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FutureFlow* project: Selection of the target model for the balancing energy exchanges

Nebojša Jović[1], Zoran Vujasinović, Dušan Vlaisavljević
Electricity Coordinating Center Ltd. (EKC)
Serbia

SUMMARY

Within the FutureFlow research & Innovation project, funded by European Commission, the four European TSOs (APG - Austria, MAVIR - Hungary, Transelectrica - Romania and ELES - Slovenia), associated with power system experts, electricity retailers, IT providers and renewable electricity providers, are working on the design of a cross-border aFRR (secondary control) balancing exchange market, which incorporates both conventional and aggregated DR/DG flexibility providers.
A comprehensive technical-economic model for the cross border integration of such services involves a Common Activation Function (CAF) tailored to deal with congested borders, with limited Cross-zonal Capacity (CZC) among the systems.
The paper describes the proposed FutureFlow target model for aFRR cross-border energy exchange with Common Activation Function, and provides the analyses of the selection among the several alternatives: control demand-based integration or control target-based integration; applying standard product only (single Full Activation Time for the whole market) or Standard & Specific Product (bids with different FAT allowed). The assessment of technical (ACE control quality), economic and market indicators is performed and described. The two parallel options for the Cross Zonal Capacity among involved TSOs are exercised: ATC-based and Flow-based.

KEYWORDS

balancing, demand response (DR), distributed generation (DG), automatic frequency restoration reserves (aFRR), Cross-zonal Capacity (CZC)

[1] nebojsa.jovic@ekc-ltd.com

INTRODUCTION

Within the FutureFlow (FF) project, the feasible models of aFRR energy exchange among the control zones (countries), with scarce transmission capacity have been analysed. Among various options, the most suitable target model has been selected through the simulations, based on the algorithm of the common activation function (CAF) based on the aforementioned concept.

FF Target Model design was required to provide certain innovation in the field of electricity balancing (on top of the actual implementation project), but still to be in line with the EU Target Model (mainly defined by Guideline on Electricity Balancing (EB GL) and Guideline on electricity transmission system operation (SO GL)), and at the same time be secure, sustainable, replicable and applicable in the situations of congested borders.

This aFRR energy exchange concept and simulations are exercised on the basis of the markets and data of the countries and their TSOs involved in the FutureFlow project (Austria, Hungary, Romania, Slovenia); however these concepts are suited to be as much as possible universal within the scope of European electricity markets, and thus replicable to other countries and regions.

The overall process of exchange of aFRR balancing energy is envisaged in the following sequence:

