of aFRR market products.

4.2.1 Procurement cycle

A first key parameter in the orchestration of the aFRR market is the procurement cycle of aFRR electricity, i.e. at which intervals in time must bids be submitted. We've seen in the review that this ranges from an annual cycle, to a weekly cycle down to a daily cycle in the current markets of the participating TSOs.

For renewable energy sources (RES), the procurement cycle is one of the parameters that may obstruct aFRR market participation. The GCT defines at which moment in time an assessment has to be made on which capacity from a specific source or portfolio can be offered to the aFRR market with a 100% (or 98.5%) availability. Given the forecasting difficulties and resulting forecasting errors of RES for longer lead times, GCT will directly impact the RES capacity offered. Using the P50 forecasted and actual power time series data of wind and solar portfolios as shown in Figure 1 and Figure 2 and an *ex post* conversion to P1.5, P2.5, P5, ... forecasts, the impact of the procurement cycle of the aFRR market can be studied with respect to the theoretical potential of RES portfolios for aFRR.

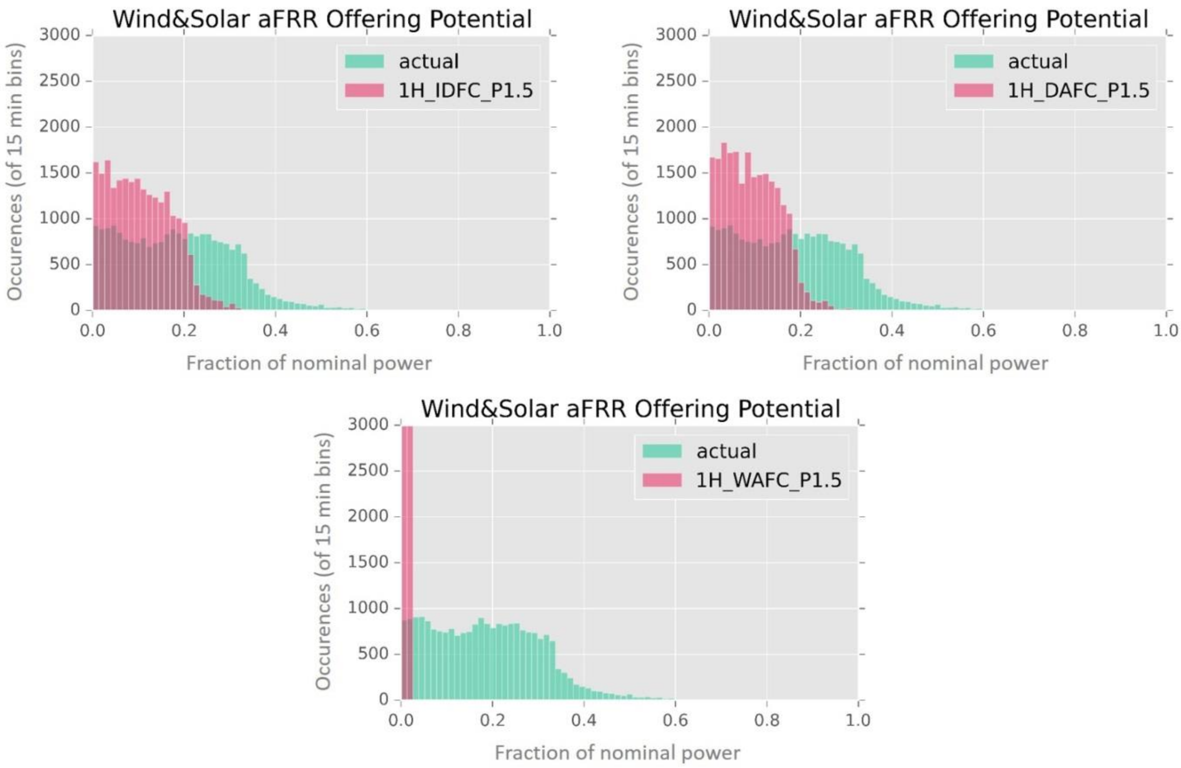


Figure 4: Histograms of actual power (green) and P1.5 forecasted power (red) of a mixed solar-wind portfolio offered at an (from left to right) intraday, day-ahead and week-ahead horizon for a 1-hour aFRR product length.

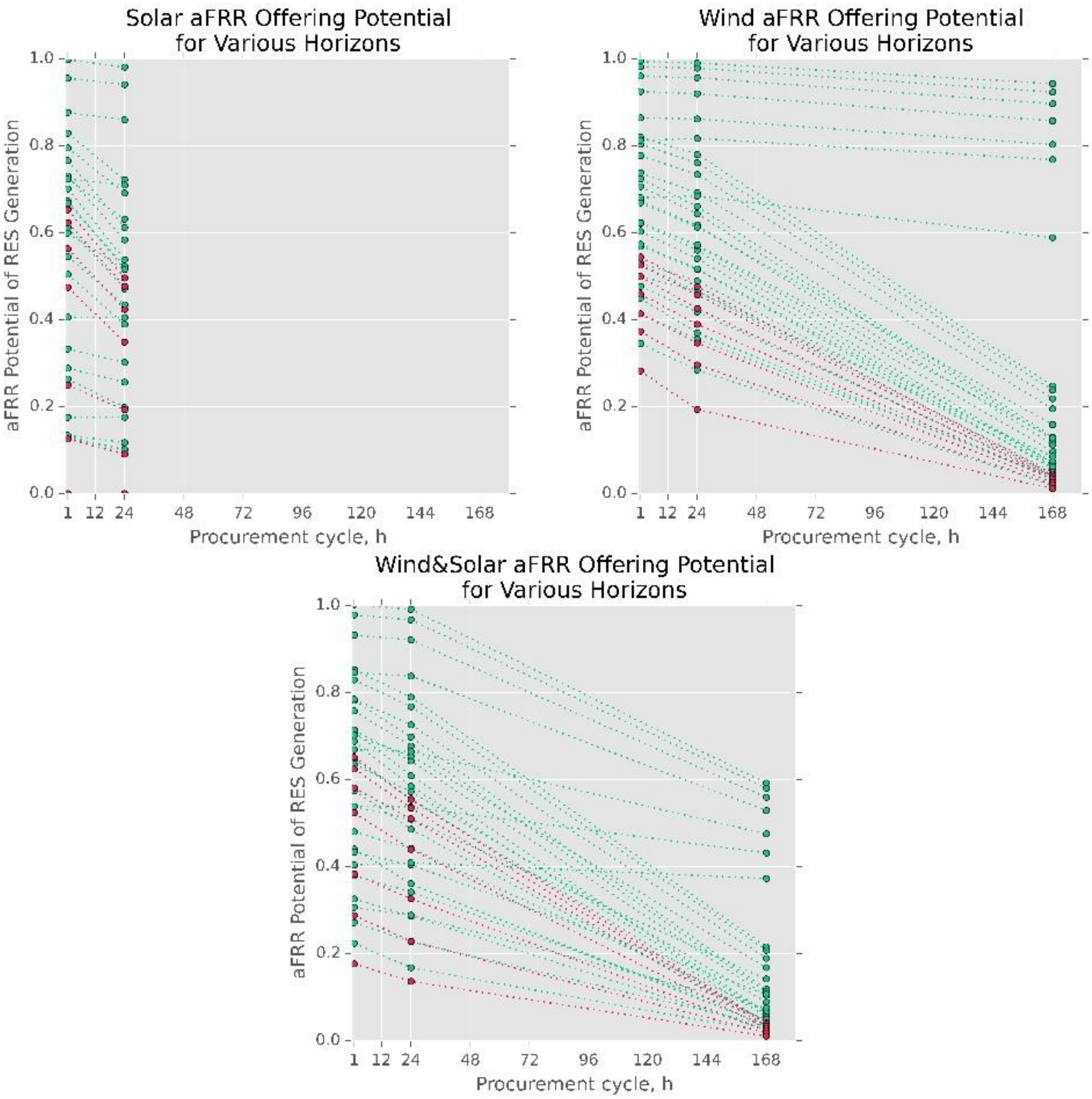


Figure 5: Resulting fractions of total generated energy of RES that could theoretically be reserved to be offered in different aFRR market designs as a function of the procurement cycle. Note that week-ahead forecasts are only available for wind generation. The red values denote the aFRR potential based on P1.5 forecasts where the different lines denote different product lengths, while the green denote the potential if a lower certainty of P5 and P10 is allowed.

The above Figure 4 and Figure 5 shows the fraction of the generated electricity from RES that can be offered at the aFRR market at which capacity as a function of the procurement cycle (expressed in hours). Three options are considered: an intraday offering of reserve capacity, a day-ahead (D-1) nomination and a week-ahead (W-1) offering of reserve capacity and/or energy. Longer procurement cycles are not considered for solar, as no forecasts are available at these moments and no reserve capacity could thus be offered to the aFRR market from RES.

Focusing on P1.5 forecasting data, we can observe that only 1 to 4% of the generated electricity[3] from RES can (theoretically) be offered to the aFRR market with a 98.5% availability at a W-1 basis due to the occurring forecasting errors; depending on all other parameters defining the market orchestration and independent of the economic competitiveness of this offer. Contrarily, 13 to 53% of the generated power from RES can (theoretically) be offered to the aFRR market with a 98.5% availability at a D-1 basis; while 18 to 62% of the generated electricity from RES can be offered to the aFRR market with a 98.5% availability at an intraday basis due to the decreased forecasting uncertainties.

Similarly, only 1 to 3% of the nominal capacity from RES can (theoretically) be offered to the aFRR market with a 98.5% availability at a W-1 basis due to the occurring forecasting errors; depending on all other parameters defining the market orchestration and independent of the economic competitiveness of this offer. However, we can observe that even at a D-1 basis maximum 30% of the nominal capacity can be offered as aFRR capacity at a very low availability: e.g. 10% of the nominal capacity can be offered as aFRR capacity with an availability of 28%.

Based on these numbers, the gains from moving from a W-1 orchestrated market to a D-1 procurement cycle (and the lack of RES potential at a W-1) basis are unambiguous; while moving from a D-1 to an intraday cycle adds little added value to the potential of RES in aFRR markets. As such: based on the available data, **a daily procurement cycle seems recommended when aiming for RES to offer aFRR electricity bids**; while an intraday cycle could be considered as nice to have, a nice to have. However, it should be noted that no H-1 or H-2 forecasts where available in this research and an hourly procurement cycle is thus not researched. Additionally, **no substantial potential is found for RES to offer aFRR capacity bids** independent of the procurement cycle**.**

4.2.2 Product resolution

A second key parameter in the orchestration of the aFRR market is the product resolution of reserve power, i.e. in which bins in time bids are submitted. We've seen in the review that this ranges 12 hour products to 1h bids with 15 minute activation bins in the current markets of the participating TSOs.

For RES, the product length is an important parameters of the market organization to participate in aFRR. The aFRR product length defines how long an offered capacity needs 100% (or 98.5%) available. Given the

[3] Note that in practice only capacity, not electricity, is offered to the aFRR market. However, capacities are different for every bid (every interval according to the aFRR product resolution). Therefore the offered reserves are measured as electricity, i.e., offered capacity * product resolution, summed for all offered intervals. This can then be easily compared to the total RES electricity yield.

variability of RES, product length may obstruct their aFRR market participation. Using the P50 forecasted and actual power time series data of wind and solar portfolios as shown in Figure 1 and Figure 2 and an *ex post* conversion to P1.5, P2.5, P5, ... forecasts, the impact of the product length of the aFRR market can be studied with respect to the theoretical potential of RES portfolios for aFRR.

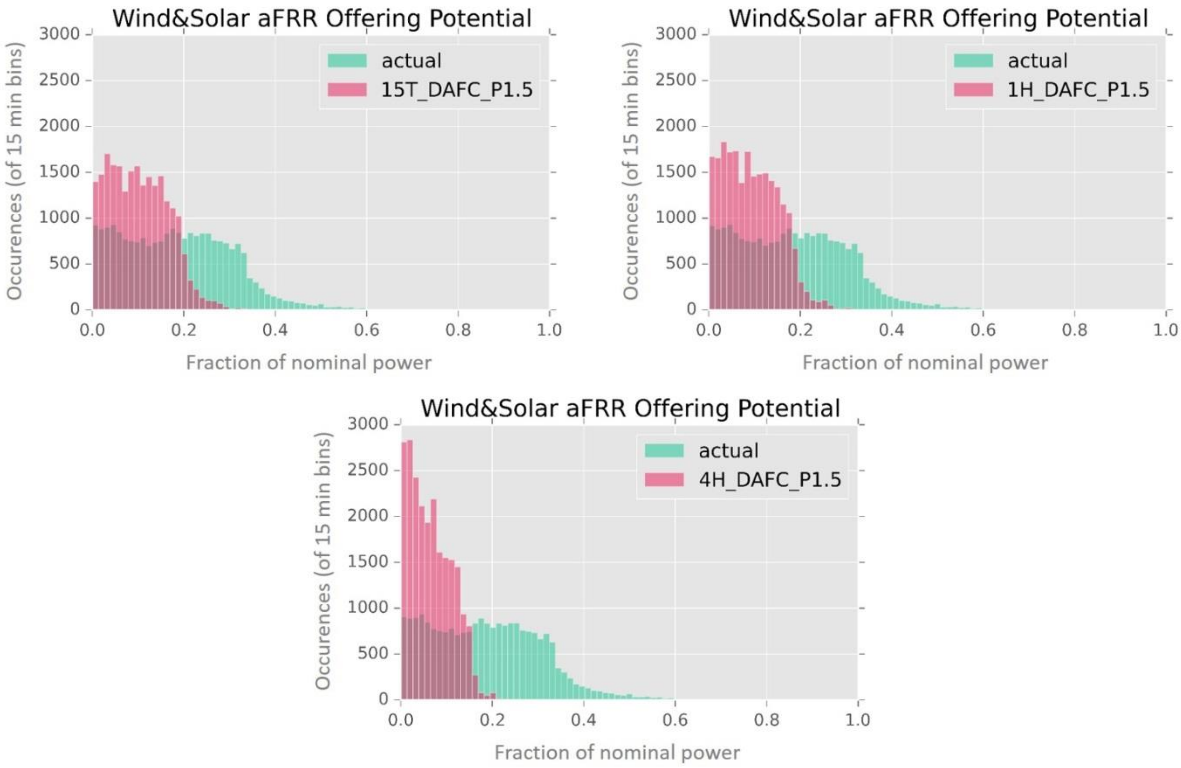


Figure 6: Histograms of actual power (green) and P1.5 forecasted power (red) of a mixed solar-wind portfolio offered at a day-ahead horizon for a (from left to right) 15 minute, 1 hour and 4 hour aFRR product length.

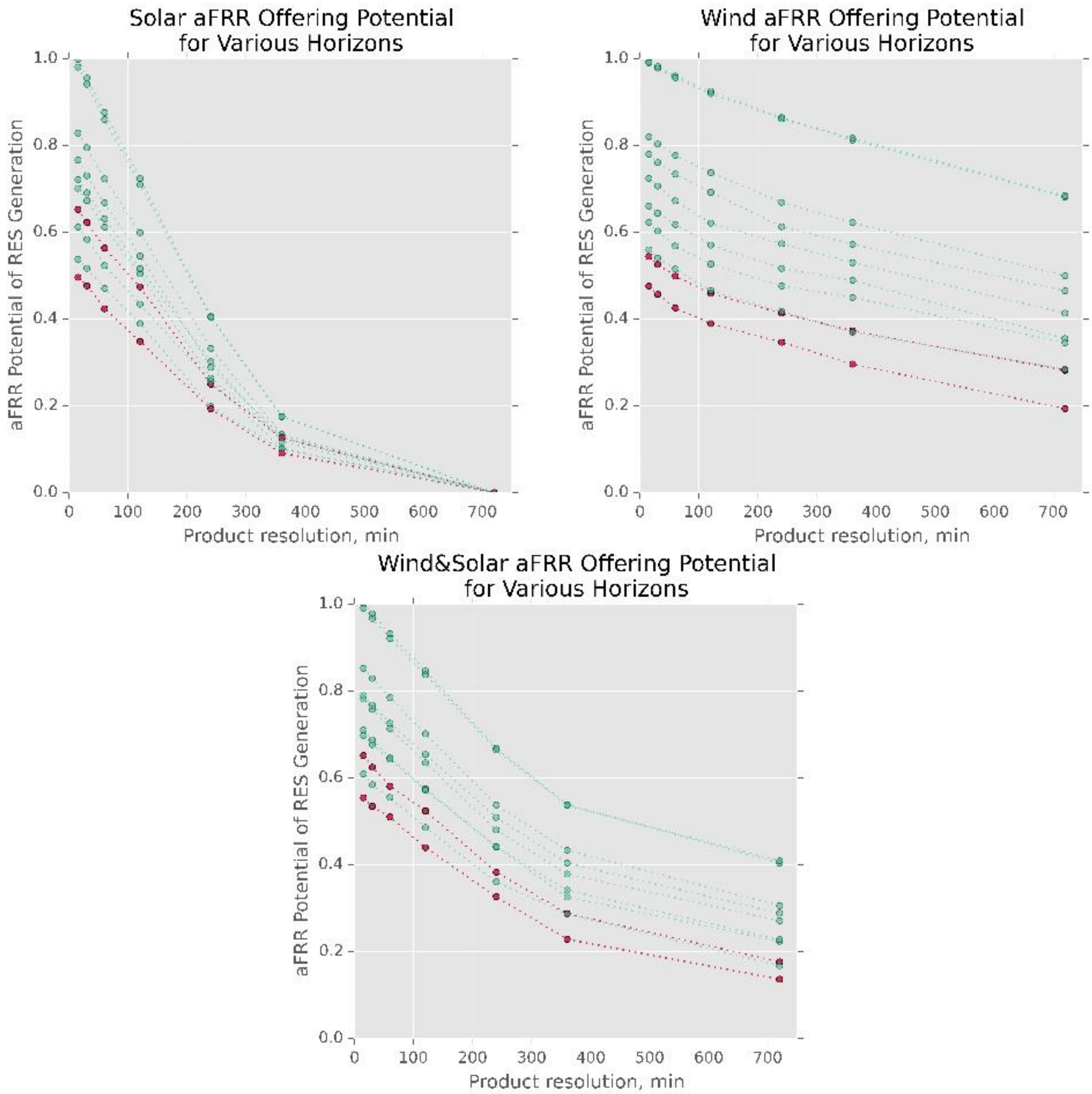


Figure 7: Resulting fractions of total generation of RES that could theoretically be reserved to be offered in different aFRR market designs as a function of the product resolution. The red values denote the aFRR potential based on P1.5 forecasts where each line denotes a possible procurement cycle, while the green denote the potential if a lower certainty of P5 or P10. From left to right: solar portfolio, wind portfolio and solar-wind portfolio.

The above Figure 6 and Figure 7 show the fraction of the generated electricity from RES that can be offered at the aFRR market at which capacity as a function of the product length (expressed in minutes). Seven options are considered, ranging from a 12 hour to 15 minutes reservation of reserve capacity. Longer reservation cycles are not considered for RES, as the variability of RES is too high and no reserve capacity could thus be offered to the aFRR market.

For the recommended D-1 procurement cycle, we can observe that only 13% of the generated electricity from RES can (theoretically) be offered to the aFRR market with a 98.5% availability for a product length of 12 hours due to the occurring variability; independent of the economic competitiveness of this offer. Contrarily, 22 to 32% of the generated electricity from RES can (theoretically) be offered to the aFRR market with a 98.5% availability at a product length of 6 and 4 hours respectively; while 51 to 55% of the generated electricity from RES can be offered to the aFRR electricity balancing market with a 98.5% availability at a product length of 1 hour or less due to the decreased variability.

Based on these numbers, the gains from moving from a 12h product length to a 1h product (and the lack of RES potential in 12h product) basis are unambiguous; while moving from a 1h to an even smaller product length adds little added value to the potential of RES in aFRR markets. As such: **A one-hour product length is recommended when aiming for RES to offer aFRR bids**; while an even shorter product length could be considered as nice to have.

Note on Product Cycle: Again, an intraday procurement cycle gives a marginal added value to the aFRR market here. Focusing on P1.5 forecasting data and an intraday procurement cycle, we can observe that only 17% of the generated power from RES can (theoretically) be offered to the aFRR electricity balancing market with a 98.5% availability for a product length of 12 hours due to the occurring variability; independent of the economic competitiveness of this offer. Contrarily, 28 to 38% of the generated electricity from RES can (theoretically) be offered to the aFRR electricity balancing market with a 98.5% availability at a product length of 6 and 4 hours respectively; while 58 to 65% of the generated electricity from RES can be offered to the aFRR market with a 98.5% availability at a product length of 1 hour or less due to the decreased variability.

4.2.3 Full activation time (FAT) and control error

A third and fourth key parameter in the orchestration of the aFRR market is the FAT and control error of the delivered balancing service. We've seen in the review that the maximum FAT ranges from 15 to 5 minutes with a control error of 1 to 3% in the current markets of the participating TSOs. The sources of information on FAT and control errors for RES in aFRR are very limited. The "Delivery of downward aFRR by wind farms" report [WindVision, 2015] presented by WindVision, Elia, Eneco and Enercon is used as main reference source here. This reports investigates the controllability, FAT and errors in controlling a wind farm to deliver downward aFRR (by controlling the blades' pitch angle) based on different input signals in a field test of an 81 MW park.

Concerning the full activation time (FAT), the 81 MW wind farm which is used as a pilot case has shown to have a symmetrical controllability of 30 MW/min (i.e. 37% of nominal capacity per minute). This shows that the controllable ramp rate of a wind farm is high and that the required FAT is not a limiting factor for the delivery of downward aFRR by RES. Contrary to the FAT, the achieved control errors could be a topic of concern. With the periods of active control in the test case, the average control error was 1.33% with a standard deviation of 2.56% for low winds (in this case defined as below 30 MW output) and was 2.78% with a standard deviation of 1.81% for high winds. These control errors are in the same order of size of the obliged maximum control errors set by the participating TSOs and could thus be a topic of concern. However, it is very complex to separate the forecast errors (which define the baseline of comparison) and the control error. These forecast errors are higher at high winds and could thus be an explanation of the higher control errors at higher wind speeds. For wind farms, the act of pitching blades on the reference production of the non-pitched part of the wind farm results in additional difficulties in meeting the control error requirements.

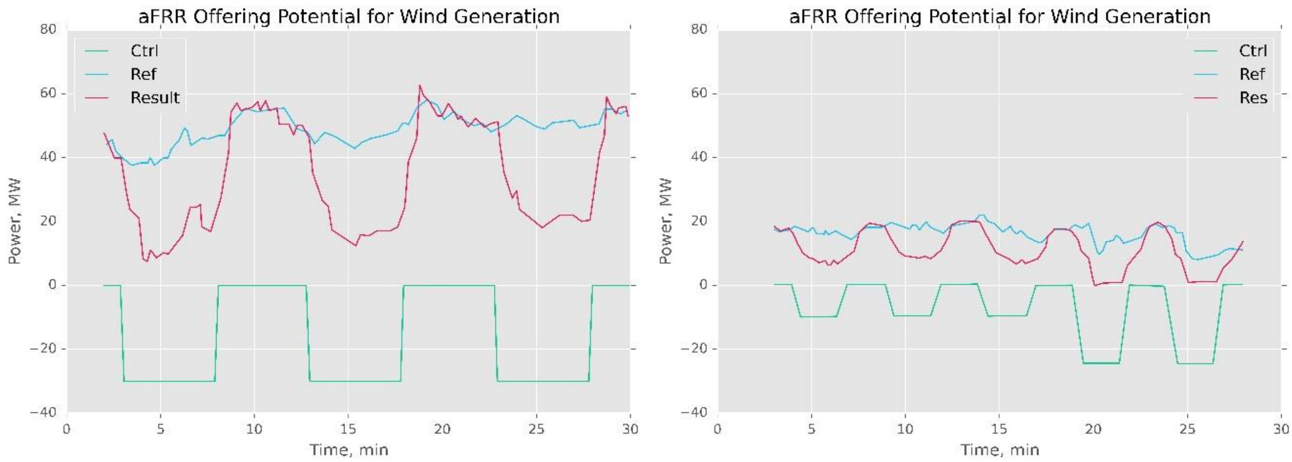


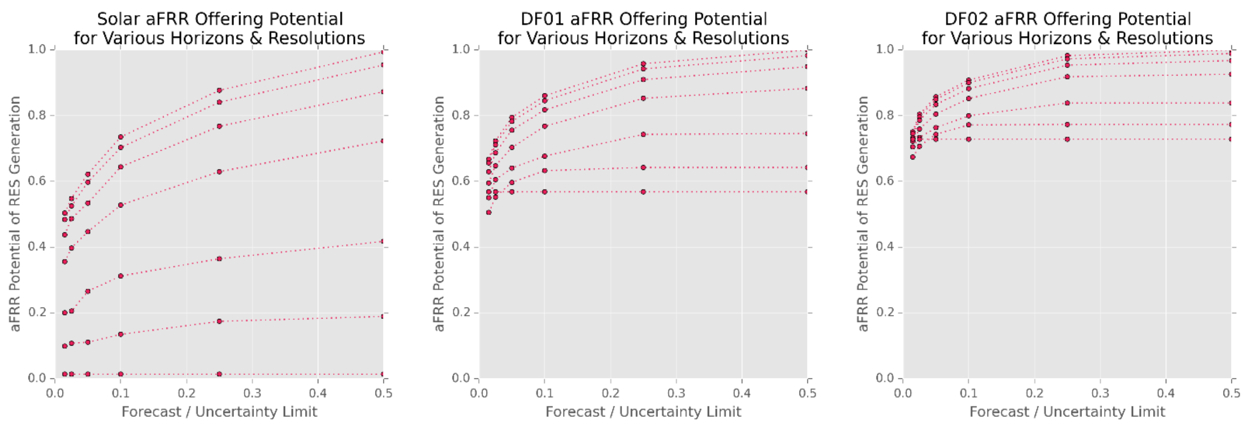
Figure 8: Time profile of a high wind (left) and low wind (right) test sequence where a wind plant provides aFRR electricity denoting the Reference available active power (AAP), the control signal and the resulting power output. (Redrawn from: [WindVision, 2015])

4.3 Recommendations for aggregators as actors in aFRR market

So far, we have only discussed or proposed changes in the aFRR market, while there is also an optimization potential in the organization of aggregators.

4.3.1 RES Portfolio improvements

So far we have only considered portfolios of solely RES, *i.e.* solar and wind resources, while the combination with conventional generation or portfolios of demand response could be complementary to the RES and reduce the main problems caused by the RES characteristics.



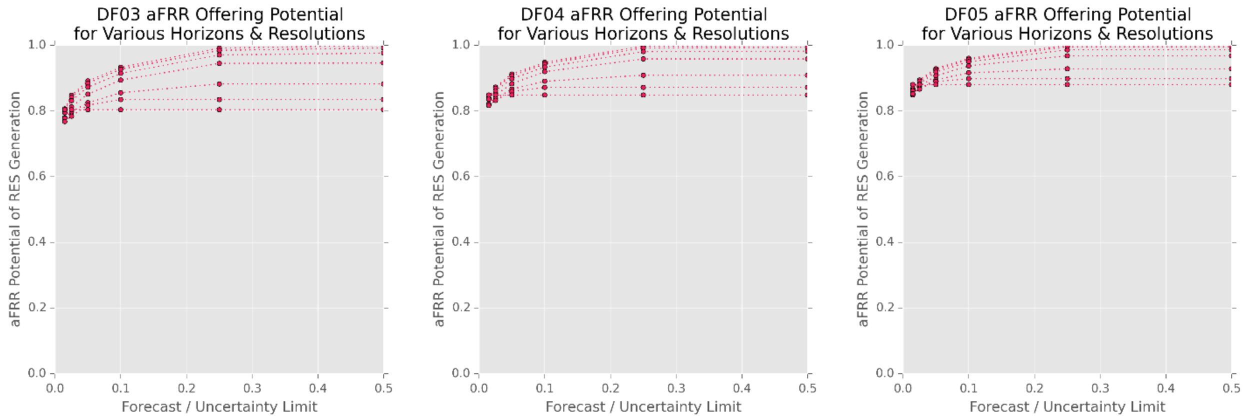


Figure 9: Resulting fractions of total generation of RES that could theoretically be reserved to be offered in different aFRR market designs as a function of the forecast limit. Here, a forecast probability of e.g. *0.1 denotes the P10 lower-bound forecast. From left to right, you can observe a portfolio of solely solar resources, or combined with 10%, 20%, 30%, 40% or 50% respectively of flexible resources (expressed as a fraction of capacity) with a 100% availability. The different lines denote the different combinations of procurement cycle and product lengths.*

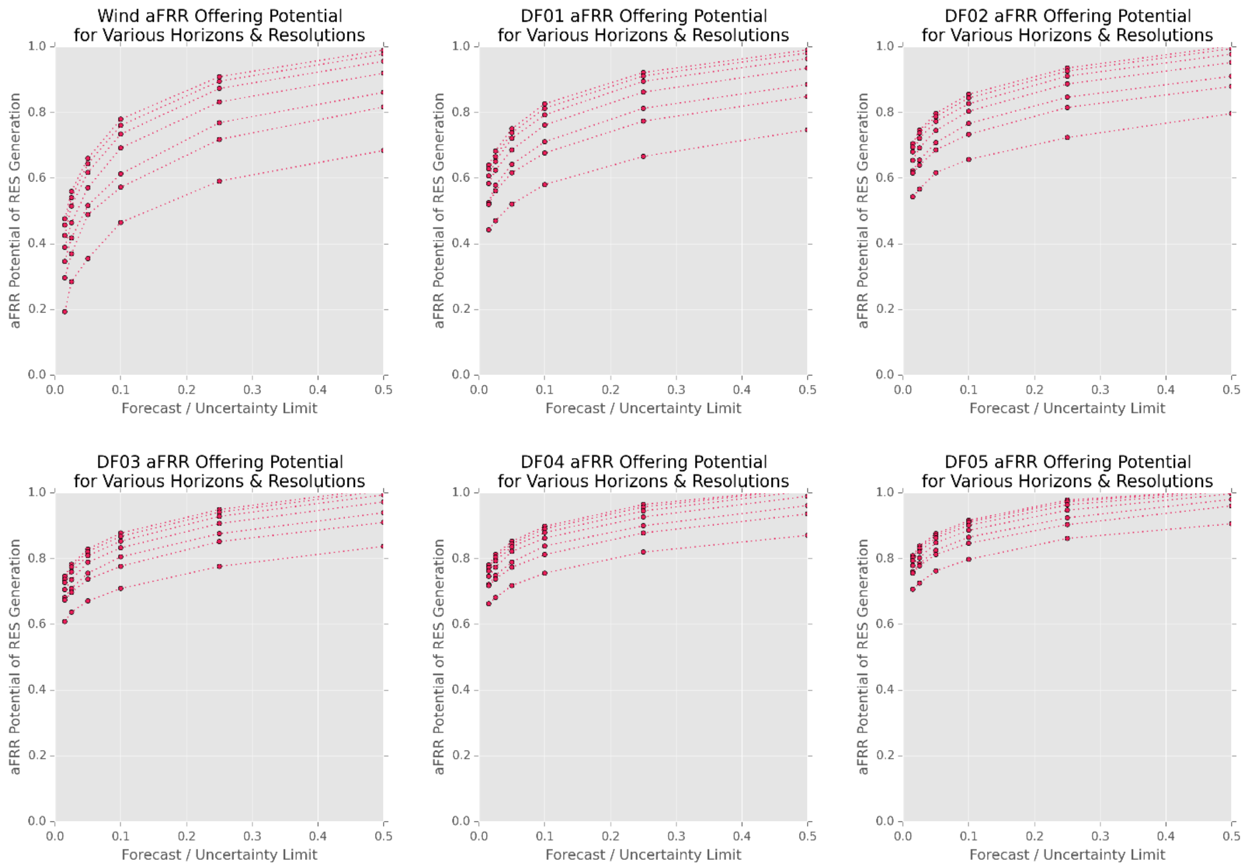


Figure 10: Resulting fractions of total generation of RES that could theoretically be reserved to be offered in different aFRR market designs as a function of the forecast limit. Here, a forecast probability of e.g. *0.1 denotes the P10 lower-bound forecast. From left to right, you can observe a portfolio of solely wind resources, or combined with*

10%, 20%, 30%, 40% or 50% respectively of flexible resources (expressed as a fraction of capacity) with a 100% availability. The different lines denote the different combinations of procurement cycle and product lengths.

The above Figure 9 and Figure 10 shows the fraction of the generated electricity from RES that can be offered at the aFRR market as a function of the forecast limit based on six different combinations of full-flexible (available) generation sources. Six options are considered: From left to right, you can observe a portfolio of solely solar resources (Figure 9) or wind resources (Figure 10) and combined with a 10%, 20%, 30%, 40% or 50% portfolio of flexible resources with a 100% availability. The stated fraction is expressed as a fraction of capacity.

Similar and slightly higher numbers can be found for a portfolio of solar resources. Focusing on P1.5 forecasting data and the recommended D-1 procurement cycle and 1 hour product length, we can observe that 44% of the generated electricity from solar resources can (theoretically) be offered to the aFRR market with a 98.5% availability; independent of the economic competitiveness of this offer. Contrarily, when combined with a 10% portfolio of dispatchable (available) loads (such as DR or conventional generation), 63% of the generated electricity from solar resources can (theoretically) be offered to the aFRR market with a 98.5% availability at a product length; while this number further increases to 73% and 79% when the portfolio of solar resources is combined with respectively 20% and 30% of dispatchable (available) loads.

Focusing on P1.5 forecasting data and the recommended D-1 procurement cycle and 1 hour product length, we can observe that 42% of the generated electricity from wind resources can (theoretically) be offered to the aFRR market with a 98.5% availability; independent of the economic *desirability* of this offer. Contrary, when combined with a 10% portfolio of dispatchable (available) loads, 61% of the generated electricity from wind resources can (theoretically) be offered to the aFRR market with a 98.5% availability at a product length; while this number further increases to 67% and 72% when the portfolio of wind resources is combined with respectively 20% and 30% of dispatchable (available) loads.

Based on these numbers, the gains from moving from a solely RES portfolio to a portfolio combined with 10% or 20% dispatchable (available) loads are unambiguous; while adding even more dispatchable loads in the portfolio adds little added value to the potential of RES in aFRR markets. As such: **Combining a RES portfolio with 20% dispatchable loads is recommended when aiming for RES in the aFRR market**; while adding more loads could be considered as nice to have, however unnecessary from a RES perspective.

5 Selection of DR and DG units for participation in aFRR markets

5.1 Flexibility potential and technical characteristics of DR and DG units in all four control zones

5.1.1 Methodology

The purpose of this section is to evaluate the existing potential of flexible power that is available in the four control zones of this project. In pursuing this goal the bottom-up approach was used, where extensive effort has been put into the investigation of potential providers of flexibility at the field level. The "door-to-door" applicative survey approach has been complemented by an investigation of the theoretical flexibility potential to enable the analysis to gain a relative perspective of the identified potential. In conclusion, the two approaches have been validated against each other by the two case studies evaluating flexibility potential by using the actual data of the two candidate flexibility providers –"industrial" and "commercial" case studies.

5.1.2 Scope and Definitions

The flexibility, which is being investigated within this project is defined as the available or unused part of power that a unit can offer on demand within the agreed time period of its availability. Flexibility is measured by the change of electrical power (+ or – kW) that a unit realizes on demand, where the speed and duration of response is also important. Flexibility can be the property of a flexible electricity demand or flexible generation of electricity. Considering the aim of the FutureFlow project - to search for new sources of flexibility - the distinction could be made between the two categories of flexibility: Demand Response and Distributed Generation, both representing a new source, compared to the conventional large centralized flexible generation units.

Demand Response (DR) could be defined as changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designated to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. Alternatively, DR could be also a voluntary temporary adjustment of power demand taken by the end-user as a response to a price signal (market price or tariffs) or taken by a counter-party based on an agreement with the end-user. In contrast to demand side management, which also comprises electricity efficiency measures and permanent and/or regular utility-driven changes in the demand pattern, DR is focused on load flexibility and short term customer action. Most demand side measures are thus designed to either enable load curtailments in times of peak demand or to shift loads to times of low demand. This is the ability that enables these new sources of flexibility to contribute to the restoration of balance between the consumption and generation of power in the electricity grid – to participate in the ancillary services, including the automatic Frequency Restoration Reserve.

Distributed generation (DG) sources provide on-site electricity generation and are generally of relatively small size, usually no larger than the amount of power used at a particular location. A brief overview of definitions of distributed generation by several organizations from the international arena has been prepared by [L'Abbate, Fulli, Starr, & Peteves, 2007]. Since there are relatively low discrepancies between these definitions a common one could be extracted as follows: During FutureFlow DG will be considered as an electric power source connected directly to the distribution network or on the customer site of the meter and smaller than 10MW.

5.1.3 Flexible processes and devices

The need to assess the flexibility potential has not been raised for the first time by this project, rather it has been recognized on several occasions before. Therefore, the potential demand response resources have been identified in a broad range of processes and devices.

Distributed Generation

The selection of distributed generation technologies has been discussed, amongst others, by [Obersteiner et al., 2008] and [L'Abbate et al., 2007] The authors have identified similar technologies as compliant with the definition, which span from non-renewable (like internal combustion and Stirling engines, combustion turbines, microturbines and fuel cells) to renewable electricity source technologies (like wind turbines, small/micro hydroelectric plants, photovoltaic and solar thermal units, biomass units, geothermal plants and ocean electricity units). Unlike demand response, the distributed generation is missing a detailed study on the flexibility potential of individual types of technologies represented by that term. The reason for its absence might be explained by the lack of statistical data and the individualized needs, which consumers have when installing such devices. Therefore, it might be more difficult to draw relevant conclusions about its flexibility potential to the same extent possible with demand response.

Residential sector

[Hamidi, Li, & Robinson, 2009] have analyzed the flexibility potential in the domestic sector and found that responsiveness level does not necessarily correspond to the overall demand level at different times. In fact, it is dependent on different types of appliances which are used. Total responsiveness level overnight is higher compared with other times, since major electrical appliances at these times are night storage heaters, and fridges which both can become responsive. The existing potential for demand response of domestic appliances has been analyzed by [Soares, Gomes, & Antunes, 2014]. Some typical patterns of usage and technical constraints, diversified set of management actions, different rates of penetration of energy management systems as well as the four degree/type of control of loads have been identified:

- Non-controllable loads: loads that when controlled may cause discomfort to the user or perturbation to ongoing activities (lighting, office and entertainment equipment, cooking appliances).
- Reparametrize loads: loads that are thermostatically controlled and allow a re-set of thermostat settings without causing discomfort to the user (cold appliances, air conditioning systems and electric water heaters).
- Interruptible loads: loads that can be interrupted during a short period of time without decreasing the quality of the electricity services provided (cold appliances, air conditioning systems and electric water heaters).
- Shiftable loads: loads whose functioning can be postponed or anticipated according to end-users'

preferences but without bringing discomfort (washing machines, clothes dryers, dish- washers and electric water heaters).

The results have been represented as the daily distribution of the controllable demand potential. It is clearly shown that the highest potential of domestic controllable demand occurs during night time, as well.

Besides technical capabilities of devices and processes also other factors might have an influence on the availability of flexibility. [Torriti, 2012] has found that the occupancy levels of households influence the construction of time-related electricity demand curves and partially determine the availability of flexible devices for DR. His results indicate that differences in social behavior of consumers might influence the suitability of different demand response approaches. For instance, high peak occupancy variance levels might be a field for experiment for so-called 'smart appliances', which can be remotely activated when single-person households are not occupied during a peak event, while low peak occupancy variance stipulates the use of manual and incentive-based DSM programs.

Non-residential sector

In the commercial and industrial sectors two classes of demand response have been encountered: demand turn down and standby generation. The theoretical response capacity available from these two groups differs significantly, with stand-by generation dominating. Stand-by generation is particularly common in sectors that cannot afford supply disruptions, such as sensitive manufacturing processes, some parts of the health sector and data centers. Here, one potential sector is the telecom sector, which seeks to meet 'five nines' (99.999%) availability and continuity of service. As a precaution stand-by generation therefore exceeds in many instances the typical load requirements of those sites. The load profile for the telecom sector is relatively flat. The presence of stand-by generators allows these sites to reduce their load on the grid without having to alter or curtail their electricity consumption. Conversely, the data from the hotel sector suggest that demand reductions here are primarily met by genuine demand 'turn down', especially in the form of suspending air conditioning chiller units, which can make up a large share of the total load. For sites with standby generators, their combined generation capacity often exceeds their typical load levels. Despite this 'overcapacity' it is in practice not always possible to achieve a 100% load reduction. Load turn down is arguably the more challenging form of demand response. The primary mechanism by which consumers in this study responded to load shifting requests was through shifting of thermal loads. Site surveys suggest that up to 60% of loads in offices can be related to cooling requirements. Suspending these for several hours is possible in some cases, before comfort levels for occupants begin to be compromised. The willingness to subject workforces and customers to the possibility of discomfort varies between sectors and sites. For some retail sites the prospect of causing discomfort to customers is unacceptable and even temporary suspension of cooling appears as a risk not worth taking. Other office sites and hotels do engage in demand response, while ensuring that comfort levels are kept within agreed bounds, for instance through strict set points for minimum and maximum temperatures. The wide distribution of responses suggests that while responses at the individual resource level are highly variable, through aggregation of many clients a more reliable resource delivering the average reduction may become available. Contrasting the level of response between the stand-by generation and the turn down response, shows that the former contributes larger and somewhat more tightly distributed reductions. Stand-by generation may therefore be a favored response mode, given its effectiveness and reliability [Grünewald & Torriti, 2013].

Shiftable loads typically feature one of the following characteristics: heat or cold storage (e.g. space heating, refrigerators), demand flexibility (e.g. washing, ventilation) or physical storages (e.g. cement industry, fresh water supply). Industrial load shifting may be limited by technical constraints, process requirements and availability of unutilized plant or machine capacity. For processes with very high utilization rates - as they are found in electricity-intensive industries - only load shedding without previous or subsequent balancing can be implemented. In residential and commercial sector, typically both load shifting and shedding can be realized. Due to higher costs and losses of comfort load shedding only for electricity-intensive industrial processes that can be shifted or shedded for at least 1 h is considered promising - Table 3 3provides an overview of processes and appliances considered promising by [Gils, 2014].

Table 3: Electricity consumers suited for DR [Gils, 2014]

Industry process/appliance	Tertiary process/appliance	Residential process/appliance
- Electrolytic primary aluminium - Electrolytic refinement of copper - Electrolytic production of zinc - Steelmaking in electric arc furnaces - Chloralkali process (membrane/amalgam) - Cement mills - Mechanical wood pulp production - Recycling paper processing - Paper machines - Calcium carbide production - Air liquefaction in cryogenic rectification - Cooling in food manufacturing - Ventilation w/o process relevance	- Cooling in food retailing - Cold storages - Cooling in hotels and restaurants - Commercial ventilation - Commercial air conditioning - Commercial storage water heater - Commercial storage heater - Pumps in water supply - Waste water treatment	- Freezer/Refrigerator - Washing machines, Tumble Drier, Dish washer - Residential air conditioner - Residential electric storage water - Residential heat circulation pump - Residential electric storage heater

A study by [Stadler, 2008] suggests not only electrical devices and processes might be acceptable for providing power flexibility, but also energy storage.

However, the decoupling of electricity generation and consumption cannot be implemented only by use of electricity storage. In the end, electricity is converted into many different electricity services - quite often into thermal energy - which is better suited for storage and has lower costs then electrical storage. Therefore, thermal energy storage is preferred than electricity storage whenever a shift of the electrical load can be achieved by use of thermal energy storage. Those non-electrical energy storage devices have been investigated and emphasis has been placed on the transition to a flexible electricity demand (demand response) with the aim of adapting electricity generation and electricity consumption. Those possibilities can be divided into three categories:

1. Transition to a flexible electricity demand by use of loads with intrinsic storage capacities. The big advantage of this kind of demand response is, on the one hand, that no investment in storage capacity is needed - it is already part of the electric appliance. And, on the other hand, by applying this kind of demand response, the user is not affected at all. The electricity service is always to his/her disposal. The following technologies belong to this category:
    - Storage heating systems
    - Electrical warm water heating systems
    - Ventilation systems
    - Refrigeration
    - Circulation pumps in hot water heating systems
2. Transition to a flexible electricity demand by change of user behavior. As opposed to category one, here the user is affected in his/her daily life
3. Transition to a flexible electricity demand by use of loads (and generation, respectively) that convert electricity into another kind of effective energy. This energy is then stored in order to achieve the desired transition to a flexible electricity demand. The following technologies belong to this category:
    - Combination of heat pumps with thermal energy storage
    - Combination of CHP systems with thermal energy storage
    - Refrigeration with cold/ice storage

Other devices and processes enabling flexibility with energy storage could also be considered, such as electrical water heaters, industry refrigeration, air-conditioning and food production, industrial process heat, indoor and outdoor swimming pools.

The summary of the results shows that the different technologies complement each other quite well. This means that for both the maximum available power and the available time, no significant seasonal differences (depending on outdoor temperature) can be identified. The biggest fraction of available control power derives from storage heating systems and CHP systems. These two categories possess characteristics in the opposite direction with regard to their dependence on outdoor temperature. Thereby, the available control power is close to being constant all over the year. If the fraction resulting from the combination of CHP systems and heat storage devices or from heat pumps and heat storage devices was neglected, the result would be completely different. This means that if one would abandon a system configuration the available control power would strongly depend on outdoor temperatures. [Stadler, 2008] concludes that the complete demand for primary and secondary control power could be covered by demand response with electrical consumer devices with intrinsic storage capacities. Even in minute reserve power, this category could be involved.

5.1.4 Flexible capacity potential

Estimating available flexible capacity is a complex process, since the actual potential depends on numerous factors, including:

- accounting for different sectors - industrial, tertiary and households sector [Gils, 2014]
- temporal availability of flexible loads, the duration of load interventions, the shifting time and the frequency of DR actions [Berger, Eisenhut, Polak, & Hinterberger, 2011]
- distinction between the theoretical, technical, economic and practical potential [Schmautzer, Aigner, Fickert, & Anaca, 2011]
- considering load shedding, load shifting to an earlier time, load shifting to a later time (Gils, 2014) and distributed generation
- willingness to participate in flexibility programs, especially within the house chores (washing, dishwashing, cooling, etc.) [Schmautzer et al., 2011]
- industrial production activity, business hours and electricity grid load (e.g. when the economy is booming the flexibility potential is lower) [Berger et al., 2011]
- household activity level and occupancy variance [Torriti, 2012]

A single research effort, which would attempt to assess the flexibility potential, while considering all the above influences is a very challenging task, which has not yet been performed. Nevertheless, several attempts have been made by various authors to analyze the flexibility potential of DR and/or DG units. While some flexibility estimation reports present only the total installed capacity of flexible devices and processes [Sweco, 2015], other consider numerous influencing factors to identify the flexible part of relevant capacities (Gils, 2014)]. Due to the presented differences and an abundance of influencing factors their results cannot be directly compared or merged. Rather, these efforts can offer a general insight into the character and size of the flexibility in the four control zones of the project.

Various authors and organizations have come to different conclusions on the extent of the flexibility potential, for instance the ENTSO-E has quantified a load reduction potential due to load management of around 11 GW available throughout continental Europe in 2009 and predicted an increase to 14 GW in 2020 [ENTSO-E, 2009]. Larger demand response potential in Europe has been identified by [Sia Partners, 2014] with estimates of 52 GW. This figure represents 9.4 % of the peak load estimated by ENTSO-E for its 34 represented countries. Looking at the share per sector, 42 % of this potential comes from residential applications, 31 % has for origin the industry and 27 % is to be found in the tertiary sector. In a detailed analysis [Gils, 2014] has identified substantial DR potentials in all consumer sectors. They add up to a minimum load reduction of 61 GW and a minimum load increase of 68 GW, available in every hour of the year. Annual averages are around 25 GW in industry, 31 GW in tertiary sector and 37 GW in residential sector. In industry, the reduction potential is almost constant throughout the whole year, whereas in both residential and tertiary sector it varies from less than 20 GW to more than 75 GW. The overall potential features significant variations during the year, which are characteristic for specific consumers and countries. Therefore, country and consumer specific approach is needed for the evaluation of flexible potential of DR and DG units in all four control zones.

Among the four control zones Austria has been (arguably) the most analyzed in terms of the evaluation of flexibility potential of DR and DG units. [Schmautzer et al., 2011] employed a bottom-up methodology in the study of load shifting potential in the Austrian household sector. This is determined based on the use of distribution of household appliances and the corresponding load profile curves. Taking into account a multitude of parameters, the authors of this study conclude that in Austria a theoretical switching potential of 600 MW exists in the household sector, the realistic potential is indicated with approximately 100 MW. [Gutschi & Stigler, 2008] have concluded in their study that sectors with high potential for load shifting are paper / cardboard, iron / steel, mining / rock and minerals, chemicals, nonferrous metals, foundries. Based on the statistical and company related data, as well as surveys they have analyzed the potential of flexible sources that are capable of load reduction for at least 1 hour within the chosen individual consumer sectors. The total of 664 MW of flexibility potential was identified in Austria. [Huetter, Schueppel, & Stigler, 2013] have defined the flexibility potential based on electricity costs. The analysis has been performed by segmenting the consumers by branches and identifying the high, medium and low potential. The results have shown that in the top 40 peak load hours spread over 12 days in 2009 have accounted for a load difference of 450 MW. Based on the numerical simulation authors have concluded that 300 MW potential for industrial demand response exists in Austria. Estimation of the industrial and commercial flexibility potential has also been performed by [Berger et al., 2011]. The authors have engaged in a top-down and bottom-up analysis which produced different flexibility estimates. For the top-down approach they have estimated the total potential at 1,516 GWh, which is 4.3% of the total electricity consumption. Calculation with the average operating hours for different sectors has indicated a 207 MW of potential across all sectors. Based on a UCTE-study they have estimated that 87 MW of flexible potential exits in peak hours limited to the industrial sector. On the other hand, a bottom-up analysis builds from analysis of actual representative industrial consumers. Specific characteristics of DR capable units, such as nominal capacity, annual electricity consumption, operating hours, ramping rates and intervals, number of interruptions, lead times between notification and activation etc., have been considered. The results are expressed as a function of the duration of demand response activity, and presented in groups for 5, 15, 60 and 240 minutes durations. The findings reveal that the industrial potential practically does not change (395 MW @ 15 min duration, 375 MW @ 60 min duration), while the service sector is highly affected by the duration of switched power (517 MW @ 15 min duration, 5 MW @ 60 min duration). In a detailed assessment of demand response potential that can be shifted or shaded for at least 1 hour, taking into account technical properties and DR behavior [Gils, 2014] has identified:

- 5250 MW of theoretical demand response potential in Austria. It is divided between 418 MW of industrial, 684 MW of tertiary and 4148 MW of household flexibility.

The same study has also identified flexibility potential in Slovenia, Hungary and Romania:

- 1222 MW of theoretical demand response potential was identified in Slovenia. It is divided between 135 MW of industrial, 170 MW of tertiary and 917 MW of household flexibility. The results indicate that 75% of the potential exists in the residential sector, 14% in the tertiary, while the industrial potential accounts for 11%.
- 4305 MW of theoretical demand response potential was identified in Hungary. It is divided between 193 MW of industrial, 644 MW of tertiary and 3468 MW of household flexibility. The results indicate that 81% of the potential exists in the residential sector, 14,5% in the tertiary, while the industrial potential accounts for 4,5%.
- 6844 MW of theoretical demand response potential was identified in Romania. It is divided between 764 MW of industrial, 429 MW of tertiary and 5651 MW of household flexibility. The results indicate that 83% of the potential exists in the residential sector, 6% in the tertiary, while the industrial potential accounts for 11%.

In Hungary small consumers can indirectly contribute to wholesale demand responsiveness by letting their suppliers/DSOs directly control electrical appliances that can be turned off without major inconvenience during peak demand periods (mainly water heaters). A report prepared in 2008 suggests that around 1604 MW load participates in this program. Also according to the report, the appliances reach their maximum load within 30 seconds after the switch on by the supplier/DSOs and after that consumption starts to decrease in an exponential manner reaching zero after 6 hours. About the practice of usage of these appliances the report suggests that these appliances cannot be individually controlled but only within larger groups and usually the groups are turned on twice a day, in the afternoon and at night [REKK, 2008].

In Romania the flexibility potential of DR and DG units has not been intensively investigated so far. Nevertheless, [Giordano, 2015] has estimated a maximum load shift at peak hour of 496 MW existed in 2014, under the assumption that 2% of daily load could be shifted.

Considering the complexity of the task to estimate DR flexibility potential it could be recognized that the results of various authors congregate within the same size class. Results clearly indicate that extensive flexibility potential – in the range of several hundreds of megawatts per country - exists. Unlike DR, the flexibility potential of distributed generation has not been researched in abundance. The reasons for this observation might be explained by the lack of available statistical data. Data scarcity could also be influenced by the individualized reasons for installation of DG in practice (e.g. technical reasons: emergency power back up, solving low grid capacity issues; economic reasons: utilization of subsidies; harnessing production process by-products etc.). While recognizing the relative difficulty of determining the flexibility of DG an attempt has been made by this project to evaluate the potential of existing devices to provide generation flexibility – based on various available sources:

- PV and wind DG capacities have been provided by ELES, APG, MAVIR and TRANSELECTRICA. In Table 4 the installed capacities have been presented, where, due to the difficulty in determining the flexible part of capacity (as elaborated in detail in Section 4), it has been assumed that in principle entire capacity could be used for electricity balancing. Nevertheless, it must be stressed that in reality the flexible capacity that could be offered on the market depends heavily on (low) availability and forecast accuracy of RES (as discussed in Section 4 of this document) and potential technical constraints, therefore practical flexibility potential could be significantly lower than presented.

- Small hydro power plants capacities have been sourced from [UNIDO & ICSHP, 2013]
- Fossil CHP (micro and small) capacities have been sourced from [CODE2, 2014; Gauntlett & Lawrence, 2015; The Energy Agency of the Republic of Slovenia, 2016; Transelectrica, 2016]
- Biomass & biogas units capacities [GreenGasGrids, 2013; OeMAG, 2016; The Energy Agency of the Republic of Slovenia, 2016; Transelectrica, 2016]
- Diesel gensets capacities have been extracted from a Europe wide capacity estimation made by [Gauntlett & Lawrence, 2015]. The capacity distributions amongst countries have been (arbitrarily) assumed proportional to the share of GDP.
- The flexible share of installed capacities have been (arbitrarily) assumed as: 100% for PV, wind and small hydro, while 50% flexibility has been assumed for fossil CHP, biomass/biogas and diesel gensets.

The summary of results of the investigation of flexibility (+ sign represents positive flexibility, e.g. production increase or consumption decrease; and vice versa for negative flexibility) potential of DR and DG units presented per individual country and consumer is presented in Table 4.

Table 4: Estimated theoretical flexibility potential of DR and DG units in all four control zones

	SI (MW)	AT (MW)	HU (MW)	RO (MW)
DR Industry[4]	**+119/-16**	**+315/-103**	**+156/-37**	**+677/-87**
Aluminium	+29/-n.a.	+0/-n.a.	+0/-n.a.	+91/-n.a.
Copper	+0/-n.a.	+1/-n.a.	+0/-n.a.	+0/-n.a.
Zinc	+0/-n.a.	+0/-n.a.	+0/-n.a.	+0/-n.a.
Chlorine	+2/-n.a.	+7/-n.a.	+37/-n.a.	+50/-n.a.
Pulp	+9/-2	+67/-17	+0/-0	+5/-1
Paper	+7/-4	+46/-28	+5/-3	+5/-3
Recycling paper	+4/-1	+44/-11	+12/-3	+8/-2
Steel	+42/-0	+46/-0	+30/-0	+255/-0
Cement	+17/-4	+57/-14	+46/-12	+223/-56
Calcium carbide	+0/-0	+2/-3	+0/-0	+0/-0
Air separation	+1/-1	+4/-5	+1/-1	+0/-1
Industrial cooling	+4/-4	+27/-25	+19/-18	+26/-24
Industrial ventilation	+4/-n.a.	+14/-n.a.	+6/-n.a.	+14/-n.a.
DR Tertiary[4]	**+91/-79**	**+363/-321**	**+349/-295**	**+231/-198**
Cooling retailing	+23/-n.a.	+91/-n.a.	+84/-n.a.	+56/-n.a.
Cold storages	+3/-2	+12/-9	+11/-8	+7/-6

Cooling hotels/restaurants	+5/-3	+18/-14	+17/-13	+11/-8
Commercial ventilation	+44/-n.a.	+178/-n.a.	+164/-n.a.	+109/-n.a.
Commercial AC	+4/-n.a.	+14/-n.a.	+26/-n.a.	+17/-n.a.
Commercial storage water	+n.a./-63	+n.a./-253	+n.a./-233	+n.a./-156
Commercial storage heating	+n.a./-0	+n.a./-0	+n.a./-0	+n.a./-0
Water supply	+10/-8	+42/-34	+39/-31	+26/-21
Water treatment	+2/-3	+8/-11	+8/-10	+5/-7
DR Residential[4]	**+128/-789**	**+602/-3546**	**+530/-2938**	**+755/-4896**
Freezers/refrigerators	+54/-n.a.	+268/-n.a.	+269/-n.a.	+397/-n.a.
Washing machines	+19/-111	+86/-517	+108/-646	+159/-953
Tumble dryers	+12/-72	+44/-263	+2/-9	+6/-33
Dish washers	+12/-71	+79/-473	+12/-72	+12/-73
Residential AC	+7/-n.a.	+1/-n.a.	+10/-n.a.	+6/-n.a.
Residential storage water	+n.a./-260	+n.a./-877	+n.a./-938	+n.a./-1088
Residential storage heater	+n.a./-275	+n.a./-1416	+n.a./-1273	+n.a./-2749
Heat circulation pump	+24/-n.a.	+124/-n.a.	+129/-n.a.	+175/-n.a.
Distributed generation*,[5]	**+581/-581**	**+6086/-6086**	**+882/-882**	**+6408/-6408**
PV	+243/-243	+800/-800	+74/-74	+1302/-1302
Wind	+3/-3	+2500/-2500	+329/-329	+2980/-2980
Small hydro	+117/-117	+1109/1109	+14/-14	+387/-387
Fosil CHP (micro/small)	+42/-42	+100/-100	+0/-0	+1068/-1068
Biomass/biogass units	+21/-21	+207/-207	+36/36	+45/-45
Diesel gensets	+130/-130	+1142/-1142	+358/-358	+522/-522
Total	**+894/1440**	**+6965/-9828**	**+1845/-4080**	**+7966/-11485**

* stated data for PV, Wind and Small hydro are equal to their "entire" installed capacity, which is explained in more detail in the text above the table

5.1.5 Existing experiences with aggregation of DR and DG for the provision of ancillary services

Current state of aggregation of DR and DG has seen significant progress in the EU Member States, which took a decision to enable Explicit Demand Response in 2013-14, others are still undergoing regulatory reviews or have decided against making any significant changes at this time. In their report [SEDC, 2015] has highlighted as standout examples the following: Belgium, Finland, France, Ireland and Switzerland have reached a level where Demand Response is a commercially viable product offering. Great Britain has got a highly competitive electricity balancing markets, and open balancing markets. Finland and Belgium have started their positive program and payment structures, which enable consumer engagement, though neither country has integrated independent aggregators fully into their systems as yet. France and

[4] [Gils, 2014]
[5] [UNIDO & ICSHP, 2013]

Switzerland have restructured their program requirements and defined roles and responsibilities of market participants specifically to allow for independent aggregation. Austria and Hungary have also enabled prequalified reserve providers (aggregators) with demand units in their portfolio to participate in the balancing energy market.

As a result of strong political and regulatory involvement since 2004, but especially after the “Brottes” law and the recent Electricity transition law France is becoming one of the most forward thinking and active markets for DR in Europe [SEDC, 2015]. DR is able to participate as a resource in the electricity balancing market since 2013, while providing ancillary services and reserves from 2014, which has led DR to be able to participate in all existing market structures in France. Aggregators are now able to compete on a level playing field with suppliers on upstream markets and with producers on downstream markets. Around 10 DR operators are “active” in France. 10% of the French frequency containment reserve (FCR) is procured through DR. 400 MW out of 1500 MW of the French frequency restoration reserves (mFRR) and replacement reserves (RR) is procured through DR (available twice a day). In 2014 12 GWh was provided to the balancing market by DR (more than 50% of which is residential load). Two specific products have been designed for DR, a “DR call for tenders” and “interruptibility” with capacities of 1700 and 600 MW, respectively [Latour, 2015].

Finland has done several steps to allow Demand Response participation, which is today legally possible for all ancillary services. On the Demand-Side Management side, the TSO Fingrid has also contracts with the largest industrial consumers to provide emergency reserves. Active market participation of Demand Response and aggregation are possible [SEDC, 2015]. Demand response capacity in 2014 has been 200-600 MW at Elspot market, 100-300 MW at Balancing power market, 70 MW at Frequency controlled disturbance reserve, 385 MW for Fast disturbance reserve and 40 MW for power reserve [Jaspers, 2014].

Elia, the Belgian TSO, started in 2013 to considerably extend the demand response contracts used for the ancillary services (in order to balance the system). Originally addressing large industrial consumers, new DR contracts developed by Elia (after approval by the CREG, the Federal Regulator for Energy) are nowadays contracted by Flexibility Service Providers (FSPs) that aggregate DR on both the Transmission and Distribution grids. In addition, a strategic reserve has been defined by the Belgian Authorities to guarantee the security of electricity supply. Out of the 850 MW constituted for the winter 2014-2015, about 100 MW have been contracted with DR aggregators. The pool made of several major Belgian large electricity users is centrally managed to achieve fully automated curtailments in less than 3 minutes [Sia Partners, 2014].

5.2 Case studies

In two case studies flexibility potential is calculated to test the theoretical results obtained by literature review and provide a link between theoretical and field study results. The methodology described by [Gils, 2014] was used, where the proposed input data for calculation have been replaced by actual consumption characteristics of the known industrial and commercial consumers. The results show that the calculations match well with the identified flexibility potential by field examinations (by surveys).

Case study 1 - Electric steel production (industry sector)

For the development of business case 1 we focused on a specific case of electric steel production company from Slovenia. The theoretical DR potential is estimated based on the methodology from article [Gils, 2014]. Final, to verify the methodology obtained results have been compared to results from survey of our customers were also economic potential could be estimated. The analysis is limited to those loads that can be shifted or shedded for at least 1 h.

The potential load reduction $P_{reduction,i}$ (t) in each hour is given by the difference between current load and minimum load of the process, Eq. (2). Its value changes during the year according to the load profile $s_{load,i}$ (t). The minimum process load is defined relative to the installed electrical capacity and given by parameter sminimum,i. The potential load increase $P_{increase,i}$ (t) is calculated from the difference between maximum load and current load, which is at least temporarily greater than zero for all processes operated at less than 100% utilization. This difference is multiplied with parameter $s_{increase,i}$, reflecting the free production capacity share available for DR, Eq. (3).

$$P_{reduction,i}(t) = \underbrace{s_{load,i}(t)\cdot W_i}_{\text{Load in hour t}} - \underbrace{P_{installed,i}\cdot S_{minimum,i} \quad (MW)}_{\text{Minimum load}} \qquad \textit{Eq. 2}$$

$$P_{increase,i}(t) = (\underbrace{P_{installed,i}\cdot(1 - S_{revision,i})}_{\text{Maximum load}} - \underbrace{s_{load,i}\cdot W_i}_{\text{Load in hour t}})\cdot \underbrace{s_{increase,i} \quad (MW)}_{\text{Shiftable share}} \qquad \textit{Eq. 3}$$

In the literature the parameter $s_{minimum,i}$ for the electric steel production industry is proposed to be 0 %. The annual electricity demands Wi and installed electrical capacities $P_{installed,i}$ the year 2015 are 170406 MWh and 42 MW respectively. Based on the above methodology, the theoretical average potential load reduction is estimated to 19.5 MW. The results from survey of our customers show that the economic potential could be estimated to 20 MW.

Based on the literature [Gils, 2014] the $s_{increase,i}$ for the electric steel production industry is 0 %, therefore the potential load increase is estimated to 0 MW.

Case study 2 - Food retailing (tertiary sector)

In general in the tertiary sector DR potentials are available in the supply of cold, heat, water and ventilation, as well as in waste water treatment. Flexible loads in these applications are calculated based on their annual electricity consumptions. In the absence of country-specific data, they are approximated by multiplying the tertiary sector demand[1-3] with average demand shares of the relevant uses. According to survey data published[4] 19.7% of the 2007 electricity consumption in EU-27 countries was used for the supply of space heat and hot water, 12.6% for ventilation, 5.9% for pumps, 8.7% for cooling appliances and 2.9% for air conditioning. All other uses are not relevant to DR.

For the specific case where the food retailing have been examined the DR potentials are available in the ventilation, air conditioning, cooling, cold storage, refrigeration, lighting, heating and warehouse. The electricity consumption for specific process is calculated as:

$$W_i^{unit} = P_{installed,i}^{unit} \cdot n_i^{FLH} \ (MWh)$$

In the assessment of potential load reduction and increase, fixed shares in current load $s_{reduction,i}$ and unused capacity $s_{increase,i}$ available for DR are assumed. In case of a load increase, all demand of the following t_{shift} hours can be advanced.

$$P_{reduction,i}(t,T) = \underbrace{S_{load,i}(t,T) \cdot W_i}_{\text{Load in hour t}} \cdot \underbrace{S_{reduction,i}}_{\text{Shiftable share}} \quad (MW) \qquad \text{Eq. 4}$$

$$P_{increase,i}(t,T) = \sum_{t_o=t}^{t+t_{shift}} (\underbrace{W_i \cdot s_{load,i}(t_0)}_{\text{Load in hour } t_0} \cdot \underbrace{s_{increase,i}}_{\text{Shiftable share}}) \leq \underbrace{P_{installed,i} - W_i \cdot s_{load,i}(t,T)}_{\text{Unused capacity}} \ (MW) \qquad \text{Eq. 5}$$

Parameters for the calculation of tertiary sector DR potentials are shown in the table below - source: [Gils, 2014].

Process/device	s_{demand} [%]	n_{FLH} [$\frac{h}{a}$]	$S_{reduction}$ [%]	$s_{increase}$ [%]
Cooling in food retailing	6.50%	5840	100%	0%
Cold storages	0.90%	5000	100%	100%
Cooling in hotels and restaurants	1.30%	5000	100%	100%
Commercial ventilation	12.60%	4380	100%	0%
Commercial air conditioning	15%	4380	100%	100%
Commercial storage water heater	1.50%	4523	0%	100%
Commercial storage heater	5%	650	0%	100%
Pumps in water supply	3%	4380	100%	100%
Waste water treatment	3%	5694	20%	50%

The calculated installed capacities and annual electricity consumption for the used process are as followed:

Process/device	P_{ins} [MW]	W_i^{unit} [MWh]
Cooling in food retailing	1.633	9536
Cold storages	0.226	990
Commercial ventilation	3.165	13864
Commercial air conditioning	3.768	16504
Commercial storage heater	1256	816

Based on the above methodology, the theoretical average potential load reduction is estimated to 4.7 MW, and could be used in the range from 1.8 MW to 9.5 MW, depending on the season, hour of the day, day of the week, outside temperature, etc.

The potential average load increase is estimated to 4.2 MW, and could be used in the range from 0.9 MW to 6 MW, depending on the season, hour of the day, day of the week, outside temperature, etc.

The results obtained from a survey of actual consumers show that the flexibility potential is estimated to be 12 MW. However, this figure also includes potentials from lighting, diesel generator and warehouse, which are not accounted for in the above methodology. Therefore, the theoretical results are fairly in line with the observed actual values.

[1] Eurostat European Statistics Database. Section nrg_10: electricity statistics - supply, transformation, consumption, dataset nrg_105a; as of November 16, 2012.

[2] International Energy Agency. Energy balances of non-OECD countries, edition 2009.

[3] International Energy Agency. Energy balances of OECD Countries, edition 2009.

[4] Bertoldi P, Atanasiu B. Electricity consumption and efficiency trends in the European Union e status report 2009. Ispra: Joint Research Center, Institute for Energy; 2009.

5.3 Field research – identifying flexibility potential of DR and DG units in all four control zones

5.3.1 Objectives

The objective of the field research was to identify the flexibility potential of DR & DG units in all four control zones and acquire relevant data needed to make the selection of the DR & DG units for participation in aFRR markets and initiate the discussion of participation in pilot test with potential candidates.

5.3.2 Strategy

The market analysis has been divided by control zones/countries (SI, AT, HU, RO). Initial market research plan has been set out to identify main prospects with flexible processes or devices. It has been decided a segmentation analysis should be performed to test the representability of the identified prospects. A market survey and customer acquisition has been found to be the start and finish of the same process, therefore a coordinated approach was needed. Therefore, two questionnaires have been prepared – basic and detailed questionnaire. Customer approaching strategy has been formed, consisting of project presentation documents and questionnaires.

Preliminary preparations for the market survey were in the first phase of market analyses mostly focused on the preparations of the lists of potential companies. Same approach had been used at all four control zones. The final target group had to consider companies, which are "pure" electricity consumers, companies with combination of consumption and production and also companies which are pure producers of electricity. This strategy of selection had a source from both suppliers' data bases. Also important: suppliers did not focus only on the existing customers, but included to their lists other potentially flexible candidates. Before prospects contacting started, additional information about the potential company had been collected (e.g. the number of measurement places, geographical locations, total electricity s consumption during past one or two years, sector of economy), type of the measurement equipment, monthly peak power or net usage classification). These information were not available for all cases.

5.3.3 Segmentation – creating a representative sample

Basic segmentation of the customers had been made: industrial, commercial and power production. On the level of all four control zones, the lists of companies were arranged by their yearly consumption/production. Survey did not omit existing companies already participating at established DR services. For better explanation for Slovenia all existing companies, who are participating in mFRR market had been included in the survey. Further steps which led into the market survey action was the detailed segmentation by sector (1st layer: production, consumption, 2nd layer: industrial, commercial, pure producers, CHPs, 3rd layer: process, non-process for consumption units, resource type for production units and flexible technology, 3rd layer: potential appliances, devices, etc.) For some companies it was difficult to gather and to estimate all those detailed data from publicly available sources. For that purpose gathering the additional data had been left to direct contacts with the company's main representatives.

In general the segmentation could be made on the basis of two main features:

- **Sector:** Industrial or Commercial or Power production; that means that the potential participant shall belong to one of the groups.

- **DR potential;** before making the direct interviews each company can be marked as Co. with or without flexibility potential.

5.3.4 Lists of customers (i.e. the sample)

Presented are some final results of the companies' lists segmentation. Numbers in tables (Table 6 and Table 6) are prepared on the basis of all acquired companies which response on the invitation to participate to this research. The main share is presented by industry; followed by the service sector. Much lower shares are presented by power production and CHP units.

Table 5: Segmentation of the companies invited to participate

Sector	In %
Industry	62%
Power Production	7%
CHP	4%
Service Sector	27%

It has to be mentioned, that the number of invited companies (all contacts) was larger than the final number of received answers. Our analyses do not consider data of all contacted companies, we took only those form received answers.

Companies that could not confirm the flexible capacity present the biggest share, 63 %. The rest are the companies with confirmed potential and those with not jet defined capability. Those companies need more support and further engagement of the project to identify potential sources of flexibility and acquire more detailed information on the type and quality of that flexible potential.

Table 6: Capacity potential

Partners with confirmed capacity potential:	13%
Minor chances to define the capacity potential:	6%
No capacity:	63%

5.3.5 Customer approaching

For this survey, for the main share of the potential companies the necessary contact data (e.g. e-mail, phone) were acquired. Firstly, the e-mails with project presentation and a questionnaire have been sent to the contacts. . Besides sending e- mails, sales representatives strived to directly contact the prospects by phone. Local Slovenian DSO used also their local general managers, who supported the procedure of approaching the potential companies by engaging in phone calls and physical meetings with customers.

Companies with highest estimated flexibility potential have been also physical approached. Those meetings were usually held in the presence of companies' general manager and person responsible for energy. In some cases also persons responsible for technology were present. These meetings proved as effective way for acquiring the information necessary for this project.

5.3.6 Customer feedback

Attempting to estimate the true market potential within this project has exposed the need for an intensive individual approach to each DR & DG customer, due to the observed differences in the knowledge of consumers in self-estimating their flexibility potentials. Nevertheless we have acquired the following feedback.

- The most frequently asked question was, what is the participant's benefit for participating in the pilot test? They expected explanations with concrete numbers, payments for their "activations". Their expectations have clearly been identified as full contribution for all other direct costs on their side which is needed.

Further, customers want to know in advance:

- When and for how long the pilot will last. The season of the pilot was also very important.
- Detailed definition about the activation: signal will start the activation, how fast must be the response, for how log. What is the minimum flexibility capacity in kW which could be offered?
- Customer's express concerns regarding the process interruptions. If one process in the factory will be given the possibility to be managed from the outside, who will guarantee, that this actions will not influence on other processes or product quality.
- It has to be mentioned, that in many cases customers neglected to give precise data necessary even to fill the shortened questionnaire. Reason was in not being yet decided whether they will participate. Meetings with the customers in many cases ended with the conclusion that the suppliers will get other more detailed data later and that from customer' point of view details are not necessary for the preliminary research.
- Understanding the project was always supported by extended explanations of similar markets in Europe
- Customers were kindly asked to sign the Letter of intent. Most project positive oriented customers signed this document (Slovenia).

5.3.7 Analysis of answers

During the campaign how to reach customers, how to establish the contact with the "right" person and how to achieve the willingness for dialogs the success was reached by asking people the shortened version of prepared questionnaire. Avoiding the basic, larger and detailed FF questionnaire, with all details regarding technology and technical issues, confirms that the general flexibility market research must be in the very first, basic phase done by fewer questions. Even though the prospects have been reached at first only with a simple questionnaire their response rate has varied between countries. Out of 3000 questionnaires sent in all four countries the response rate in Austria has been significantly higher than elsewhere. This could be attributed to the fact that Austria has proven to have the most advanced balancing energy market from the perspective of DR and DG participation, which presumably contributes to the higher customer awareness and their willingness to participate (in the questionnaire). The "lively" environment has also enabled other authors to perform large numbers of research investigations in Austria (as described in Section 5.1.4). The least responses have been acquired in Hungary and Romania, likely because of the lack of awareness of the potential for DR&DG to participate in balancing energy market. Furthermore, the FutureFlow electricity suppliers' lack of end-customers in Hungary and Romania makes them fairly unknown to the general public, which also increases the cautiousness of prospects to reveal their internal information, thus reducing their response rates. Tables 7 and Table 8 present the efforts of information gathering and sums the responses:

Table 7: Overview of the market research; the number of questionnaires and received responses

Current results	SI	AT	HU	RO
Number of customers/companies with a aFRR potential	955	410	61	813
Material sent & Direct contact	413	410	35	813
Received short questionnaire	57	357	2	19
Positive answers for the capacity	41	40	2	9

Table 8: Overview of the market research – customer feedback in percentage

Current results	SI	AT	HU	RO
Number of customers/companies with a aFRR potential	43%	100%	57%	100%
Received questionnaires	14%	87%	6%	2%
Positive answers for the capacity	72%	11%	100%	47%

The numbers in tables do not allow direct evaluation of the results. It is difficult to evaluate the level of success. In general the results confirm the complexity of new services which shall be available on the (future) markets. Best results have been achieved in Austria and the explanation is in already established aFRR market. Another important issue: higher is the number of analyzed customers lower is the number of received answers. (Example: DSOs in Slovenia send surveys every year, response is every year app. 15%, after many direct phone contacts the level is 55%). The results somehow show the level of knowledge of the customers: small customers have less interest for new, complex services, especially when services are in very tight dependence with their process or even technology. Large industrial customers, who have their own experts have higher interest and are good co-speakers. Result also show, how large is the existing electricity market of participated suppliers in each country. We cannot compare directly the numbers of costumers in each country. The percentage of successfully contacted customers with positive answers for the capacity confirms that this research was successful.

In general the results in percentages are for this first phase satisfactory. Next activities which have for the aim to collect test field flexibility potential need very focused activities of sales representatives.

The level of received FF questionnaires analyzed by a sector is shown in Table 9. For this analysis we took only the data from adequately answered questionnaires with positive answers regarding the capacity units or with estimation about it.

Table 9: Segmentation by sector, number of received FF questionnaires with the aFRR potential

Type of prosumer	AT	HU	RO	SI	SUM
No answer	0	0	0	4	4
Commercial	9	0	1	20	30
Industry	30	2	9	29	70
Power Production	2	0	9	4	15
SUM	**41**	**2**	**19**	**57**	**119**

From the results, we can see that industrial and commercial customers hold most flexibility potential; power production is represented by much lower numbers. Those results were also somehow expected, because power production had confirmed lower interest to participate. CHPs have for the aim producing energy (electricity, heat) and not to change the production, even for few kW-s or for limited time. To all involved customers only general information about the duration of single activation had been given. The reason was that the duration was not jet known for certain (task of use cases in WP4). Customers were also informed that the activations are not going to be long, not longer than app. 30 minutes. The information regarding the duration was taken from basic rules for the secondary reserve participation.

Next interesting answer was, operating production units. It is important to know, whether industrial and commercial customers have production units inside their buildings, industrial processes, because capacity could be found in these units. Good case is paper and pulp industry (steam and electricity production is an important flexibility potential).

Table 10: Production units operating at industrial and commercial customers, number of companies

	No answer	No	Yes	SUM
AT	**5**	**25**	**11**	**41**
Commercial	1	7	1	9
Industry	4	18	8	30
Power Production	0	0	2	2
HU	**0**	**0**	**2**	**2**
Industry	0	0	2	2
RO	**0**	**8**	**11**	**19**
Commercial	0	0	1	1
Industry	0	8	1	9
Power Production	0	0	9	9
SI	**2**	**24**	**31**	**57**
No answer	0	2	2	4
Commercial	1	11	8	20
Industry	1	11	17	29
Power Production	0	0	4	4
SUM	**7**	**57**	**55**	**119**

FutureFlow

On the other hand, for FF project DG production units are considered as potential flexibility assets. During market research production units located at bio gas facilities, solar, combined heat and power, hydro power production units have been identified. The potential for aFRR market is in participating with power production and aggregation of those units. In further steps, the aggregation approach has to be defined.

When preparing the questions for the survey, the data about the sector were considered also as important. A shortened overview had been prepared, but in general some conclusion might be gathered.

Table 11: Sector, the intermediate results, number of companies/customers

Sector	AT	HU	RO	SI
No answer	1	1	1	7
Agriculture	0	0	1	0
Carpentry and joinery	0	0	0	2
Ceramics	0	0	1	0
Chemical	3	1	0	2
Coating materials	1	0	0	0
El. producer	0	0	4	4
El. production from biogas	2	0	3	0
Fertilizers	1	0	0	0
Foundry	0	0	0	2
Lime, sands and gavel production	0	0	0	1
Machinery industry	0	0	1	0
Manufacture of basic metals	0	0	0	1
Manufacture of glass fibers	0	0	0	1
Manufacture of irradiation, el. and el. eq.	0	0	0	1
Manufacture of motor vehicles	1	0	3	1
Manufacturer of installation switches and sockets	0	0	0	2
Metal industry	2	0	0	0
Petroleum & Oil	1	0	0	1
Pharmaceutical products	0	0	0	2
Plastic	2	0	1	1
Prefabricated Building Materials	0	0	1	0
Production industry	1	0	1	2
Production of cement	0	0	0	1
Production of Cushion Vinyl floor coverings	0	0	0	1
Pulp & Paper	10	0	0	3
Quartz and sand production	1	0	0	1
Refinery	1	0	0	0
Textile industry	3	0	1	0
Waste recycling	0	0	0	1
Services Sector	11	0	1	20

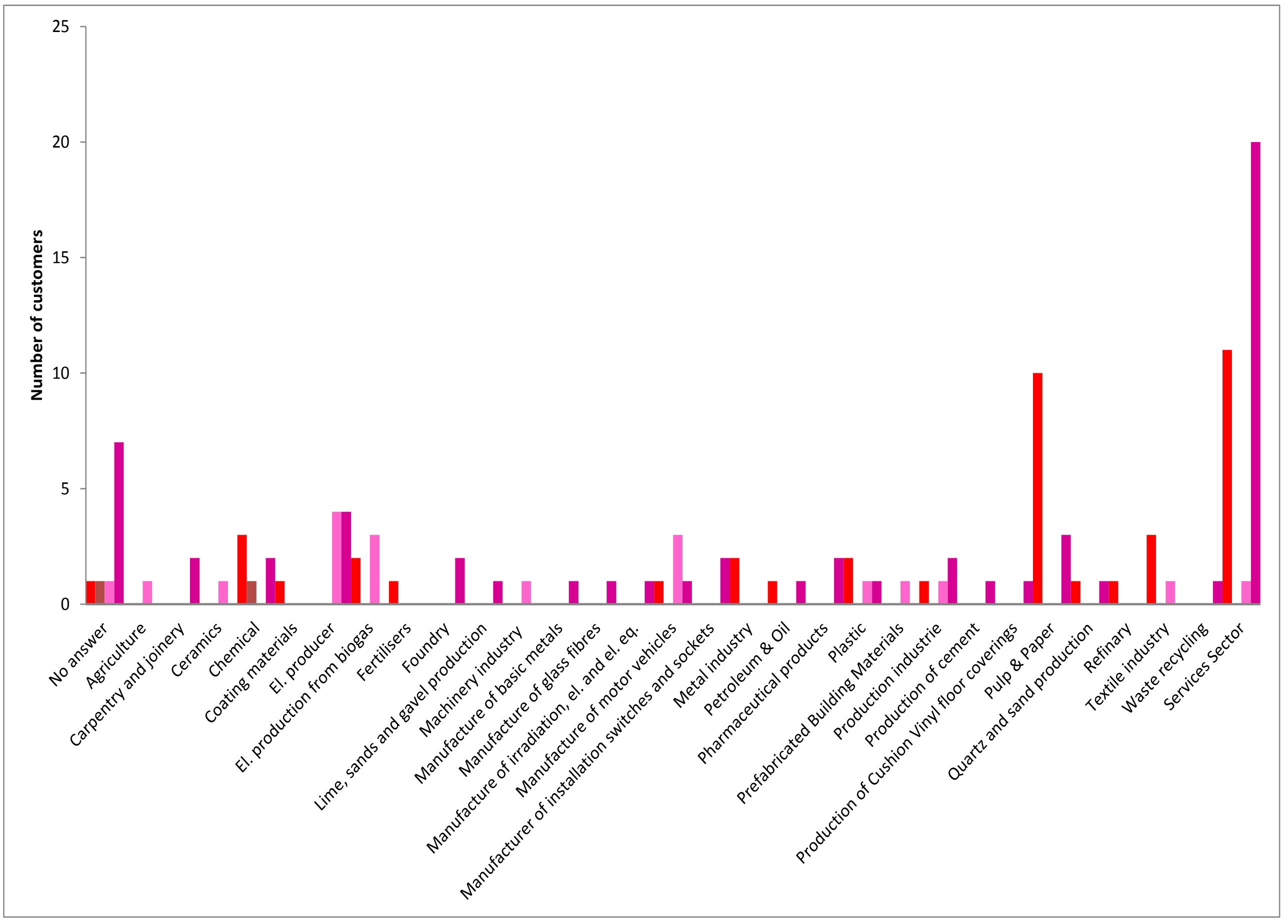


Figure 11: Sector-Graphical overview

Table 11 and Figure 11 provide an indication, which sector might have the biggest available power potential. The services sector includes all those companies, which do not belong to manufacturing. The Figure 11F shows that the commercial customers present the largest number of potential participants, but it is important to mention that a high number of mainly small, spread capacity units can be found in that sector. Going into details, the offered capacity is concentrated in one or more separate devices installed in business buildings (companies which offer sports activities, telco companies, tertiary education, transit traffic, transportation of concrete and bulk, wholesale and retail trade; repair of motor vehicles and motorcycles, retail sale of food, gambling and betting activities, shopping centers, finance and banking, food and dairy, collection of non-hazardous waste…). This sector provided good information about the capability and preparedness to participate.

The results for the manufacturing sectors are more or less as expected. Industrial customers reported considerable potential to provide flexible capacities.

5.3.8 Results

The current result of gathered data from the market shows that the level of received information is sufficient for the first estimation of the theoretical potential.

Within the search for suitable candidates for performing the pilot test in WP5 of this project 318 MW of potential flexible theoretical capacity had been identified, but It must be noted that practical flexibility potential might not be equal to the theoretical estimation of flexibility potential (most likely smaller).

Table 12: Capacity potential

	Number of Capacity units	Estimated power flexibility in kW
AT	**40**	**153400**
Commercial	9	500
Industry	29	112700
Power Production	2	40200
HU	**2**	**50000**
Industry	2	50000
RO	**9**	**31100**
Commercial	1	800
Industry	2	12000
Power Production	6	18300
SI	**41**	**83219**
No answer	3	21200
Commercial	15	16143
Industry	19	43911
Power Production	4	1965
SUM	**92**	**317719**

The identified capacities that are presented in Table 12 do not represent the entire existing flexibility potential. Comparing field results with theoretical estimation shows that the field research has located less flexible capacities. For instance, in Austria only for the industry the theoretical potential is 418 MW, while field research confirms 112.7 MW. Similar situation is in Slovenia. The surveys gave us 83 MW capacities; the theoretical industrial flexibility potential 135 MW.

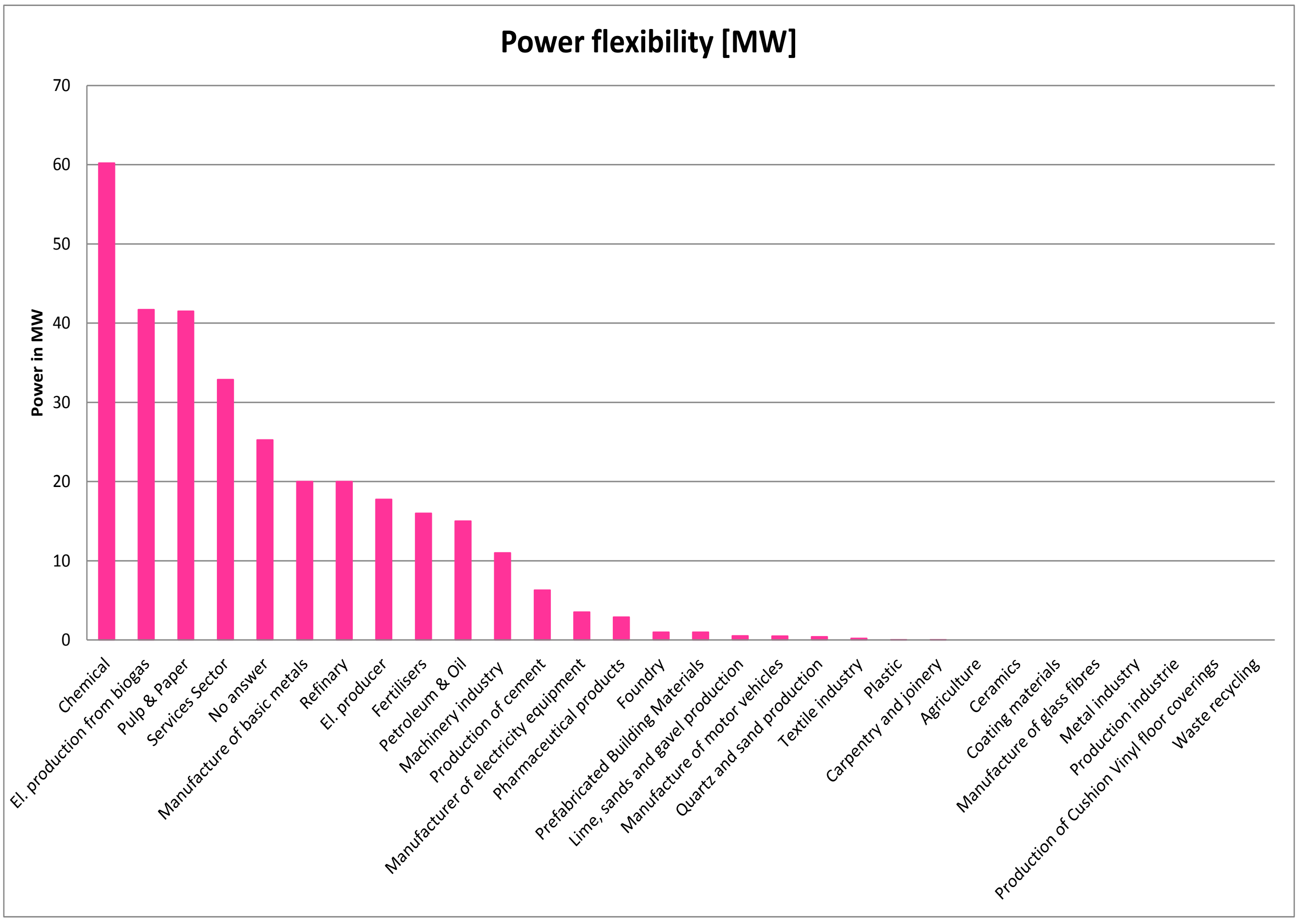


Figure 12: Graphical potential of capacity in industrial sector

Additional important issue is to present the flexibility potential spread among the sectors. The leading manufacturing (industry) sector is Chemical, the second is Production of Energy, the third Pulp & paper and on the fourth place is Services Sector. Service sector is the fourth on the graph, but can offer capacity only as a summarized entity.

Flexible Energy potential

The energy potential can be calculated by the capacity and time of activation. Let assume that the time frame is going to be 15 minutes, than we can count with the potential of 15 minutes multiplied by capacity units in kW-s. But there has to be taken into account, that capacity units can have different availability. Described estimation could be used just for basic evaluation of the energy potential.

Power Response rate (ramping) and response profile (stepwise change, linear change …)

Not yet defined in details, but in general all customers can provide linear response load/production profile, some of them spoke about stepwise. It is important to expose, that we did not yet inform our customers with finally defined time frames of activations, e.g. in which part of the year, how many times per month, week or day. In a lot of conversations with the customers, those data were needed for appreciation of the response rate. We asked customers to be prepared for the executions as fast as possible and that the procedure will be started automatically.

5.3.9 Conclusions

When comparing the results – the allocated flexibility potential, one important characteristic of the surveys is that we have considered as potentially suitable only those capacity units which have known availability. For participating at aFRR time availability is a certain constraint to the manufacturing process. Our feedback gathered from the surveys confirmed that availability is a major attribute that need to be considered. Most customers have devices which can be remotely controlled, but the activations are limited by seasons, working days, day/night time… Our results confirm the highest practically ready flexibility potential lies in the industry and the same conclusion were made in reports of the theoretical capacities.

The results presented in the tables should be considered as theoretical, since the differences in the knowledge and understanding of the potential of flexibility between the subjects of the field survey has proven to be substantial. Therefore it is difficult to consider all information equal in quality, to directly compare them or consider them in a single summed value. The practical flexibility can only be acquired with detailed analyses of each customer, using an individual approach.

5.3.10 Further work

The individualized detailed analysis of the power flexibility will be needed to acquire suitable candidates to perform pilot tests. The process will be supported by the use of the detailed questionnaire and will take place during the customer acquisition task in WP5. Acquired information will enable the project a better insight into the "intimate" character of the flexibility potential, thus providing a better understanding of the practical potential for aFRR in the four control zones. Further work performed in WP5 will therefore provide an upgrade to the identified theoretical flexibility potential of this initial research.

Analyzing the capacity units and inviting customers to participate has proven not to be the process which could be concluded at once. Interested prospects require additional information and more time, before confirming their final participation in the pilots and to be able to decide on formally joining by signing contracts. This process is continuously running and is also one of the which will be partly done in WP5 within Task 5.1 at customer acquisition and selection of appropriate units – before signing of contracts.

5.4 Recommendations for aFRR market design from a C&I perspective

Europe's electricity goals and political promises, which are reflected through the European Network Codes, the Energy Efficiency Directive and the European Commission's Energy Union Communication, are striving to achieve a low carbon, efficient electricity system at a reasonable cost, secure supply, renewables integration, improved market competition and consumer empowerment. Demand-side flexibility has been recognized as an important facilitator of these public aims.

To fulfil Europe's energy goals and political promises, it will not be sufficient to engage one group of consumers, in one program type, for one market. The full range of demand-side resources available (at competitive prices) must be engaged, and the full range of consumers must have the ability to benefit from their flexibility. These demand-side resources may include their consumption, use of distributed generation and/or storage capabilities [SEDC, 2015]. While the flexibility potential from the residential sector might not be negligible, some studies [Feldman & Lockhart, 2014]) imply that even with new technology, residential DR won't provide the peak load reduction the grid needs. In addition, the financial incentive for C&I facilities to participate in DR is far more lucrative than for residences. Another problem with residential demand response as a resource for grid reliability is engagement of consumers, since savings on monthly electric bills may not be enough to entice consumers to change electric use patterns. On the other hand, the C&I participation in the demand response programs has already proven to be a functioning market (see Section 5.1.1).

(Explicit) Demand Response requires the coordinated participation of the full electricity value chain. The players involved include the TSO in balancing markets, the DSO, the supplier, the Balance Responsible Party (BRP) and the aggregation service provider. Most consumers do not have the means to trade directly into the electricity balancing markets. In order to engage, consumers therefore require a clearly defined offer, which is both simple to use and contains clear benefits. And they require a party with expertise in selling and providing this offer through aggregation. Aggregation service providers (who may or may not be electricity suppliers) are therefore central players in creating vibrant demand-side participation and Explicit Demand Response. An aggregator's success is entirely dependent upon the successful participation of the consumer in Demand Response programs. The introduction of this role into a market creates critical momentum around the growth of Demand Response, attracts private investment and spurs competition between service providers.

To enable the participation of independent aggregation service providers in a safe manner, the relationship between the BRP and the aggregator has to be clearly defined. Standardized processes for information exchange, transfer of electricity, and financial settlement between these parties are a critical requirement in order to facilitate the smooth functioning of the markets and ensure consumer protection. These should protect consumers' right to choose providers freely, while at the same time ensuring that market functions remain stable, in particular the one of the BRP [SEDC, 2015].

5.4.1 Regulatory needs

To enable conditions for healthy competition between the different market actors, traditional and new, the regulatory environment should create a level playing field for all competitors, where not only the very largest industrial consumers, with their own bilateral power purchasing agreements, can participate in Demand Response programs. To enable consumer participation, a set of regulatory steps (made by TSOs and National Regulatory Authorities) should be fulfilled. Considering the aim of this project, which is resting on top of the Europe's energy goals, firstly:

1. Cross-border organized market should be established

   Opening the market would increase the number of potential resources, thus increasing competition which should lower the prices on the competing market. Increasing the market size - to which resources can have access - would likely enable the cheaper sources to be activated more, which would in turn further decrease the cost of aFRR balancing energy activation mechanism. In cases where the competition and flexible capacities are insufficient, cross-border activation of resources could prove as an important enabler of the aFRR market formation or its liquidity.

   Available cross zonal capacity (CZC) is needed to transfer the balancing energy between control zones. CZC in some directions where there are underutilized CZC by the electricity market, the available CZC could be potentially used to open access to additional resources. Additionally, if the CZC prices will allow for it even on congested borders we could see reservation of CZC for balancing electricity.

   Allocation of CZC and its price needs to be transparent, since it might influence the price of cross-border bids and their position on the common merit order list. Cross-border market design should ensure that no arbitrary or non-transparent interventions in the amount or price of CZC are made by TSOs to ensure efficient and fair functioning of the cross-border aFRR market. Further integration of balancing markets into a single market would be beneficial in terms of lower total required amount of aFRR.

Secondly, following are the basic requirements for DR & DG inclusion in aFRR markets, which are in some parts still not implemented in some countries:

2. Participation of demand-side resources in electricity markets should be authorized
3. Aggregated load should be allowed and encouraged to participate
4. Enabling independent aggregation

   Create a level playing field on which new market participants (small production units and loads) typically pooled by aggregators can compete with (larger) incumbent companies, encouraging market competition, improved services and freedom of choice for consumers. This includes provisions that allow aggregators to offer Demand Response services to consumers independently of the consumer's BRP/supplier, which is potentially its competitor.
5. Include processes for correcting the volumes in each affected balancing group, rules for

compensation between BRP and aggregator, and provisions for information exchange that safeguard commercially sensitive information.

6. Create a standardized framework to allow the market to function reliably

   Standardized rules should set out definitions and processes on:

   - Volumes: Standardized processes for assessment of the traded electricity between the BRP and the aggregator, as well as the development of measurement and verification requirements (baseline methodologies).
   - Compensation: A price formula to calculate the price for the transferred electricity.
   - Data exchange: A clear definition of what data needs to be exchanged between BRP and aggregator to ensure both can fulfil their obligations whilst not having to share commercially sensitive information. Communication protocols that are provided on the competing market by reasonable amount of commercial providers should be used.

7. Technology biased program participation requirements should be avoided

   Consumers may be blocked by historical reasons, which were designed for the convenience of the national generation fleet only, and have not yet been updated to include the capabilities of demand side and distributed generation resources, thus preventing the access to the market to new players.

8. Shifting the attention from the resource towards the aggregator

   Prequalification, registration and measurement responsibilities should take place at the aggregated level. It is important that, in the case of aggregation (by third party aggregators or suppliers), the communication protocols imposed are between the system operator and the aggregator. These protocols should not be mandated down to the individual customers. The latter communications should be at the discretion of the aggregator and his customer(s), so long as the aggregator is able to appropriately aggregate the data from his customers and pass that data to the system operator per specified protocols. This ensures that the system operator secures the data without additional special communications equipment and avoids the system operator the requirement of further transposing the data between communications systems once received.

   This distinction is necessary because services provided by aggregated load can involve communications with hundreds of remote customer sites: quite a different situation from centralized generation. Communication requirements that may seem reasonable for a large power station are often prohibitively burdensome when applied to hundreds of individual customers. In the case of prequalification process in a highly developed aFRR market with massive participation of resources (households, for example) would require substantial efforts and costs (for TSOs and aggregators) due to frequent changes caused by the tendency towards customer empowerment and their free choice of service (aggregation) providers.

9. The market should be more transparent

   Payment criteria, volumes and values should be more transparent and based on open and fair competition. For similar services delivered to the system, meeting the requirements of the market, compensation for Demand Response services should be commensurate with those services delivered by generation.

10. Fair treatment based on risk for the system should be implemented and regulation should not favor one resource over the other

    It is important that regulators do not use a one-size-fits-all model or they may unintentionally shut out consumer participation: Meter accuracy, IT and communication infrastructure (hardware and software) requirements, penalties for non-compliance are all needed to ensure reliability, so both supply-side and demand-side resources should be responsible for its contribution. That said, requirements for each may need to be differentiated depending on the market and resource. The calculation should be realized on risk for the system, related to the non-compliance impact (different for each market and resource). For example, the same measurement and communication requirements should not be used for a 500 MW power plant and a household. Unnecessary and unleveled requirements might be a major cost driver for smaller participants and a major consideration in what type of facilities may be able to participate in the market or program.

5.4.2 Product design

In order to enable the inclusion of new sources of flexibility to the aFRR market, the products should be designed by considering their characteristics and limitations these sources are facing.

1. Full Activation Time (call time)

   The more time consumers have to prepare for an event, the higher the participation level and the lower the cost. FAT of 15 minutes is therefore recommended.

2. Minimum and maximum bid quantity

   The minimum bid quantity should be as low as possible, since DR and DG are by definition smaller than conventional flexibility providers. Based on currently existing limitations of the minimum bid size in the four control zones and across Europe, 1 MW is recommended as minimum bid size.

3. Symmetrical products

   Few consumers and distributed generators (especially RES) can increase and decrease consumption or production equally. A requirement for symmetrical bids acts as a significant market barrier to consumer participation.

4. Price of the bid

   - Prices should be transparent and communicated in advance. Presumably auction based with publicly cleared prices and clearly defined type of the settlement.
   - They should also be the same for all market players, including DR & DG.

5. Divisibility (minimum and maximum load amounts)

   There should be no minimum load size for any single consumer who joins an aggregated pool. This should be set by the service provider, not the TSO (or the DSO).

6. Product resolution (in time)

   Shorter duration of activation would enable significantly more prosumers to participate with their available capacities and presumably for lower costs. Nevertheless, considering that availability requirements would not apply downstream aggregators, then the product resolution does not disable the participation of low availability flexibility units nor affects the harnessing of potential flexibility capacity available to aFRR. In the case of aggregation of flexible resources the product resolution of 1 - 4 hours is recommended.

7. Mode of activation

   A description of how a device is turned on/off and communication requirements and activation of the consumer should be the aggregator's role.

6 aFRR measurement and verification methodologies

6.1 General introduction

In an aFRR control system the behavior of the units providing the service must be monitored in real time for several reasons. Since most units applicable to aFRR are used for more than one purpose at the same time, e.g. generation of power for the electricity balancing market and provision of aFRR to the TSO in parallel, it is essential to define and monitor two values: the current measurement of generation or consumption and the baseline, which represents the planned point of operation if the unit would not be in activation (i.e. it would not provide aFRR electricity in that moment). In many cases the baseline is not identical with the minimum or maximum of available power of the unit but between those two values. The difference between measurements and the baseline is the activated power for aFRR, as show in Figure 13. In the verification procedure the activated power has to be compared with the set-point which is continuously calculated and sent out by the TSO. The same principle is applied whether a unit is considered as a net generator or a net consumer. The TSOs will use the values of activated aFRR submitted by the units to evaluate if the unit provides the requested power output within a tolerances band and if the unit reaches the requested power within the predefined full activation time (FAT).

The methods for verification which are discussed in this chapter can be applied on unit level or on portfolio level. In general there should not be a difference between the evaluation of a single unit with large capacity or a portfolio of units with lower capacity; from TSO's perspective the portfolio should be treated like a single unit.

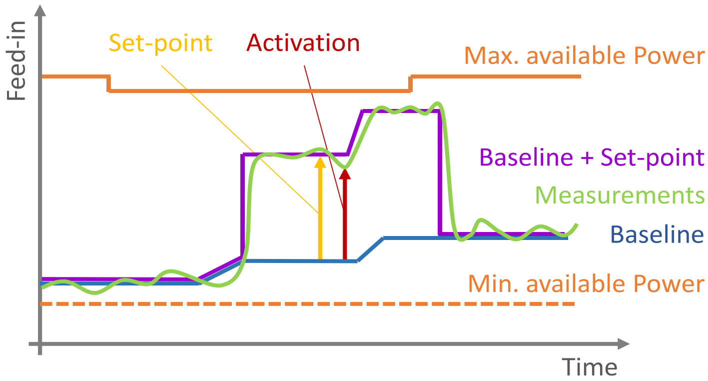


Figure 13: Definition of the aFRR power provided by a unit as the difference between current measurement and baseline. Generation is considered as positive and consumption is considered as negative.

In the FutureFlow project reserved flexible capacities can be activated by a TSO to reduce the area control error (ACE) of the own control zone or of another control zone. Assuming that the TSO-TSO-model [ENTSO-E, 2015 a] will be applied, it is always the task of the connecting TSO to verify the aFRR provision.

It is the aim of this chapter to give an overview about some common practices for taking measurements and calculation of the baseline. Focusing on the four control zones, currently applied rules and methods are explained in brief to provide a deeper understanding of the challenges of aFRR measurement and verification. It is not indented to propose a general rule or recommendation but rather to show several good practices which are applicable in different cases. Further the different approaches in different control areas are explained in some subchapters.

Primarily the power activated for aFRR is used for the P/f-control process but the data measured on-side of the unit and submitted to the TSO will also be used for further purposes like monitoring of the units performance and its compliance with the TSO's requirements, the accounting and financial compensation of the service, ex-post correction of power market schedules (power market clearing), calculation of imbalance costs on system level and balance group level and even calculation of grid fees.

To be applicable to the above mentioned purposes the verification methodology must fulfil the following requirements:

- Transparent calculation rules.
- Accuracy, including lack of bias and appropriate handling of weather-sensitive resources.
- Reproducibility.
- Consideration of characteristics of different resource types.
- Simplicity and as a consequence low computation effort.
- Prevention of gaming.

While the measurements must be submitted in real time some TSOs require that the baseline will submitted in advance of several hours or minutes (at least equal to full activation time, FAT) while other TSOs prefer to receive the baseline in real time.

Initially the rules for aFRR markets have been developed for large generation units but in the past years new sources of flexible capacities have started to enter aFRR markets and proven to be reliable providers. These units are distributed generators and distributed loads which are characterized by a smaller unit size and smaller flexible capacity compared to conventional generation units and are therefore aggregated into pools of flexibilities. With respect to aggregations of units into pools additional rules have proven to be good practices in some control zones:

- The TSO treats a pool of distributed units like being one large physical unit. The control of the distributed units inside the pool is duty of the pool operator.
- Pool values are the sum of individual values (measurements, baselines, etc.) of the units in the pool.
- An individual baseline should be defined for each unit.
- In most cases it makes sense to use a dedicated baseline only during a called activation of the unit, during the rest of time the baseline should be identical with the measurement in order to prevent unintentional indication of delivery.

- Close to real-time verification is usually done by TSO on pool level.
- Verification of individual units is done by BSP for the purpose of internal accounting.
- Recurring validation of measurements is duty of the aggregator.
- BSPs or TSOs archive data of each individual unit but only the pool values are sent to the TSO periodically (e.g. in 2 s interval).
- BSPs may be required to archive data of individual units for several months for ex-post verification of the whole pool; TSO may use archived values for random verification of an activation. Archive data must be stored for several months or until the second clearing.
- Verification is performed by TSO with respect to the following characteristics:
  - Activated power during at a stable operation point (activation with constant power for a duration longer than the FAT)
  - Ramping behavior of pool: Ramping-up and ramping-down behavior must comply with the FAT.
- If a single generation unit or a pool will provide more than one service at the same time (e.g. participating in RR, aFRR and mFRR market during the same period) the baseline must be the same for all markets. Specific rules of the TSO have to be taken into account in order to distribute the deviation from ideal delivery amongst the provided products.
- Depending on the characteristics of a unit inside a pool, the unit can be activated only in discrete steps or follow to continuous set-points (received from BSPs). It is the duty of the BSP to arrange the portfolio of units and control the individual units in such way that the set-point received from the TSO can be fulfilled by the BSP.

6.2 Measurement

6.2.1 Definition of metering points

Due to the fact that new providers of aFRR may be operating an industrial power grid connection several loads and generators the definition of the metering point has become an important issue. Figure 14 shows the two approaches for the location of the measurements for aFRR purposes.

Case A represents the classical approach where the power exchanged with the public grid is measured directly at the grid connection point (directly after in parallel to the billing meter) and being used to provide the measurements to the TSO for the purpose of verification. Further the TSO may require that measurements of relevant units (generators and loads which are technically feasible and qualified to provide aFRR) are monitored and archived internally. This method is applied for classical power plants.

The advantage of this approach is that the direct effect on the public grid is measured and submitted to the TSO and that the billing meter can be used for validation of the power measurements. On the other hand the control variable (measurements used for control) are a sum of the facility's loads and generators which may cause enormous power fluctuations on the gird connection point. In most cases it is a challenge for the internal generators to compensate the load fluctuations in order to reduce the fluctuations on the control variable. Thus the method is better suitable for mFRR where the required interval between measurements is longer than for aFRR with required intervals of max. 2s.

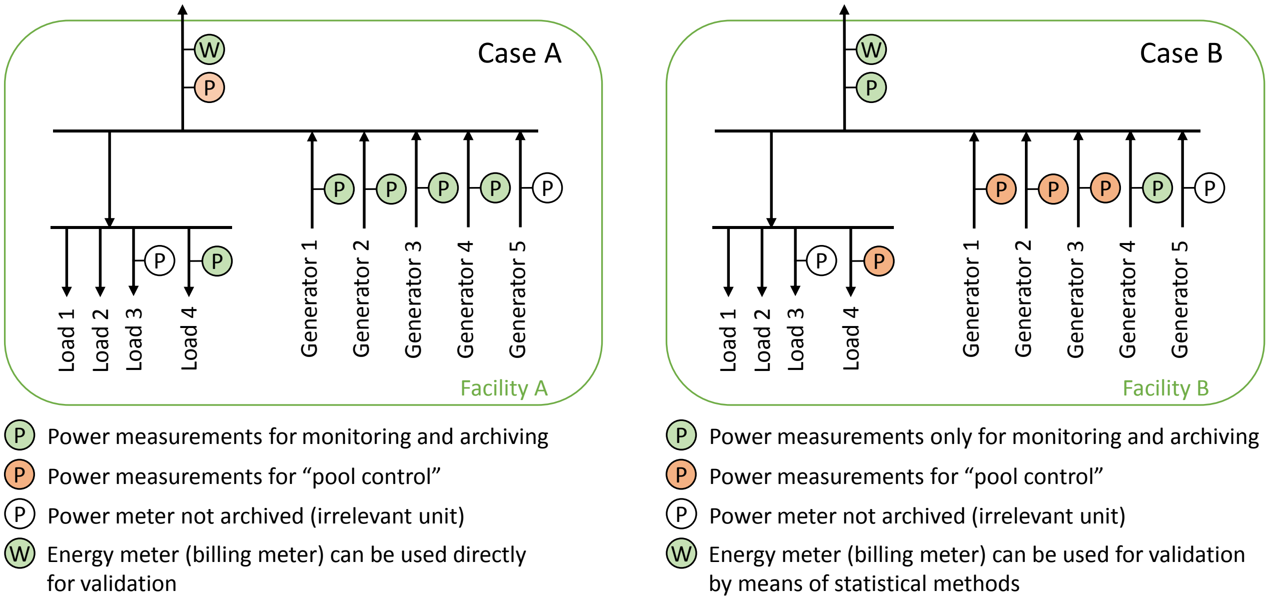


Figure 14: Possibilities to define the metering level for aFRR. "Pool control" mean the values provided to the TSO directly or to the BSP, who forwards it to the TSO. Some TSO may also require or accept other definitions of the metering level.

Case B ("meter behind the meter") uses measurements on machine level to build the control variable as the sum of the qualified units (e.g. Load 4, Generator 1, 2 and 3 in Figure 14) while the measurements at the grid connection point and of further relevant units (e.g. Generator 4 in Figure 14) are monitored and archived internally in order to proof the correct behavior in average. The advantage of this approach is the avoidance of fluctuations caused by units which are irrelevant for the control. These fluctuations are influencing the power system in any case and thus should not be influencing the control variable, too.

The disadvantage is that a direct validation of the control variable is not possible. Statistical methods must be applied to evaluate the correlation between the control variable and the billing meter readings. In some technical configurations the method could be vulnerable for un-intentional counter-steering against the control variable, e.g. if Generators 1-5 would be supplied by a common steam generator and steam rail. Therefore, the applicant has to proof the ability to reliably control the internal units during the pre-qualification procedure.

6.2.2 Accuracy of measurement devices

In many control zones the required precision of the measurement devices (voltage transformers, current transformers and power transducers) is given with an accuracy class of 0.5% related to the maximum measurement range. Some TSO even require devices with an accuracy of 0.2 %. These requirements is derived from the historic fact that rather large units were used to provide aFRR.

Nowadays distributed RES and industrial resources can also be applied in aFRR systems. With respect to industrial applications the tight accuracy requirement represents a barrier for some facilities, since internal power measurement in industry often only has a precision of 1% and a replacement of existing devices with more accurate ones is not economic in the usual case.

BSPs argue that a relative accuracy of 1% would be sufficient because of the lower capacity of decentralized units. As shown in Table 10 the range of absolute error of a small unit is very low compared to the absolute error of a conventional generation unit. Further BSP claim that due to the high number of units inside the pools there is an averaging effect which should reduce the relative error of the pool compared to the accuracy class of the individual units.

Table 13: Comparison of measurement accuracy and range of absolute error

	Nominal power	**Accuracy**	**Range of absolute error**
Combined cycle gas turbine (CCGT) block	400 MW	0.5 %	±2 MW
Gas turbine	50 MW	0.5 %	±0.25 MW
Industrial steam turbine	10 MW	1 %	±0.1 MW

As a compromise the TSO may agree to use data from a measurement device with an accuracy worse than 0.5% if the unit commits to over-perform at least with an amount covering the maximum expectable error caused by the lower precision of the applied measurement infrastructure. For example, if a unit with a nominal capacity of 20 MW is equipped with a meter with an accuracy of 1% instead of 0.5%, the over-performance could be either 0.5% of the requested power or 0.1 MW over the whole range of operation.

On the other hand, if a TSO defines tight requirements for under-performance and over-performance, this requirement can present a barrier to the participation of demand response in aFRR markets.

6.2.3 Filtering of measurements

As mentioned above some units may show significant fluctuations on the power measurement signal. This can have an impact on the aFRR activation calculated as difference between actual (fluctuating) generation and (constant) baseline value. In order to reduce the short-term power fluctuations on the aFRR activation signal the measurements could pass a low pass filter. It has to be taken into account that many simple filtering methods like moving average calculation will result in a signal delay, which must be kept short because of the general requirement of maximum 5 s of signal transmission delay [ENTSO-E, 2009]. This correction method might be questionable in some cases and requires an agreement between TSO and flexibility provider in the prequalification procedure.

6.3 Online data requirements of TSOs

In order to maintain the closed control loop and for close-to-real-time verification the aFRR providers have to send online data of the flexible resources to the TSOs during periods of active participation in the aFRR market. In case of a pool or portfolio only the pooled values must be submitted in order to keep the data traffic to be processed by the TSO in manageable limits. Usually TSOs require that data must be submitted in intervals of 2 s or spontaneously if a change appears. According to the Continental European Operational Handbook [ENTSO-E, 2009] the sample interval should not exceed 10 s and the largest transmission delay (between field measurements and secondary controller of the TSO) should not exceed 5 s.

Usually required data:

- **Actual Measurement Value.** Representing the current sum of all actual measurement values of units in the pool
- **Baseline of the pool**. This signal represents the current sum of all actual baseline values of all units in the pool.
- **Baseline Forecast**. The (indicative) baseline forecast is defined as the baseline value in 5-15 min (in the future). In an interval of 2s a single value is sent to the TSO representing the (expected) value of the baseline in a future moment (e.g.5 min in the future). This "forecasting time" is a predefined constant value and must be at least equal to the required full activation time. This method is usual in Austria and Germany and can also be used to submit a binding baseline.
- **Provided active power** (aFRR activation). This value represents the sum of activated power in the pool, which is calculated on unit level by the difference between measured value and baseline.
- **Returned Set-point**. The TSO sends the set-point for the aFRR activation of the pool to the VPP. The VPP must return this value to the TSO in order to monitor the correct function of the control loop, the communication line and signal delay.
- **Status of the pool**. A binary value indicating the availability of the pool to provide aFRR
- **Available Positive Capacity** for aFRR. The currently existing (reserved) capacity to provide positive direction aFRR out of the pool is sent to the TSO.
- **Available Negative Capacity** for aFRR. The currently existing (reserved) capacity to provide negative direction aFRR out of the pool is sent to the TSO.

  Depending on TSO's specifications; these may be a fixed values representing the reserved capacity based on accepted bids or a dynamically calculated value based on reserved capacity and current activation, e.g. a pool reserved 10 MW positive direction capacity and 5 MW negative direction capacity and the current activation is -2 MW. In that moment the available pos. capacity is 12 MW and the available neg. capacity is 3 MW. Depending on the TSO's requirements the available positive and negative capacity should be sent as an absolute value or relative value.

Current measurements are required by all TSOs in the FutureFlow project. Most TSO additionally require the currently provided active power (aFRR activation), the Returned Set-point and Status of the pool. Further online signals as explained above may be required by some TSO.

Some TSO require the submission of a baseline (schedule) some hours in advance instead of a real-time value. This requirement is limiting the applicable methods for baseline calculation.

6.4 Baseline methodologies

6.4.1 Overview

A baseline is a way to express the expected consumption or generation profile of a unit and it is a basis for all monetary settlement of aFRR provision. Observed resource consumption or generation values during an activation are compared to baseload prediction in absence of an activation like shown in Figure 15. Based on data or algorithms to calculate the behavior without activation a baseline is constructed which makes it possible to evaluate the effect of the activation.

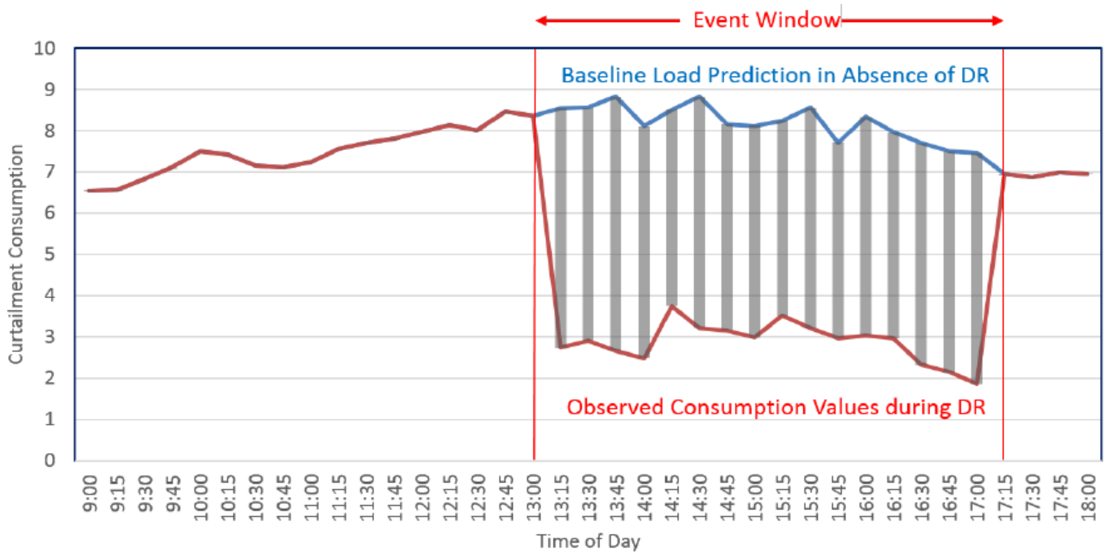


Figure 15: Conceptual diagram of consumption reduction estimation [Chelmis et al, 2015].

There are several standard ways to calculate a baseline, each having its advantages and weaknesses in terms of simplicity or practicality.

Only few literature is available about baseline calculation rules. In this chapter some frequently used baselines methodologies and fields of application are described. The order of appearance in the text does not mean a ranking of better or less suitable methods. A qualitative comparison of different methodologies is not intended because the special characteristics of different sources of flexibilities, the TSO's approach for P/f-control and the national clearing rules for the power market will require the application of different baseline methodologies. Awareness must be raised that there is no general baseline methodology which could cover all the different needs. Many TSOs accept different baseline methodologies in order to adapt to the characteristics of various sources of flexibilities. As long as the requirements for baselines (see 6.1) and aFRR provision are met by a resource the provider should be free to define a baseline on unit level appropriate for the behavior of the specific unit. This approach is already supported by several European

TSOs and has been proven as a driver for the participation of new sources of flexibilities like RES and industrial generators or loads.

It has proved to be good practice to calculate baselines on the level of individual resources. If several resources are aggregated to build up a pool the baseline of the pool is the sum of the baselines of the individual resources. If this rule is applied, then there is no need that the baseline calculation method must be identical for all resources in a pool.

In the following fundamental baseline methodologies are described. To support the understanding of the reader some simplified figures with a constant activation profile are added to the text to explain the main principles. The reader must be aware that in real aFRR activations the set-points can change continuously. In systems with pro-rata activation it is very unlikely that a unit will receive a constant aFRR set-point over a longer period.

6.4.2 Baseline correction

Some baseline methods, e.g. if the calculation is based on historic profiles or on the power market trading schedule, will usually show a gap between the forecasted profile and the real generation or consumption of a resource. In fact many units will operate with a certain level of imbalance in relation to the power market schedule. If a unit participates in an aFRR system the level of the baseline is of higher importance because of the impact on the calculation of the aFRR activation, as explained schematically in Figure 16. In case (1) no baseline correction is applied. A unit, which was imbalanced before the command for activation, would only change the generation until the difference between generation and baseline are equal to the requested activation. The net effect of generation change is depending on the level of imbalance before the start of the activation but will be different from the activation requested by the TSO and this behavior may cause a negative impact on the quality of P/f-control. Case (1) may be favorable for some generators because the imbalance (and related costs) would disappear during the activation.

In order to provide the expected effect on the power system a correction of the baseline must be performed, e.g. as indicated in case (2). If the resource receives a command for aFRR activation the profile of the trading schedule is shifted vertically to reach the level of generation at the moment of received activation command. The amount of correction should stay constant during the whole activation. If the generation shows significant fluctuation, an average of measurement values during a short period before reception of command can be used as target value for the profile shift. Due to the baseline correction the net effect on the power system will be according to activation command. For the generator the calculated imbalance level at time of reception of activation command will continue during the whole activation. Thus the generator will be motivated to keep the initial imbalance (in times without activation) low to reduce the risk of imbalance costs.

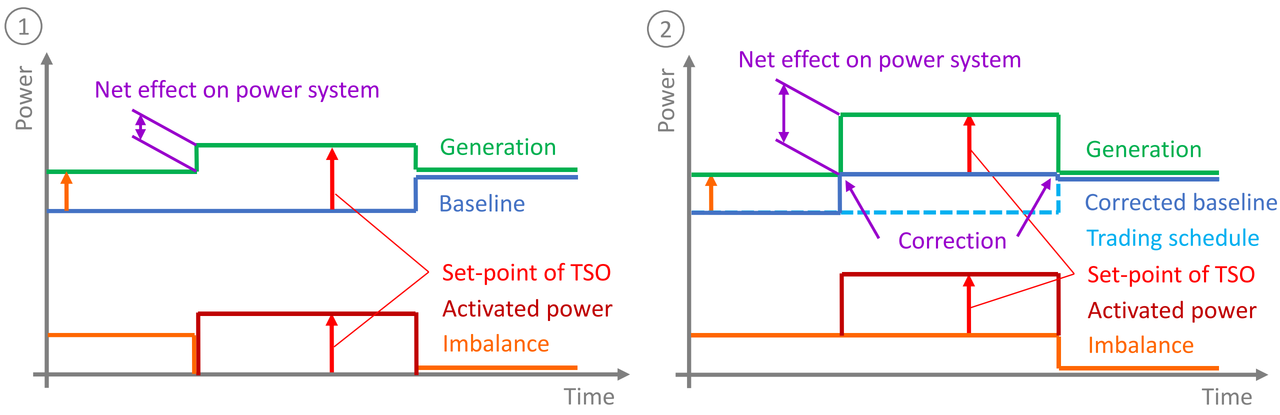


Figure 16: Impact of baseline correction: The net effect of an aFRR activation and the calculated imbalance is influenced by the baseline correction. (1) no baseline correction; (2) baseline is corrected by a vertical shift to fit to the actual generation value before the start of the activation. Correction of baseline only takes place at the beginning of an activation and eventually after the end. During the activation the baseline should not be corrected again.

If the baseline is sent to the TSO in advance the correction must be performed by the TSO as part of the verification procedure. Additionally, the provider also has to calculate the correction in order to determine the appropriate point of operation of the unit. Experience shows that even a short time delay between the baseline corrections done in parallel by two separate systems may result in a deviation which may be in the range of the tolerance band if there is fluctuation on the measurement. This is the main drawback of a baseline correction. As a countermeasure the TSO can loosen the tolerance for over-performance, which gives the provider the chance to operate on the safe side.

In case of a baseline sent in real-time the correction is only performed by the control system of the unit or the pool, thus the challenge explained above will not appear.

6.4.3 Type of baseline applicable for aFRR

Baseline based on power market trading schedule

The utilization of the power market trading schedule is a generic and obvious method to define a baseline. This method is applicable in many cases, especially for conventional generation units where it is feasible to follow a schedule without considerable imbalances. The schedule can be based on the day ahead market or even include the intraday trading. In the ideal case the schedule at gate closure time of the intraday market will be used as baseline. An issue can arise if the TSO requires submission of the baseline before intraday gate closure time. In such case intraday trading must be stopped for the relevant period as soon as the schedule has been submitted to the TSO.

Power market schedule with corrected steps

If the baseline is based on a power market trading schedule, it will show discrete steps, e.g. at the end of an hour or quarter-hour. In reality each spinning machine has a maximum ramping rate and cannot perform discrete steps. The aFRR activation value is calculated in short intervals as the difference between generation and baseline. As indicated in Figure 17, the application of a baseline with discrete steps will lead to significant deviations in the calculated aFRR power if the unit cannot follow a discrete step. In order to minimize this effect the steps in the baseline must be converted into ramps with gradients equal to the ramping rate of the unit.

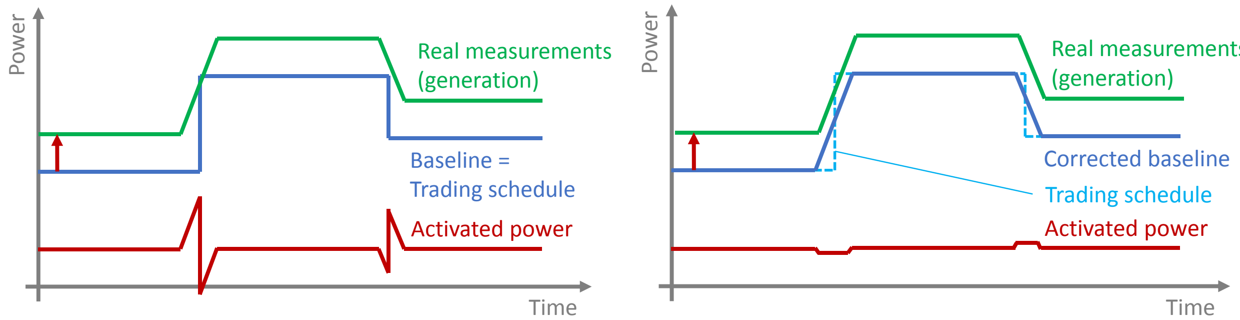


Figure 17: Effect of discrete schedules for spinning machines (left) and improved calculation of aFRR activation due to the conversion of steps to ramps (right).

Remark: A similar correction method with a total ramping duration of 10 min is defined for hourly exchange programs of cross-border exchange transfers between control areas [ENTSO-E, 2009].

Baseline values submitted with short lead time

As explained in 6.3 some TSO require a baseline forecast value to be submitted periodically with the online data. This value indicates the baseline value at a moment in the near future, exactly a predefined timespan ahead. If this predefined timespan is equal or larger than the FAT, the value can be used as the baseline. In that case it is of importance which algorithms are used to calculate the baseline value since gaming is avoided by the criteria that an activation command will be received by the unit at the same time or shortly after the future baseline value has been reported to the TSO. This method is accepted in Germany and other European countries.

Continuation of the current measurements value available at reception of activation command

The easiest way to construct a baseline is simply to take the last active power measurement before the activation takes place and to consider it as a constant value during the time of activation. Such baseline is admittedly simple but it works well for generators as well as loads showing rather low generation or load volatility, e.g. in case of run-off-river power plants or large industrial consumers:

$$Baseline = P_{load}(-1) \qquad \textit{Eq. 6}$$

where the time of aFRR activation is denoted by $t = 0$ and the time of one measurement before is denoted by $t = -1$.

The advantages of this method are the simplicity, transparency and rather low requirements concerning computing power.

On the other hand the method is not applicable if a step in the operational schedule of the unit is expected during the time of the activation. In that case the unit would cause additional imbalance to the system due to not being able to follow the schedule.

Figure 18 demonstrates the application of the method on a generator. As soon as an aFRR activation set-point has been received the last measurement is used as the baseline value as long as there is an active aFRR set-point. The baseline stays constant if the set-point changes the values or even the sign of activation is changed. If there is no set-point different from zero received any more the baseline stays constant for some additional time in order to be able to report the down-ramping behavior correctly.

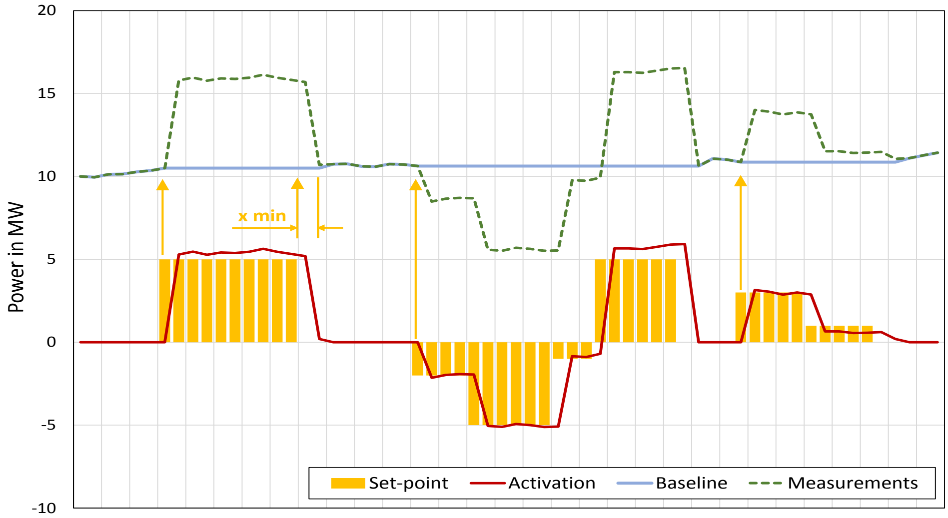


Figure 18: Example of the baseline method "continuation of the current measurements value at reception of activation command"

Instead of taking the last measurement one can take also the average of several latest measurements to eliminate noise from the data:

$$Baseline = \left(\sum_{t=-15}^{-1} Pload(t)\right)/15 \qquad \textit{Eq. 7}$$

where 15 values from $t = -15$ to $t = -1$ have been taken into account. The averaging period can be chosen individually for a resource according to the time constant of noise resp. periodic fluctuations.

A sophistication of this method would be to use the ARIMA (Autoregressive integrated moving average) models where one derives a certain formula (and not a simple average value) for the calculation of next baseline values based on previous measured values. ARIMA models are based on certain autocorrelation properties of measured data that can perhaps be observed from the data.

This simple baseline approach of previous paragraphs fails in the case that the last measurement was taken approximately in the local time-maximum of consumption or generation of the unit considered. In this case, the electricity consumption or generation would slowly fall anyway but by the shown approach this would be wrongly counted and also enumerated to the resource. By using the much more complicated ARIMA models the number of such cases could perhaps be minimized but could not be totally eliminated. The drawback is that these models reduce the advantages of the underlying method, namely simplicity and transparency

Baseline for wind power

With the increasing share of wind power in the generation fleet there is not only a growing demand for balancing but also additional flexible capacity available. There are two main strategies to provide capacity for balancing from a wind generator. The simpler strategy is to operate the wind generator on maximum available power determined by the wind speed or according to a schedule which can be fulfilled with a very high probability. In this case negative balancing capacity can be exploited by reducing the output of the wind generator to a value lower than the maximum possible value.

If the wind generator is by default operated on a level lower than the maximum possible feed-in or possible feed-in with a high probability the output can be controlled in both directions and also positive balancing electricity can be provided. Following this advanced strategy will mean that there is a permanent loss of renewable electricity due to the reduced generation for reserving positive capacity.

In general, the exploitation of flexibility of wind generators is still in an early phase and there is no common approach across Europe so far. Two main approaches for baseline definition and verification are discussed or already applied at the moment. These approaches are shown in Figure 19

The first method is based on a probabilistic schedule which can be provided by the wind farm with a very high probability (e.g. at least 99,5%). This probabilistic schedule requires a generation forecast which has to be calculated as close to the delivery as possible. Analysis show that the time to delivery must be lower than 4 h, but maximum 1 h is recommended to reach an adequate quality of forecast [Fraunhofer, 2014]).

The second method is related to real time assessment of possible feed-in based on wind speed and wind direction measurements and the given generation characteristics of the wind generator or wind park. This method has the advantage of maximum exploitation of the renewable resource. On the other hand the control of the feed-in to keep a constant difference to the potential feed-in is more challenging than maintaining a fixed level of feed-in.

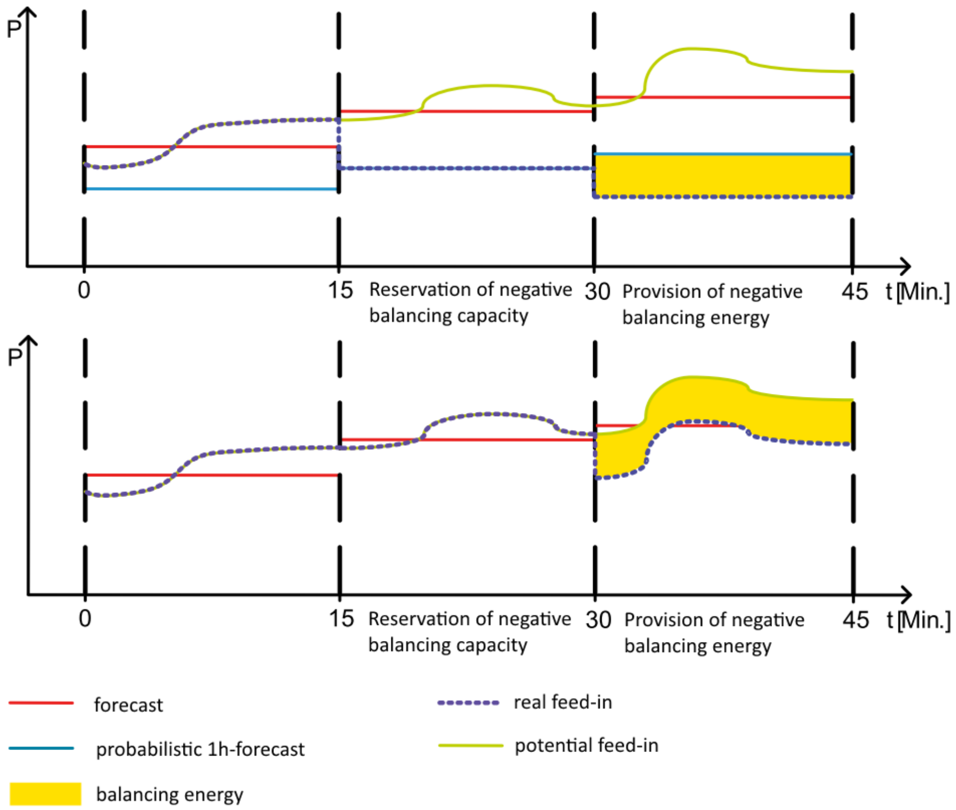


Figure 19: Different approaches for providing balancing reserve from a wind generator based on a short term schedule with high probability (above) or based on the available active power calculated in real time (below); [Jansen, 2014]

At the current stage of implementation there is a lack of experience and some open issues still have to be solved. For instance, shadowing effects may appear if only some generators of a whole wind park would be reserved for balancing services. A crucial question is the required backup. The required backup is closely related to the quality of forecast, which is influenced by the timespan between forecast and delivery and the geographical distribution of the pool of wind generators.

Finally, a generation forecast usually provides data as an average of 15min, a reasonable minimum interval would be 3 min because the underlying weather forecast will not be available in a higher time resolution. Interpolation methods must be applied to receive a continuous schedule in 2s intervals as required by many TSO.

US types and derived baselines

The US have been leading for more than a decade in promotion of flexibilities from the load side (demand response) in order to reduce the system peak load or even to participate in capacity auctions. In order to evaluate demand response activations, it has been understood that advanced baseline methods have to developed, standardized and regulated. Today most literature about baseline methodologies is available for the US markets. It is worth to mention the fundamentals and approaches which can be found in these markets in order to provide a comprehensive overview about the topic of baseline definitions.

There is a common way to construct a baseline for a load customer, which can be composed of several physical load customers and even internal generation. The idea is that the electricity consumptions profiles reflect the human activity during the day or during workdays and non-workdays of a week or even seasonally during the year. Since human and industrial activity follows certain patterns (day-night, workday-weekend) it follows that those patterns can be traced also in the load profiles. Proper clustering of the data is essential. For example, it is to expect to reasonably calculate a baseline separately for each hour of a working day:

$$BaselineBaseline(h) = \left(\sum_{day=Monday}^{Friday} P_{load}(day, h)\right)/5 \quad \text{Eq. 8}$$

This type of baseline calculation is basically used in the United States for the verification of Demand Response activations, mainly for the purpose of peak load reduction. [California Energy Commission, 2003] and [ENERNOC, 2011] provide a good overview about frequently applied methods. These methods are briefly explained in the following.

The Default Baseline Profile is calculated as a 10 day average baseline load profile (BLP) plus additive adjustment based on actual electricity use for 1-2 h prior to activation signal. This procedure is shown in Figure 20.

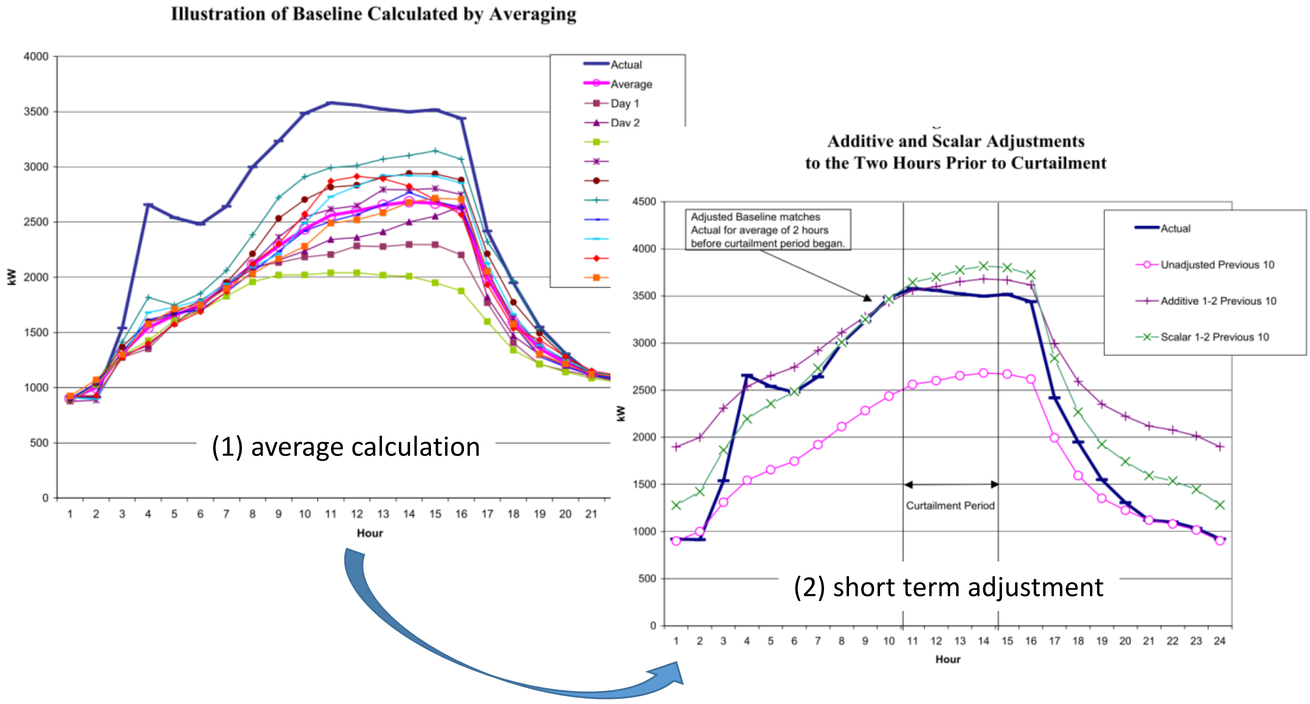


Figure 20: General approach of US-type baselines: (1) The hourly average load of a number of significant days is calculated ("unadjusted average"). (2) A correction is performed on the unadjusted average with the aim to match the baseline with the consumption of the actual day during a timespan before start of the activation. [California Energy Commission, 2003].

Further, alternative profiles are defined, which provide a refinement of the Default Baseline profile, for instance:

- The Default Baseline Profile but additive adjustment based on actual load for 3-4 h before activation.
- A weather model to construct the BLP based on actual average outside temperatures when activation signal was sent.
- Only the highest five of the last 10 days are used to construct the BLP, without any adjustment for the control day.
- Only the highest five of the last 10 days are used to construct the BLP, with adjustment based on a Temperature-Humidity Index load model.
- The highest 10 of the last 11 days are used to construct the BLP without adjustment for control day conditions.

The main purpose of these baselines is demand response for peak load reduction, where measurements are based on hourly averages and the focus is mainly on working days. There is no peak load situation expected on weekends. It is obvious that these methods cannot be applied directly for aFRR. But in case of units which show a characteristic daily load profile, like small C&I consumers or (geographically distributed) Photovoltaics the fundamental idea of a characteristic daily load or generation profile to be used for baseline calculation can make sense. Additional discussion is needed about the procedure to reduce the measurements interval to 2 s, in particular concerning the required computation effort to calculate the average daily profile with a resolution of 2 s and a method to reduce the fluctuations (numeric noise) on the calculated average values.

6.5 Proposed approaches for verification methodology

As mentioned in the beginning of the chapter there is no perfect verification method which could cover all types of units with the underlying characteristics and all the different requirements of the individual TSOs approaches and requirements of market clearing rules. In particular, the FAT requirement of the individual TSOs varies between 5 min to 15 min, and the tolerance bandwidth for aFRR activation is defined differently by each TSO. Each TSO defines some specific terms depending on the characteristics and requirements of the control zone but anyhow tries to avoid unnecessarily strict rules, which could result in a barrier for new market participants and as a consequence the TSO or balancing market operator would have to deal with the disadvantage of low market liquidity or even too less market participants to provide the required amount of aFRR.

Given to these facts it seems to be a reasonable approach to be flexible in the definition of baselines as long as a transparent and reliable method is applied. It proved to be a good practice that the provider can propose a baseline calculation method during the pre-qualification procedure which will be evaluated by the TSO. There is no known baseline methodology which could cover the specific characteristics of many industrial consumers or portfolios of industrial consumers. Usually these consumers can provide flexible capacity only for a limited time period. The integration of industrial consumers with limited availability into portfolios and the reduction of aFRR product duration should facilitate the reliable provision of flexible capacity. Some TSO and portfolio operators mention that product durations longer than 4 h are not favorable for these kind of consumers and recommend further investigations to develop a new baseline methodology for industrial consumers.

Since baselines based on power market trading schedules are a commonly used baseline method, the procedure for verification of an aFFR activation based on the analyzed requirements is summed up in Figure 18.

The basis is a data series of real measurements and the trading schedule (1). The measurements are sent to the TSO in real time (or close to real time) but the schedule can be sent in advance in some cases. In case of too much noise on the measurements a real time filtering method might be applied before sending the data to the TSO. Additionally, discrete steps in the baseline must be converted into ramps (2). As soon as an aFRR activation command is received the baseline must be corrected to the level of the last measurements (3) and will then be fixed for the duration of the activation. If the baseline has to be send in real time in parallel to the measurements, the correction also must be performed in real time. Finally, the aFRR activation is calculated as the difference between the filtered measurements and the corrected baseline (4). Then all the required data is processed and can be send to the TSO close to real time.

This procedure provides a quite general approach. Depending on the resource characteristic, the behavior of a pool of resources and the requirements of the TSO some of the steps might be negligible in certain cases.

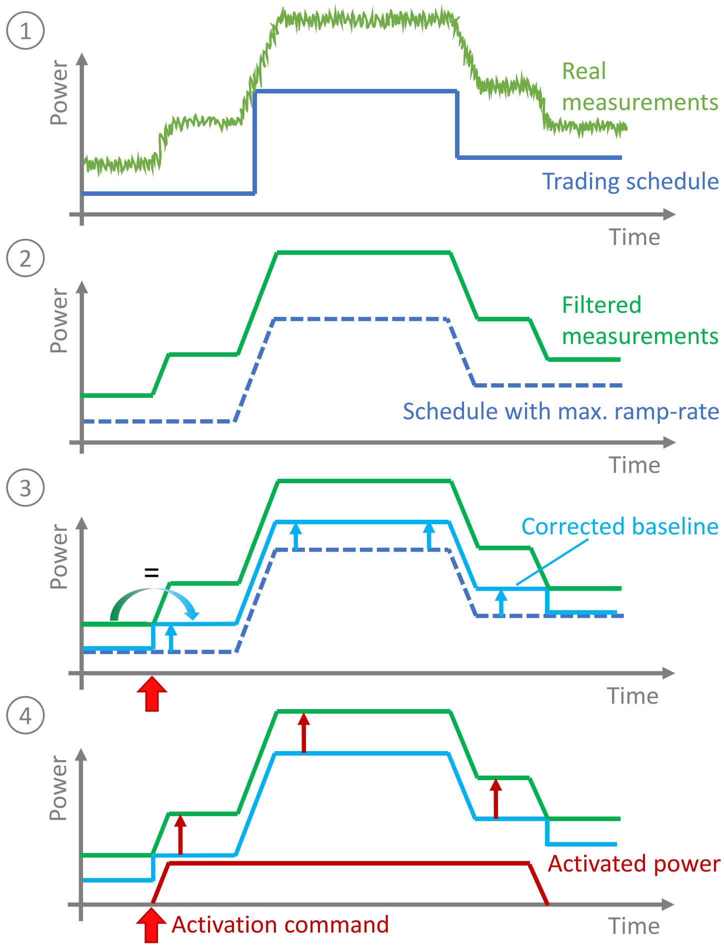


Figure 21: A general approach for verification of an aFRR activation

6.6 Prequalification process

Because of the high technical requirements of aFRR systems each unit has to pass a prequalification procedure before being allowed to participate in the aFRR market. As an example the prequalification process of Austrian Power Grid (APG, the Austrian TSO) includes the steps listed below. Details can be found on the homepage of the TSO [APG, 2016].

1) The provider contacts APG and expresses interest in participation in the aFRR market.
2) APG requests a comprehensible concept before establishing contact to the SCADA specialist.
3) The provider discusses the concept with APG in detail. If necessary, the provider will adapt the concept.
4) The provider submits the completed forms and information about technical data of the unit, the power control concept, available backup units, baseline calculation methods, the ICT infrastructure, ICT security measures, the balance group, connecting DSO, etc.
5) APG sends the documents to an external reviewer.
6) APG receives the respective result and informs the provider.
7) The provider passes the communication tests and performance tests.
8) The provider signs the framework contract for aFRR delivery.

The prequalification has to be renewed after three years.

If the control system of the provider has already passed a prequalification, then there is a simplified procedure for additional units which are added to the pool of the provider.

The pre-qualification rules of many TSO require a unit based pre-qualification, which is also in practice in many other control zones. Some providers and TSOs would prefer a portfolio based prequalification, which is the only effective way to deal with a large amount of small units (e.g. RES) which are managed in a portfolio.

7 Survey of ICT technologies for balancing markets

Real time data and information exchange is a prerequisite for future aFRR ancillary services from DG/DR. A simplified view of top down electricity marketplace actor relations is presented in Figure 22. It is characterized by multi layered structure and different types of information flows present on each layer. Electricity market combines operations to enable multiple cross border TSO to share information for aFRR balancing services. Exchange of electricity aFRR market information comprising of e.g. bids and prices. It is natural to consider cloud implementation for such centralized, democratized access to information on this level. Such arrangement can establish central, multi region CMO of aFRR bids. TSOs are connected with a pool of BSPs within each control zone and they exchange requests and availability information of capacities available for aFRR services in each region. TSO signals to BSP the activation schedules of capacities to aFRR in order to maintain stable power grid. BSP and TSO have agreed on electricity volumes provided up front (e.g. 24 h day ahead) and confirmed this a short timeframe before gate closure time (e.g. 30 min to 1 h). BSP on the other hand must communicate with multiple customers that own capacities to form offered portfolio of products to TSO, in our case MW for short time frame, as required by aFRR service. Measurement of electricity flow before and after activation of these capacities must be recorded and reported with short reporting periods (e.g. 2 seconds) to BSP. Signals for set point change or on/off of capacity are directed from BSP to customer. Customer needs to have in place systems and operations to monitor its power consumption and consumption of its main loads and generators, if he is to successfully participate as capacity provider to BSP.

All information transport as described is happening over WAN. Electricity consumption, baseline , load profile and status measurements at customer premises must be encapsulated within suitable protocols such that WAN communication is possible over multiple hops, types of communication networks and physical interfaces (e.g. fiber or copper based xDSL, wireless, cellular/mobile, IP based) and network providers (e.g. telecom operators, utility owned, service provider owned).

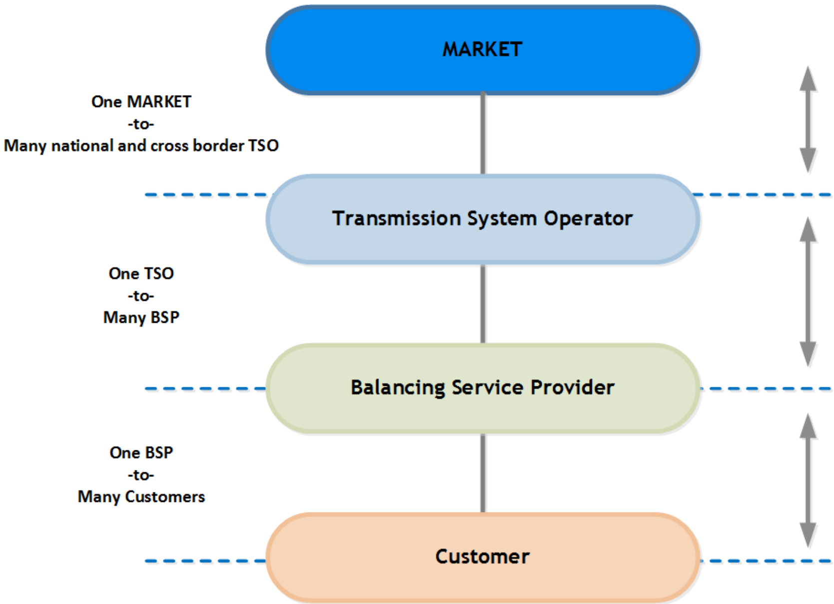


Figure 22: Simplified view of top down electricity marketplace main actors' relations.

The preferred way of integration from customer to BSP is via direct attachment and information exchange from customer energy management systems (e.g. ISO 50001 based [ISO, 2011]) through standardized application programmer's interfaces. EMS at customer site assures coherent operation of PLC or SCADA systems there. If EMS as centralized management software is not provided, then it is possible to exchange information by attachment to PLC or SCADA systems, via OPC UA, OpenADR, IEC 60870-6-503, IEC 60870-5-104 or Web programming interfaces. In the most rudimentary cases there still exist smart meter (absolute minimum requirement) either on the boundary of customer-utility for billing purposes or a collection of smart meters installed per large loads or generators at customer premises. Attachment to smart meter can be (in order of preference): IEC 60870-5-104, DLMS/COSEM on Modbus, RS485 or Ethernet physical interfaces and optical interface (LED or IR LED with 1 pulse/Wh resolution).

7.1 Information exchange functions

A preliminary wish list could be provided for functions of information exchange from the actors on electricity market point of view as follows:

1. Standards based.
2. Low cost implementation.
3. Straightforward integration with existing systems.
4. Well known, already deployed protocols to shorten time to implementation.
5. Single channel for multiple data types (e.g. measurements to bids).
6. Scalable, to more connections and more functionality.
7. Secure.

However, first we must get preliminary answers as to the present state of communication capabilities of main market actors and how do they accomplish communication on multiple levels.

7.2 TSO Questionnaire results summary

The questionnaire's objective was to acquire information of present state of information exchange and communication solutions between electricity market players (stakeholders). The assessment was directed in three domains of data interchange:

- Real time data. It comprises the data flow from capacity owner, its SCADA and/or electricity measurement systems to market players on aggregation hierarchy level (e.g. aggregator, BSP), flows between aggregation hierarchy level and TSO. Types of data flow protocols for aFRR, mFRR, SCADA were recorded separately.
- Business-to-business data. It describes use of EDI formats for business processes between stakeholders, BSP-TSO, TSO-TSO, TSO-electricity market.
- Structural data. It defines static data of various models that support the electricity market operation, e.g. use of CIM formats, congestion notification.

Summary is presented in Table 14: Real time data, Table 15: B2B data and Table 16: Structural data (Table entry with "X" denotes that the protocol is used at least in one TSO).

Table 14: Real time data

Protocol Real time data exchange	**aFRR**	**mFRR**	**Imbalance netting**	**Aggregator (VPP)**	**SCADA EMS**
IEC 60870-5-101 (IEC 101)	x	x	x	x	
IEC 60870-5-104 (IEC 104)	x	x	x	x	x
IEC 60870-6 TASE.2 or ICCP	x		x	x	x
OPC Data Access (OPC DA)					
OPC Unified Architecture (OPC UA)					
Other	Modbus (TCP/IP) NAP	Modbus (TCP/IP) NAP		Modbus (TCP/IP) NAP	
Manual activation		x		x	
Telephone set points [MW], activation				x	
XML baseline schedule email				x	

Real time data protocols can be divided into three standardized groups:

- IEC 60870-5-101. Non IP based protocol, clear text data transfer. It is used for data exchange for aFRR, mFRR, imbalance netting services and aggregator-TSO links.

- IEC 60870-5-104, IEC 60870-6-503 (TASE.2, ICCP). TCP/IP based protocols. Both types are used for data exchange for aFRR, mFRR, imbalance netting services, aggregator-TSO links and direct communication with prosumer SCADA.
- OPC DA, OPC UA. SCADA data exchange originated TCP/IP based protocols. Although this protocol family was not used, we do not see any particular technical reason that they cannot be implemented.

Other type was also recorded, to take into account legacy implementations. Modbus over TCP/IP was the only type used.

Information about activations, set points and baselines exchanges complement the assessment. These data are automatically exchanged between aggregator-TSO for aFRR and semi-automatic (manual input of parameters to web platform) or manual fashion (email of file attachment) for mFRR.

There is a considerable improvement potential for real time data exchange, particularly implementation of protocols that can cover the complete set of services, offer information security and support scalable, dynamic operation of aFRR market needs.

Table 15: B2B data

Standards ENTSO-E EDI (Electronic data interchange)	**TSO**
Scheduling system (ESS)	ELES (SI) V3.3 MAVIR (H) V2.3, V3.3 TE (RO) V3.3
Reserve resource process (RRP)	MAVIR (H) V2.0
Capacity allocation nomination (ECAN)	ELES (SI) V5.0 MAVIR (H) V4.0 TE (RO) V4.0
Settlement process (ESP)	MAVIR (H) V1.1 TE (RO) V1.1
EDI libraries for balancing services	ELES (SI) ESS, ECAN MAVIR (H) ESS, RRP TE (RO)
Other	ELES (SI) ENTSO-E Acknowledgement Implementation Guide, Accounting and Settlements Implementation Guide MAVIR (H) IEC 62325-451: EMFIP TE (RO) IEC 62325-451: EMFIP

ENTSO-E defined and standardized number of electricity market processes. Although TSOs try to keep up with keep up with the latest versions of standards, this is not always the case, but this should not prevent interoperability, since parallel use of versioned standards applies and business data content remains the same EU electricity market process guidelines (e.g. scheduling, settlement, capacity allocation and nomination, acknowledgement) codified as IEC 62325-451 [IEC325, 2015] may also be used, since ENTSO-E cooperates with IEC TC57 on harmonization of electronic data interchange and CIM.

Table 16: Structural data

Standards Structural data exchange	**IDCF**	**DACF**	**CIM export compliant**	**SCADA CIM XML data exchange (IEC 62559)**
IEC 61970-452				x
IEC 61970-456				x
IEC 61970-453				
ENTSO-E CGMES implementation (Common Grid Model Exchange Standard)				
ENTSO-E CGMES for SCADA/EMS				
ENTSO-E CGMES for congestion forecasting		x		
UCTE DEF	x			

Structural data description comprised three standardized groups:

1. IEC 61970-45X. This group of standards defines the EMS application program interfaces and operations.
2. ENTSO-E CGMES. It is a superset of CIM with TSO specific requirements for system operation.
3. UCTE DEF. This is standard in operative use at TSOs and is based on former UCTE association that became part of ENTSO-E.

Table entry with X denotes that the protocol is used at least in one TSO. The main purpose of these protocols is to automate information exchange about transmission link congestions and forecasting (inter and day ahead level) and integration of EMS and SCADA systems.

We see that structural data exchange is still in its infancy. Their use may proliferate due to aFRR dynamic operations and need for transmission line automatic management. The important benefit will be exchange of results of analytical procedures for real time transmission line congestion calculations (e.g. PTDF method based).

8 ICT recommendations for allowing DR and DG participation in aFRR

8.1 Basic requirements for information exchange solutions

This chapter presents a few requirements for inter stakeholder communication solutions in the context of smart grids and focuses primarily on electricity markets operations, specifically aFRR and redispatch.

8.1.1 IP protocol

The use of the IP protocol [RFC791, 1981], [RFC686, 2013], i.e. IPv4 or IPv6 [RFC1883, 1995] is the basic requirement for communication among stakeholders and building blocks within FutureFlow design domain. This enables wide interoperability, virtually any physical layer communication technology implementation (i.e. PHY, MAC) and plethora of communication protocols that run on top of IP and multi communication profile protocol solutions (e.g. IEC 61850). Furthermore, realization of inter protocol mappings on application layer is straightforward, while preserving bottom network IP layer semantics. The benefit of using IP protocol stack is apparent from the requirements for diverse data and message types, reporting periods and data bandwidth (data volume) of communications between stakeholders. IP packets can be routed over WAN, which is essential for inter-regional information exchange.

Bridging the gap to non IP protocols and devices

The implication of IP only communication is that we disregard legacy non IP based protocols that may still be in use, e.g. IEC 61870-5-101, Modbus, DNP. On the other hand, there is a set of protocols that run directly over Ethernet to minimize latency, but are used in closed environments.

There exists a set of communication protocols that are not using IP, which are shortly mentioned below. Without loss of generality or limiting future implementations, they will not be used within the project.

- IEC 61870-5-101 [IEC10, 2003]. This is a telecontrol equipment and systems protocol with coded bit serial data transmission for monitoring and control over WAN, running on top of X.24 or V.28 physical layer transport. All packets are sent as clear text and as such represent inherent security vulnerability. It was largely superseded by IEC 61870-5-104 [IEC10, 2006], IEC 61870-6-503 (TASE.2/ICCP) [IEC503, 2013] for the same purposes. Alternatively, one can use the protocol encapsulation gateway approach, to bring -101 to IP world. A hardware intermediary is used to connect to -101 on one side, capture signals and bit message, encapsulate them in protocol on top of IP and release them on suitable physical interface (e.g. Ethernet over fiber) on the other side. The added benefit of such arrangement is also the enhanced security, using all known mechanism from IP domain.

- IEC 61850, only SV, GOOSE type messages [IEC850, 2003]. This is the protocol used within substations and intended to provide wide range of interoperability between all devices. Parts of the protocols, specific messaging formats, so called sampled values (SV) and generic object oriented substation events (GOOSE) are not using IP due to requirements for low latencies (< 4 ms) and are instead implemented over Ethernet directly (ISO/IEC 8802-3 Ether type), since the primary use is for protection activation. However, we can use the concept of SV over IP for measured values of power at consumer, capacity provider.

8.1.2 Development with existing frameworks and standards

Dependence on existing frameworks and standards is critical. This prevents design of solutions from scratch, and works towards direct use of existing standards in specific domains, proposes additions to them and furthers development of sub standards (e.g. new communication profile). Some interesting to take into account are presented in subchapters below.

Electronic data interchange library.

Electronic data interchange library contains definitions and implementation guides for electronic data interchanges [EDI 2016]. Primary focus are business-2-business application interfaces. IEC CIM extension called Common Grid Model Exchange Standard (CGMES) caters for TSO data exchanges for power system data management and applications covering various domains (e.g. load flow analyses, capacity calculation for allocation and congestion management, market information). Business processes for electricity balancing markets are (almost) harmonized with CIM EU market standards IEC 62325-351 and IEC 62325-451-1. The non-harmonized items include terminology, so ultimately decision must be made upfront either to follow ENTSO-E EDI or IEC 62325-451 CIM format. For example, Nordic market participants have decided for CIM format [NEG, 2016]. There is also a standardized ebIX format for information exchange maintained by European forum for energy Business Information eXchange that covers the needs of retail market and connection with to the wholesale market [Ebix, 2016].

Smart grid architecture model, CEN-CENELEC-ETSI

Smart grid architecture model is an EU framework that consists of a reference architecture with representation of functional information data flows between domains and introduces their interoperability aspects in zonal and layered approach [SGAM, 2012].

Framework and roadmap for smart grid interoperability standards, NIST

Framework and roadmap for smart grid interoperability standards is the oldest framework, and many others use it as a reference [NIST, 2014]. It focuses on a combined view of ICT, command-control for achieving improved performance, reliability and user awareness. Architectural framework presents design processes, views and descriptions that define characteristics, uses, behavior, interfaces, requirements and standards of the smart grid. A comprehensive view on cybersecurity strategy with specifics for cloud computing and utilities is included [NIST, 2010].

Smart grid reference architecture, SCE-Cisco-IBM

Smart grid reference architecture framework is utilities oriented and emphasizes ICT technologies and their multi-layered security as the foundation for development of smart grid services [SGRA, 2010]. Common architectural views discuss services deployment as centralized or edge based with grid state awareness. Business requirements comprehensive list for each stakeholder and its services are presented with supported functions and discussion of markets operations.

Smart energy reference architecture, Microsoft

Smart energy reference architecture framework is a top view of smart grid developments, with specific focus on the cloud based implementations for big data analytics, discovery and deployment of new insight and master data management [MS, 2013].

Standards for smart grids, CEN-CENELEC-ETSI cooperation [ETSI, 2011].

Standards for smart grids is a report, which outlines standardization requirements for implementing the EU smart grid vision and includes introduction to relevant standards. Information security is reviewed from IEC 62351, ISO/IEC 27000 and NISTIR 7628 points of view [ETSI, 2011].

TC 57 Power systems management and associated information exchange

TC 57 Power systems management and associated information exchange is produced by Technical Committee 57 that is continuously developing a set of protocol standards that cover smart grid essentially end-2-end: IEC 61970, IEC 61968 and IEC 61850 [IEC57, 2016]. These standards span generation, DER, transmission, distribution, metering. CIM is defined in IEC 61970 and IEC 61968 and deals also with automation of distribution systems, exchange of grid topology data, GIS and asset management. CIM builds data model and system interfaces for backend distribution management IT systems. IEC 61850 family focuses on the communication within the distribution equipment, substations and functionality for automation. It defines multi-layer data model of the distribution equipment and comprehensive multi profile communication protocols for different types of data and information exchange (e.g. low latency, management, static).

IEC 60870 Telecontrol equipment and systems

IEC 60870 Telecontrol equipment and systems is a large set of telecontrol (SCADA) communication protocol standards defining all aspects from physical layer electrical interfaces to data payload types [IEC870, 1988]. Notable specifications are covered in 60870-5-101 [IEC101, 2003], IEC 60870-5-104 [IEC104, 2006], IEC 60870-6-504 (also called TASE.2 or ICCP) [IEC504, 2013]. It is widely used today for TSO-BSP communication, metering data exchange, advanced smart meters and remote terminal units [Eat, 2013], [Sat, 2013].

OPC foundation standards

There are two broad sets of OPC foundation standards for SCADA data interchange: Data access (DA) [OPC 2003], Unified architecture (UA) [OPC, 2015]. They define interoperable client/server type of architecture with their capabilities and interfaces between data acquisition and backend IT systems. New implementations prefer UA. UA specification was recently updated to cover also publish/subscribe model of communication, to cater for IoT and embedded systems to cloud integration via AMQP 1.0 protocol with JSON data encoding [AMQP, 2012] [RFC4627]. UA also defines comprehensive server information model and defines end-2-end security model (threats on physical, hardware, software levels). BSI has recently published positive security assessment of UA with recommendations [BSI, 2016].

Open automated demand response (OpenADR) alliance

Open automated demand response alliance devised protocol was designed for DR services and offers a flexible data model for information exchange between electricity service providers (DSO), aggregators (BSP) and customers [OADR, 2011]. OpenADR is based on publish/subscribe model where virtual top nodes publish information to automated customers (e.g. capacities) called virtual end nodes. Specified services are focused towards DR, DG. It even conveys pricing information, which may be used to enable various capacity node actions (e.g. on/off, change of operational set point). This is application level data model only, completely agnostic of physical, transport communication network layers. Information security was designed-in to meet U.S. Cyber Security requirements [CRS, 2013]. IEC 62746-10-1 is going to harmonize the OpenADR by end of 2016 [IEC627, 2016].

Simple object oriented protocol (SOAP)

SOAP is W3C standardized, lightweight protocol intended for exchanging structured information in a decentralized, distributed environment [SOAP, 2007]. It runs in conjunction with HTTP (session establishment) and uses XML for message data (payload) encoding. SOAP is widely used for Web communication interfaces implementations (the other being pure HTTP with RESTful architecture model).

MQ Telemetry Transport protocol (MQTT)

MQTT is ISO and OASIS standardized messaging protocol that enables truly lightweight implementations (e.g. minimum message size is only 2 bytes) of publish/subscribe mechanism, over TCP/IP and can support smallest measuring and monitoring devices transmitting data over WAN and is fully adaptable to a variety of messaging and communication needs, since it supports three levels of QoS [OASI, 2015], [ISO, 2016]. Information model is not prescribed, since MQTT is data centric, but this makes it scalable in scope (vertical) and adaptable to various purposes (e.g. smart grid/home/metering [Mats, 2014] to financial and electricity markets [Eure, 2012], [Hup, 2015]). JSON is the preferred method of data encoding, but others can be used, to suit the particular application type and adapt to communication bandwidth constraints (e.g. XML, tightly coded binary). Security can be implemented on multiple layers simultaneously: network (by provider via VPN), transport (using TLS/SSL protocols) or application (e.g. use of application messaging encryption, or even augmented with hardware embedded secure elements) [Sin, 2015]. Cloud implementation is straightforward on many platforms [Ama, 2016], [IBM 2015], [SAP, 2015]. On one hand it is open source, on the other is was adopted by OASIS, ISO and IEC standardization bodies to enable wide and fast market take-up implementations in IoT and cloud domains [OAS, 2015], [ISO, 2016]. Horizontal scalability was one of its design objectives, and there are server implementations on the market that support > 10^9 nodes. A closely related protocol, MQTT-SN, is the extension to other networking transports: UDP, ZigBee, 6LoWPAN. There exist numerous server implementations and was already integrated with other protocols (either on server side or as a software gateway), e.g. HTTP, AMQP, RMQ, CoAP, WebSockets, STOMP. New PLC and SCADA systems offer MQTT protocol as a standard interface beside classical ones [Beck, 2016], [Mae, 2016], [Prol, 2016].

Other protocols

There are many other protocols that can be considered in the domains of smart grids, metering, IoT,e.g. XMPP, CoAP, HYPERCAT, WOOPS, DDS [XMPP, 2016], [RFC7252, 2014], [Hyp, 2016], [Woop, 2015], [OMG, 2016].

8.1.3 **Scalability**

Scalability assures that our communication solution can scale and grow both horizontally and vertically. The usual approaches to scalability involve hierarchical design on multiple levels of abstraction (physical, protocol, organizational). Horizontal plane scaling assures the same performance of communication regardless of the number of stakeholders on the same horizontal plane, e.g. regardless of the number of customers connected to BSP or BSPs to TSO, or TSOs to cloud. For example, the number of customers per BSP may grow from 1 to 1000s and two order of magnitude growth may happen in BSP to TSO case, too. Note that the number of active customers, prosumers will rise sharply, at least 1000 fold, when households and their capacities start to participate in electricity markets. Indeed, to accommodate for EU future smart grid and decarbonisation goals we are witnessing growth in horizontal expansion already, particularly on the level of capacities, DER and loads and taking into account industrial, commercial and home users, that act as prosumers and EV fleet with EV charging stations. Vertical growth is concerned with growth and change in range of capabilities and resources (also called functional scalability) and thus volume, i.e. required communication bandwidth, among different types of stakeholders, e.g. between customer and BSP or BSP and TSO. For example, BSP may start with simple message exchange with TSO, but in time make communication protocol more verbose, offering more information to TSO so that it may make decision process later in the chain (e.g. towards cloud) more intelligent. In the extreme case, we may change protocol itself or add new authentication functionality. Change in range of capabilities assures that the volume and types of information exchanged vertically can scale, too.

8.1.4 Information security

The prime concern of large scale smart grid deployments and their future full integration within society should be information security. Information security is also the most talked about (and researched) item in smart grid domain. The security research today focuses on:

- Assessment of current communication protocols for smart grid specific use [BSI, 2016].
- Enhancement of protocols in use, based on newly discovered vulnerabilities [BHA, 2016].

Development of new methods and algorithms for better security. Methods may employ a combination of hardware assisted, software based encryption or novel process solutions. Embedded hardware secure elements (e.g. eUICC) at the nodes of smart grid network, i.e. customer communication equipment in combination with publish/subscribe mechanism were already deployed in smart grids [GSMA, 2016], [Sun, 2015], [Jin, 2015]. Novel algorithms may use of include multivariate nonlinear polynomial maps over finite fields to make brute force attacks virtually impossible due to NP-hard problem complexity [Eder 2015]. An example of process innovation is usage of peer-to-peer block chain principle, without central authority, that was pioneered by Bitcoin electronic currency and was recently brought into banks and IoT to assure secure transactions [Hype, 2016], [Naka, 2008], [Plan, 2016].Recent security attacks and penetrations into supposedly closed secure grid environments have prompted us that the notion of "secure closed access" is no longer valid [SANS, 2016]. It is thus of paramount importance to make a secure communication paths from SCADA edge nodes to cloud, end-to-end, including electricity production facilities (large and DG), distributed service type oriented customers and electricity service providers.

8.2 Information centric view of electricity marketplace

Our goal is to observe electricity market place from the information exchange point of view, so called information centric view. In information centric view we observe major marketplace stakeholders and their data and information exchange interactions. This allows us to map suitable communication protocol types on top of each information exchange stakeholder pair transaction. Stakeholders are organized in layered fashion, which suits the development of multilayer information security mechanism, too.

A simplified information centric view of e communication interconnection between main actors on electricity marketplace is in Figure 23. There are several aspects within the proposed future model worth discussing.

Scale market place with more players. Horizontal scaling, with more customers bringing in flexibilities and a more diverse set of BSPs. BSP may be focused on particular type of flexibility offerings, e.g. VPP or include also larger power plants, e.g. hydro.

Level the playing field

The first step towards levelled playing field is information democratization, i.e. open the information flow to all stakeholders that are playing on the electricity marketplace. Current practice is to introduce central database store (e.g. via cloud implementation) of key information for each stakeholder to operate in competitive, cost effective and non-discriminatory manner including the rights and roles for accessing and providing data. For example, we may introduce the central database of all power measurements from all capacity nodes and from all customers (e.g. generators, loads, energy storage, larger hydro power plants) [Elh, 2016], [Siem, 2015]. An upfront defined process with secure access can provide relevant information to any BSP. The main goal is to increase real time data flows that can leverage system wide optimizations, e.g. transmission line congestion forecasting and power grid topology optimization (reconfiguration) on MV and HV levels or real time tracking of baseline which can now become measured real time quantity within TSO EMS system.

End-2-end security

In order for level playing to function properly we have to guarantee secure transactions. A form of TSP is introduced. Its function is to provide mechanisms for secure cipher key exchange to all stakeholders involved in information transaction processes. Solutions can be purely software based or augmented with hardware embedded secure elements integrated at each stakeholder and end node elements.

Use of modern communication protocols

Use of modern communication protocols must go hand in hand with deployment of novel information security measures. Our goal is to introduce already used protocols that are scaled in scope (e.g. define new communication profile or messages) or propose use of existing protocols that were not yet used in smart grid domain, but were developed for efficient web and IoT transaction processes (e.g. MQTT [OASI, 2015], Woopsa [Woop, 2015]). Novel use of communication protocols shows the opportunity to eliminate for many different protocol data transitions on some connection pairs in today's situations, e.g. different protocols for measurement and bidding transactions.

Cross border operation

This is the final step of expansion that enables much larger scale of operations of aFRR market and thus finding more opportunities for optimization and cost effective operation of the whole region across control zones. Cloud operator acts as a natural point of information exchange, or alternatively for larger regions we may see a set of cloud operators exchanging information.

There are not many protocols available, if any, that can offer true end-2-end (from bottom to top) information exchange, have many communication profiles available, fully functional information model for each mid layer and that they are fully scalable. Queuing protocols, e.g., MQTT, are showing the right direction and are gaining widespread use also on SCADA implementations, but at present lack standardized smart grid aligned information models.

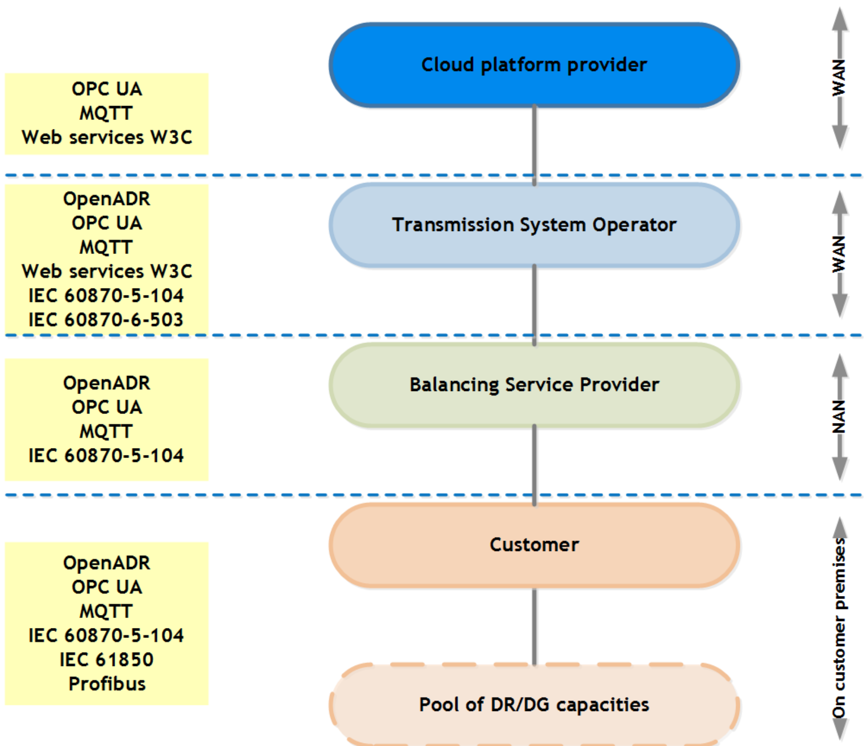


Figure 23: Electricity marketplace today: Information centric view.

8.3 Communication networks for massive flexibility participation

The key objective of providing aFRR services from DR and DG sources is to widen pool of capacity resources on scale and on scope of types in order to achieve security of supply under wide variety of circumstances, i.e. to make a robust aFRR delivery system. Timely information availability from all stakeholders and sources is key to achieve this. But what does cost effectiveness mean? We argue that use of existing cellular networks offer the long term cost effective solution to connect massive numbers of capacity sources into marketplace and various stakeholders (e.g. BSP, BSP and DSO, BSP and DSO and TSO concurrently). We have to note that innovative business models and SLA presented from telecom operators towards smart grid community are key for wide acceptance.

8.3.1 Types of information flows

Types of information flows occurring in the electricity marketplace depend on the types of tuples <source, destination> and layer of transaction.

Data flow bandwidth required is highest at the bottom level, i.e. on transactions <customer with capacity sources, BSP> or <customer with capacity sources, cloud operator>. High bandwidth is the result of number of capacities, i.e. scale on the horizontal bottom level. Type of data flow in the same transaction pairs is measured values of power at capacity source. Period of reporting is on the second level. This information is usually efficiently coded resulting in short packets. Example formats include those from smart meters (HDLC based), PLC concentrators, PMU devices to XML wrapped (e.g. IEC 61968-100) [IEC056, 2007], [IEC850, 2012], [LG, 2015]. Measuring process with key requirements can be modeled according to Business requirements for measure, determine meter read [Ebix, 2015].

Middle and upper layers cumulatively require less bandwidth to convey structured information, since we have fever nodes (i.e. small number of BSPs and TSOs) and reporting period is considerably longer, on the minute to 15 minute level. However, messages are longer, even emails can be exchanged, and are much more verbosely enveloped to expose Web service, e.g. SOAP over HTTP over TCP/IP or SMTP over TCP/IP [SOAP, 2007]. Several energy communication platforms exist and are in operation on EU electricity market [Unic, 2016]. The inter actor information transactions are in accordance with ENTSO-E Harmonized electricity market model [Ents, 2015].

8.3.2 Communication bandwidth estimation for capacity nodes

We can make a rough estimate of required bandwidth for communication between capacity nodes at customer premises to BSP. We assume that measurements take largest proportion. Reporting period is on the second level, and upper bound is 1 sec, since currently we see aFRR requirements from TSO for 2 sec measurements. We base our assumptions on protocols (IEC 61850-90-5) that were developed for high speed (10 - 50 Hz) measurement reporting for PMU devices, but will scale down accordingly [Cef, 2016], [IEC850, 2012].

We can conservatively estimate required bandwidth at < 15 kbps, when using similar format to IEC 61850-90-5 for a capacity node (DG, load) equipped with up to 10 measurement transducers (e.g. 3x P, 3x U, 4x I), with reporting frequency of 1 Hz.

8.3.3 Cellular networks for capacity sources scalable connectivity

The central question is how to efficiently and most cost effectively facilitate interconnection with end node capacities? Let us consider possibility of reuse of existing cellular (mobile) wireless networks, particularly focusing on 4G (LTE). Historically, 2G (GPRS) and 3G (UMTS) cellular networks were widely used for backhaul transport from PLC concentrators (each packing data from approximately 100 smart meters) for billing purposes, albeit with very long reporting periods of 1 h, 6 h or 24 h, 2400 bps speeds, allowed many repeat attempts (up to 6) and up to 90 % transport success rates [Enex, 2013]. Cellular networks capabilities have gradually increased in performance and scope: higher offered bandwidth, lower latency, larger number of simultaneously connected users, denser network of base stations, low cost per end terminal device. 4G standardization is also pushing towards support for machine type communication (MTC, M2M, IoT) to offer lower complexity and thus lower cost solutions, reduced transmit bandwidth, lower power consumption and extended area coverage making it suitable in particular for smart grids [3GPP, 2014]. It is expected that 5G deployments that are being developed with MTC requirements (e.g. device-to-device communication) are on the 3-5 year horizon [5G 2016].

Assessment of suitability of recently MTC specifically developed LTE technologies is based on the expected measurement bandwidth required per capacity node [Eric, 2016], [Ser, 2016]. Measurement types of transactions will be highly asymmetric, i.e. majority of data bandwidth will be used up link (from customer capacity node to BSP) and small proportion down link. For the 2017 time frame one can expect two LTE based and one significantly refurbished GSM based technology available for long range, low cost MTC (Table-Machine type communication LTE and GSM technologies). All three offer much more bandwidth compared to our required estimate (200 kbps - 1 Mbps). We can expect future LTE devices placed within capacity nodes (i.e. per DG, load) to be based predominantly on LTE-NB (also called LTE-NB-IoT) and LTE-M solutions used for MTC at customer premises level to collect measurement data from many capacity nodes (data concentrator functionality). Both LTE-NB and LTE-M are future proof, since their solutions on PHY and MAC layers are going to be incorporated in 5G specifications, too. EC-GSM solutions will be deployed in smart meters and nodes with highest price pressures and are not of interest for aFRR applications.

We can conclude that LTE cellular technologies are suitable solution for capacity nodes measurement data transport towards BSP. Other access network communication technologies, already in service at customer premises can be readily used, too (e.g. xDSL, fiber).

Table 17: Machine type communication LTE and GSM technologies.

Technology Attribute	EC-GSM	LTE-NB	LTE-M
Range	15 km	15 km	10 km
Data rate	< 100 kbps	< 200 kbps	1 Mbps
Duplex	half	half	half, full
Duty cycle	100 %	100 %	100 %
Spectrum	GSM licensed	LTE licensed	LTE licensed
Bandwidth	200 kHz	200 kHz	1.4 MHz
Complexity	very low	low	medium
Cost	very low	low	low
Modulation	single carrier	multi carrier	multi carrier
Chip vendors	Ericsson, Huawei	Ericsson, Qualcomm, Intel	Ericsson, Qualcomm, Intel, Altair
Module vendors	NA	Ericsson, Qualcomm, Intel, Sequans,	Ericsson, Qualcomm, Intel, many
Availability	Q4/2016	Q4/2016	Q2/2016

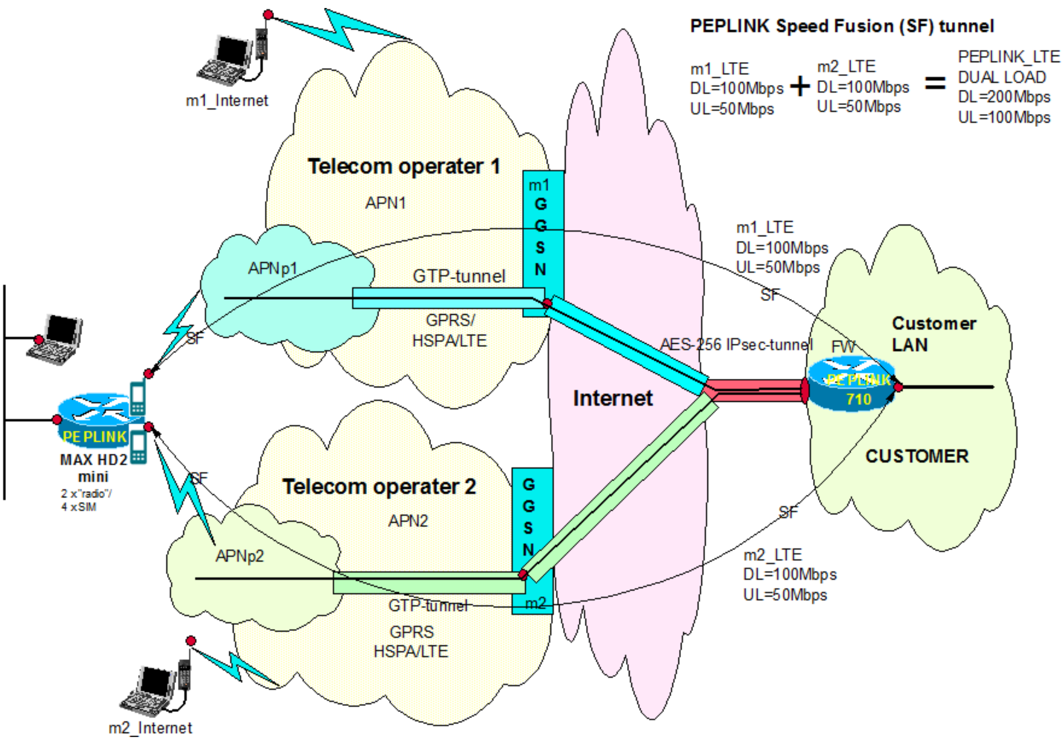


Figure 24: Customer or BSP simultaneous interconnect with two mobile operators for highly resilient data transport.

8.3.4 Capacity nodes communication connectivity

The originator of measurements from capacity nodes is the installed SCADA or PLC system. Classical smart meters cannot provide measurements on second level reporting periods. Other solutions in form of so called energy hubs are possible, but they are largely not standardized, yet [Ser, 2015]. Any number of capacity nodes (DG, loads) are metered with sufficient accuracy (e.g. Class 0.2S, Class 0.5S) with transducers (e.g. current transformer, Rogowski coil, shunt) directly connected to PLC system. PLC contains at least two physical communication channels (e.g. Ethernet, RS-485). These are used for transport of industrial protocols, e.g. IEC 61850 communication profiles and IEC 61400-25-2 information model, IEC 61870-5-104, OPC UA. These are application protocols that are encapsulated within the TCP/IP protocol payload. Integration with EMS of utility is straightforward, since their backend IT software solutions support these industrial domain protocols and their information models by default.

Recent trend is to bring programmable logic controller (PLC) and SCADA closer to IoT and ease integration with cloud services and MQTT protocol is offered to accomplish this [Beck, 2016], [OASI, 2015], [Prol, 2016]. This brings smart grid services into domain of IoT. Integration with ubiquitous cloud platforms and operators is straightforward. But we must be extremely careful regarding information security, especially from this point forward.

8.4 Recommendations

We propose a multi-step approach for the implementation of information exchange and communication interfaces. The global objective of multi-step approach at each actor is to achieve fast time to market or time to implementation, yet be opened and prepared for upgrades and changes that are already on the horizon. This will eventually result in greatly interoperable electricity market ecosystems. A summary of proposed actions per actor type is below.

1. TSO adheres to and implements ENTSO-E network codes and EDI for all electricity market based activities.
2. TSO-BSP information exchange based on IP encapsulated (via gateway) protocols (e.g. IEC 60870-5-101) or IEC 60870-5-104 or Web services (e.g. SOAP) or messaging protocols (e.g. MQTT), with multilayer information security measures implemented.
3. TSO full interconnection with fiber VPN (IP/MPLS) through international telecommunication operators or e-Highway.
4. TSO open software interfaces for information exchange with cloud implemented services based on Web services (e.g. SOAP, HTTP with RESTful) or messaging protocols (e.g. MQTT).
5. BSP-customer information exchange based on IP encapsulated (via gateway) protocols (e.g. IEC 60870-5-101) or Web services (e.g. SOAP) or messaging protocols (e.g. MQTT) or OpenADR Ver2, with multilayer information security measures implemented.
6. BSP communication interconnection with local telecom operator for wired line (fiber, VPN (IP/MPLS) and cellular/mobile (APN) secure communication connectivity. For highly resilient services use two providers with separate physical networks (They must not be virtual providers.).

7. Customers that act as capacity providers implement a form of EMS. This includes PLC and/or small SCADA systems.
8. Customers install PLC and/or SCADA with modern protocols, e.g. OPC UA, particularly supporting DR, e.g. OpenADR and easy cloud interconnection, e.g. HTTP, MQTT. But classical IEC based protocols, IP encapsulated (via gateway), e.g. IEC 60870-5 series or native IP (e.g. IEC 60870-6-503) are a good starting points.
9. Energy metering is implemented per capacity node (load or generator) with sufficient resolution (> 12 bit), reporting period (at least 2 seconds) and accuracy to fulfil Class 1S or Class 0.5S (> 6 kHz sampling of power line is required) and direct interfacing with EMS.
10. Customer's communication interconnection with local telecom operator for wired line (fiber, VPN (IP/MPLS) and/or cellular/mobile (APN) secure communication connectivity. For highly resilient services use two providers with separate physical networks (They must not be virtual providers.).
11. Each actor can demonstrate cloud interoperability of its application programing interfaces with global cloud provider (e.g. Amazon, T-Systems) and/or local one (e.g. IBM, SAP, telecom operator) to speed up later interconnection with other actors on electricity marketplace.
12. Multiple layers of information security on all communication interfaces must be designed from the start. Encrypt message types and data payload for maximum privacy. Do NOT assume any by default secure environments, but rather realize the process of implement-check-periodically test of security policies across the board.

9 Conclusions

Based on the aFRR rules currently defined by the participating TSOs, the analysis clearly shows the limited potential of RES offers in the aFRR market caused by the current combinations of procurement cycles and product lengths. In the current market organized by ELES and APG, less than 1% of the available wind and solar generation can be offered to the aFRR market if it is not part of a much larger portfolio which can complement with switchable loads to meet the requirements. The main restriction is the annually or weekly procurement cycle of the respective markets. Contrary, the aFRR markets of MAVIR are more open for RES portfolios, due to more suitable market design.

Research results show that moving from a week-ahead (W-1) orchestrated market to a day-ahead (D-1) procurement cycle basis is unambiguous; while moving from a D-1 to an intraday cycle adds little added value to the potential of RES in aFRR markets. Additionally moving from a 12 h product length to a 1 h product basis is unambiguous; while moving from a 1 h to an even smaller product length adds little added value to the potential of RES in aFRR markets.

As such: A possibility for daily procurement cycle or bidding and one-hour product length is recommended when aiming for RES in the aFRR market.

The Full Activation Time (FAT) is also an important parameter when talking about aFRR, but considering RES, document shows that FAT is not a limiting factor, due to RES characteristic which can provide fast reaction time.

Considering maximum availability of flexible capacity, moving from a portfolio solely containing RES to a portfolio combined with 10% or 20% of other DR or DG is unambiguous and recommended in a systems.

Based on a field survey, case studies and theoretical analysis the DR & DG flexibility has been identified to exist in a wide area of devices and processes in the industry, tertiary and household sectors. Due to higher specific costs for households and better equipped (technology and knowledge wise) C&I sector, the latter is considered more suitable as the starting point of including DR & DG to aFRR. The theoretical flexible DR capacity of the C&I customers in the four control zones in SI, AT, HU and RO are identified to be +200/-95, +678/-424, +505/-332, +608/-285 MW, respectively. Furthermore, substantial DG flexible capacities have also been identified. However, these are only theoretical limits. Customers expect not only participation in the pilots, but also their inclusion into aFRR services afterwards. Their actual participation depend on technical capability of these units to provide aFRR and the financial motivation which can be at risk due to low electricity prices in general.

These results imply on the existence of a large DR & DG flexibility potential, which is expected to be less costly than conventional solutions (demand reduction is likely cheaper than conventional generation units). Harnessing the identified flexibility potential on the aFRR market requires considering the characteristics and limitations these sources are facing. Firstly, the cross-border participation of demand-side resources and their aggregation in electricity markets should be authorized. The attention should be shifted from the resource towards the aggregator, which should be solely responsible for providing aFRR services within the regulatory requirements (chooses at his discretion the electricity generation technology and limitations of its technical performance, communication standards towards flexibility units and type of their activation etc.), while recognizing the fair treatment of market participants based on the risk for the system – proportional requirements should apply. Secondly, full activation time (call time) should be as long as possible, while keeping the minimum bid quantity as low as possible. Symmetrical products should not be obligatory. Prices should be transparent, communicated in advance and be the same for all market players.

In general, if the TSO-TSO-model is applied, the measurement and verification of aFRR provision should be the task of the connecting TSO. Nevertheless, it turned out to be a challenging topic since there are a lot of individual rules in each control zone and in the current state there is no common standardized procedure of the four TSO. In order to deal with the existing heterogeneity, it is recommended that the participating TSOs discuss possible harmonization of rules for the scope of the research project. Many TSO allow any source of flexible capacity as long as the main requirements for aFRR provision are fulfilled; this is a good approach to facilitate the participation of DG and DR. It could be supportive to re-interpret certain historically grown requirements in order to promote new sources of flexibilities like RES and industrial loads organized in pools and managed by VPPs. In the past many rules have been defined to deal with large generators only, some of these rules may become a barrier for smaller flexibilities managed in portfolios.

The definition of suitable algorithms for baseline calculation are crucial for participation of portfolios in aFRR markets. The baseline methodology has to comply with the TSO's approach for P/f-control and verification, different characteristics of various resources of flexibilities and in some cases even with the national power market clearing rules. The investigation showed that there is no common procedure for baseline calculation which could meet all the various requirements in the four control zones. Therefore, it is important for TSO not to insist on too strict rules but rather to allow different approaches for the verification of unit operation as long as the fundamental requirements are fulfilled. The report explains six different baseline methodologies, of which four fulfil aFRR requirements for sure and are proven practice in some control zones. These methods are a) (corrected) power market schedule, b) baseline submitted with short lead time, c) continuation of the current measurements and d) available active power (of renewable generators). Further methods may also be applicable but are not approved by sufficient practical experience yet. In case that the real-time calculation of provided aFRR power requires a short-term baseline correction it is preferable that the provider performs the correction, which of course requires transparent rules to support ex-post verification by the TSO.

Some TSO accept new proposals for verification methods developed by the providers of flexibilities as long as reliability and transparency fulfil the requirements for aFRR provision. This approach proved to be good practice to facilitate the participation of RES and aggregators in balancing markets. Alternatively, the provider could choose a baseline method from a catalogue of methods already verified by the TSO.

Currently the aFRR prequalification procedure has to be performed for each participating unit individually. If a portfolio based prequalification procedure would be introduced, this could facilitate the participation of portfolios of smaller units like DG and DR.

Considering information exchange among actors in aFRR market the report clearly distinct between protocols and their possible application for communication among actors on the electricity marketplace. Several possible protocols were identified for each layer within the end-to-end communication structure. For small pilot testing and small scale implementations it is recommended to apply currently popular protocols (e.g. IEC 60870-6-503, OPC UA, Web services), but to upgrade their information models. Scope enhanced information models will serve specifics on each layer, e.g. transport of measured data from the individual unit to the pool operator as Balancing Service Provider (BSP) or exchange of market related data (e.g. bidding process) among TSOs and between BSP and TSO.

Communication bandwidth requirements are especially important to be considered in the access network, i.e. between individual unit and BSP. For this purpose, the existing telecom operator's communication infrastructures can be used. The required bandwidth from unit to BSP can be estimated conservatively at < 15 kbps for capacity nodes (DG, load) equipped with up to 10 measurement transducers and with measurement data reporting time at 1 s. Review of forthcoming machine type oriented protocols for 4G (LTE) shows that demands can be fully met with cellular networks, too.

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A. General terminology

Following Table 18 is a result from WP1 and presents general terminology – glossary, which will be used within FutureFlow project and is a basis for further work. Content in the table is from various sources and literature, such as: [ENTSO-E, 2015 a], [ENTSO-E, 2015 b], [ENTSO-E, 2015 c], [European Commission, 2016].

Table 18: Glossary

Term	Acronyms	Definition
Activation Optimization Function	AOF	Activation Optimization Function means the role to operate the algorithm applied for the optimization of the activation of Balancing Electricity bids within a Coordinated Balancing Area.
Allocated Volume		Allocated Volume means an electricity volume physically injected or withdrawn from the system and attributed to a Balance Responsible Party, for the calculation of the Imbalance of that Balance Responsible Party.
Area Control Error	ACE	Area control error or 'ACE' means the sum of the power control error ('ΔP'), that is the real-time difference between the measured actual real time power interchange value ('P') and the control program ('P0') of a specific LFC area or LFC block and the frequency control error ('K*Δf'), that is the product of the K-factor and the frequency deviation of that specific LFC area or LFC block, where the area control error equals ΔP+K*Δf;
Automatic frequency restoration reserve	aFRR	Automatic FRR means FRR that can be activated by an automatic control device.
Automatic frequency restoration reserve Activation Delay		The period of time between the setting of a new set point value by the frequency restoration controller and the start of physical Automatic FRR delivery.
Balance Responsible Party	BRP	Balance Responsible Party means a market-related entity or its chosen representative responsible for its Imbalances.

Balancing		Balancing means all actions and processes, on all timelines, through which TSOs ensure, in a continuous way, to maintain the system frequency within a predefined stability range as set forth in [Article 19 Frequency Quality Target Parameters] of the Network Code on Load Frequency Control and Reserves, and to comply with the amount of reserves needed per Frequency Containment Process, Frequency Restoration Process and Reserve Replacement Process with respect to the required quality, as set forth in [Chapter 6 Frequency Containment Reserves, Chapter 7 Frequency Restorations Reserves and Chapter 8 Replacement Reserves] of the Network Code on Load-Frequency Control and Reserves.
Balancing Capacity		Balancing Capacity means the contracted Reserve Capacity.
Balancing Electricity		Balancing Electricity means energy used by TSOs to perform Balancing.
Balancing Electricity Gate Closure Time	GCT	Balancing Electricity Gate Closure Time means the point in time when submission or update of a Balancing Electricity bid for a Standard Product on a Common Merit Order List in a Coordinated Balancing Area is no longer permitted.
Balancing Market		Balancing Market means the entirety of institutional, commercial and operational arrangements that establish market-based management of the function of Balancing within the framework of the European Network Codes.
Balancing Services		Balancing Services means either or both Balancing Capacity and Balancing Electricity.
Balancing Service Provider	BSP	Balancing Service Provider means a Market Participant providing Balancing Services (portfolio or separate service; aFRR, mFRR, redispatch) to its Connecting TSO, or in case of the TSO-BSP Model, to its Contracting TSO.

Capacity Procurement Optimization Function		Capacity Procurement Optimization Function means the role to operate the algorithm applied for the optimization of the procurement of Balancing Capacity within a Coordinated Balancing Area in which Balancing Capacity is exchanged.
Central Dispatch		Central Dispatch means a scheduling and dispatch arrangement in a Responsibility Area where the TSO performs the Integrated Scheduling Process; and where the TSO issues dispatch instructions directly to the dispatchable Power Generating Facilities and Demand Facilities.
Commercial and Industrial consumers	C&I	
Common grid model	CGM	Common grid model means a Union-wide data set agreed between various TSOs describing the main characteristic of the power system (generation, loads and grid topology) and rules for changing these characteristics during the capacity calculation process;
Common Merit Order List	CMOL	Common Merit Order List means a list of Balancing Electricity bids sorted in order of their bid prices, used for the activation of Balancing Electricity bids within a Coordinated Balancing Area.
Connecting TSO		Connecting TSO means the TSO which operates the Responsibility Area in which Balancing Service Providers and Balance Responsible Parties shall be compliant with the terms and conditions related to Balancing.
Contracting TSO		Contracting TSO means in case of the TSO-BSP Model the TSO which has contractual arrangements with a Balancing Service Provider in another Responsibility Area or Scheduling Area when appropriate.
Coordinated Balancing Area	COBA	Coordinated Balancing Area means a cooperation with respect to the Exchange of Balancing Services, Sharing of Reserves or operating the Imbalance Netting

		Process between two or more TSOs.
Cross Zonal Capacity	CZC	Cross zonal capacity means the capability of the interconnected system to accommodate electricity transfer between bidding zones; It takes into account Operational Security Limits.
Deactivation Period		Deactivation Period means the time period for ramping, from full delivery or withdrawal back to a set point.
Delivery Period		Delivery Period means a time period of delivery during which the Balancing Service Provider delivers the full requested change of power in-feed or withdrawals to the system.
Demand side response	DR	
Dimensioning Incident		The highest expected instantaneously occurring Active Power Imbalance within a LFC Block in both positive and negative direction.
Distributed generation	DG	
Divisibility		Divisibility means the possibility for the TSO to use only part of the Balancing Electricity bids or Balancing Capacity bids offered by the Balancing Service Provider, either in terms of power activation or time duration.
Exchange of Balancing Capacity		Exchange of Balancing Capacity means the process of procuring Balancing Capacity by a TSO in a different Responsibility Area or Scheduling Area when appropriate than the one in which the procured Balancing Service Provider is connected.
Exchange of Balancing Electricity		Exchange of Balancing Electricity means the process of instructing the activation of Balancing Electricity bids for the delivery of Balancing Electricity by a TSO in a different Responsibility Area or Scheduling Area when appropriate, than the one in which the activated Balancing Service Provider is connected.

Exchange of Balancing Services		Exchange of Balancing Services means either or both Exchange of Balancing Capacity and Exchange of Balancing Electricity.
Flexible Capacity	FC	Portion of power, which can be offered to TSO for providing balance services.
Flexible Capacity Units	FCU	Units providing flexible capacity (aFRR, mFRR, redispatch)
Flow-based approach	FB approach	Flow-based approach means a capacity calculation method in which electricity exchanges between bidding zones are limited by power transfer distribution factors and available margins on critical network elements.
Full Activation Time	FAT	Full Activation Time means the time period between the activation request by TSO and the corresponding full activation of the concerned product.
Future Flow	FF	
Frequency Containment Reserves	FCR	FCR means the active power reserves available to contain system frequency after the occurrence of an imbalance.
Frequency Restoration Control Error	FRCE	Frequency restoration control error or 'FRCE' means the control error for the FRP which is equal to the ACE of a LFC area or equal to the frequency deviation where the LFC area geographically corresponds to the synchronous area;
Frequency Restoration Reserves	FRR	Frequency restoration reserves or 'FRR' means the active power reserves available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore power balance to the scheduled value;
FRR Delay Time		The period of time between the set point change from TSO and the commencement of FRR delivery.
Generating Unit		A generating unit is an indivisible set of installations

		which can generate electrical electricity. The generating unit may for example be a thermal power unit, a single shaft combined-cycle plant, a single machine of a hydro-electric power plant, a wind turbine, a fuel cell stack, or a solar module. If there are more than one generating unit within a power generating facility that cannot be operated independently from each other than each of the combinations of these units shall be considered as one generating unit.
Imbalance		Imbalance means an electricity volume calculated for a Balance Responsible Party and representing the difference between the Allocated Volume attributed to that Balance Responsible Party, and the final Position of that Balance Responsible Party and any Imbalance Adjustment applied to that Balance Responsible Party, within a given Imbalance Settlement Period.
Imbalance Adjustment		Imbalance Adjustment means an electricity volume representing the Balancing Electricity from a Balancing Service Provider and applied by the Connecting TSO for an Imbalance Settlement Period to the concerned Balance Responsible Parties, for the calculation of the Imbalance of these Balance Responsible Parties.
Imbalance Area		Imbalance Area means the Imbalance Price Area or a part of an Imbalance Price Area, for the calculation of an Imbalance.
Imbalance Netting Process Function	INPF	Imbalance Netting Process Function means the role to operate the algorithm applied for operating the Imbalance Netting Process.
Imbalance Price	IP	Imbalance Price means the price, positive, 0 or negative, in each Imbalance Settlement Period for an Imbalance in each direction.
Imbalance Price Area	IPA	Imbalance Price Area means either a Bidding Zone, part of a Bidding Zone or a combination of several Bidding Zones, to be defined by each TSO, for the

		purpose of calculation of Imbalance Prices.
Imbalance Settlement	IS	Imbalance Settlement means a financial settlement mechanism aiming at charging or paying Balance Responsible Parties for their Imbalances.
Imbalance Settlement Period	ISP	Imbalance Settlement Period means time units for which Balance Responsible Parties' Imbalance is calculated.
Instantaneous FRCE Data		A set of data of the FRCE for a LFC Block with a measurement period equal to or shorter than 10 seconds used for System Frequency quality evaluation purposes.
Integrated Scheduling Process		Integrated Scheduling Process means an iterative process that uses at least Integrated Scheduling Process bids which contain commercial data, complex technical data of each Power Generating Facilities or Demand Facilities which explicitly includes the start-up characteristics, the latest Responsibility Area Adequacy analysis, and the Operational Security Limits as an input to the process; which then simultaneously optimizes reserve procurement, congestion management and Balancing Electricity procurement over a set time horizon in order to produce an indicative Active Power output schedule for the dispatchable resources in order to ensure Operational Security.
Integrated Scheduling Process Gate Closure Time		Integrated Scheduling Process Gate Closure Time means the point in time when the submission or update of Integrated Scheduling Process bids is no longer permitted for the given iterations of the Integrated Scheduling Process.
Load-frequency control area	LFC area	LFC area means a part of a synchronous area or an entire synchronous area, physically demarcated by points of measurement at interconnectors to other LFC areas, operated by one or more TSOs fulfilling the obligations of load-frequency control

Load-frequency control block	LFC block	LFC block means a part of a synchronous area or an entire synchronous area, physically demarcated by points of measurement at interconnectors to other LFC blocks, consisting of one or more LFC areas, operated by one or more TSOs fulfilling the obligations of load-frequency control
Load frequency control	LFC	Control scheme created to maintain balance between generation and demand, to restore the frequency to its set point value in the synchronous area and, depending on the control structure in the synchronous area, to maintain the exchange power to its reference value.
Load-Frequency Controller	LF Controller	Automatic control device designed to reduce the Frequency Restoration Control Error (FRCE) to zero. Physically this is a processing computer that is usually implemented in the TSOs control center systems (SCADA/EMS). The LF Controller processes FRCE measurements typically every 4-10s and provides - in the same time cycle – automated instructions to aFRR providers that are connected by telecommunication connections.
Manual Frequency Restoration Reserves	mFRR	Manual FRR means FRR that is activated manually, with full activation time.
Merit order	MO	Merit Order List means a list of Balancing Electricity bids sorted in order of their bid prices
Mode of Activation		Mode of Activation means the implementation of activation of Balancing Electricity bids, manual or automatic, depending on whether Balancing Electricity is triggered manually by an operator or automatically by means of a closed-loop regulator.
Net Imbalance		The resulting imbalance that remains after netting of all BRP imbalances, i.e. the absolute sum of all imbalances.
Net Transfer Capacity	NTC	Net Transfer Capacity is the maximum capacity for

		exchange of power between two areas, compatible with security standards applicable in both areas and taking into account the technical uncertainties on future network conditions.
Open Loop Area Control Error	ACE OL	The open loop ACE for a control area is an indicator of the total imbalance, and is the sum of the ACE for that control area and the activated reserves.
Open Loop Frequency Restoration Control Error	FRCE OL	The open loop FRCE for a control area is an indicator of the total imbalance, and is the sum of the FRCE for that control area and the activated reserves.
Position		Position means an electricity volume representing the sum of scheduled commercial transactions of a Balance Responsible Party, on organized electricity markets or between Balance Responsible Parties, for the calculation of the Imbalance, or, where appropriate, means an electricity volume representing scheduled injections, scheduled withdrawals or the sum of scheduled injections and withdrawals of a Balance Responsible Party, for the calculation of the Imbalance of that Balance Responsible Party.
Preparation Period		Preparation Period means the time duration between the request by the TSO and start of the electricity delivery.
Prequalification		Prequalification means the process to verify the compliance of a reserve providing unit or a reserve providing group with the requirements set by the TSO;
Ramping period		Ramping period means a period of time defined by a fixed starting point and a length of time during which the input and/or output of active power will be increased or decreased
Replacement Reserves	RR	Replacement reserves or 'RR' means the active power reserves available to restore or support the required level of FRR to be prepared for additional system imbalances, including operating reserves

Requesting TSO		Requesting TSO means the TSO that requests Balancing Electricity.
Self-Dispatch		Self-Dispatch means a scheduling and dispatch arrangement in a Responsibility Area where the schedule of all generation units and Demand Side Response is determined by the unit's owners.
Set point		A target value for any parameter typically used in control schemes.
Specific Product		Specific Product means a product different from a Standard Product.
Standard Product		Standard Product means a harmonized Balancing product defined by all TSOs for the Exchange of Balancing Services.
Synchronous area	SA	A set of synchronously interconnected elements that have no synchronous interconnections with other areas. Within a synchronous area the system frequency is common on a steady state.
System frequency		System frequency means the electric frequency of the system that can be measured in all parts of the synchronous area under the assumption of a coherent value for the system in the time frame of seconds, with only minor differences between different measurement locations;
Time to restore frequency		The maximum expected time after the occurrence of an imbalance smaller than or equal to the Reference Incident in which the System Frequency returns to the Frequency Restoration Range for Synchronous Areas with only one LFC Area; for Synchronous Areas with more than one LFC Area the Time to Restore Frequency is the maximum expected time after the occurrence of an imbalance of an LFC Area within which the imbalance is compensated.
Transfer of Balancing Capacity		Transfer of Balancing Capacity means a transfer of Balancing Capacity from the initially contracted

		Balancing Service Provider to another transfer receiving Balancing Service Provider.
Transfer of Balancing Capacity Function		Transfer of Balancing Capacity Function means the role to operate the algorithm applied for the optimization of the Transfer of Balancing Capacity.
Transmission system operator	TSO	
TSO Electricity Bid Submission Gate Closure Time		TSO Electricity Bid Submission Gate Closure Time means the latest point in time when a Connecting TSO can forward the Balancing Electricity bids received from a Balancing Service Provider to the Activation Optimization Function. The TSO Electricity Bid Submission Gate Closure Time is after Balancing Electricity Gate Closure Time.
TSO-BSP Model		TSO-BSP Model means a model for the Exchange of Balancing Capacity or the Exchange of Balancing Electricity where the Contracting TSO has an agreement with a Balancing Service Provider in another Responsibility Area or Scheduling Area when appropriate.
TSO-TSO Model		TSO-TSO Model means a model for the Exchange of Balancing Services exclusively by TSOs. The TSO-TSO Model is the standard model for the Exchange of Balancing Services.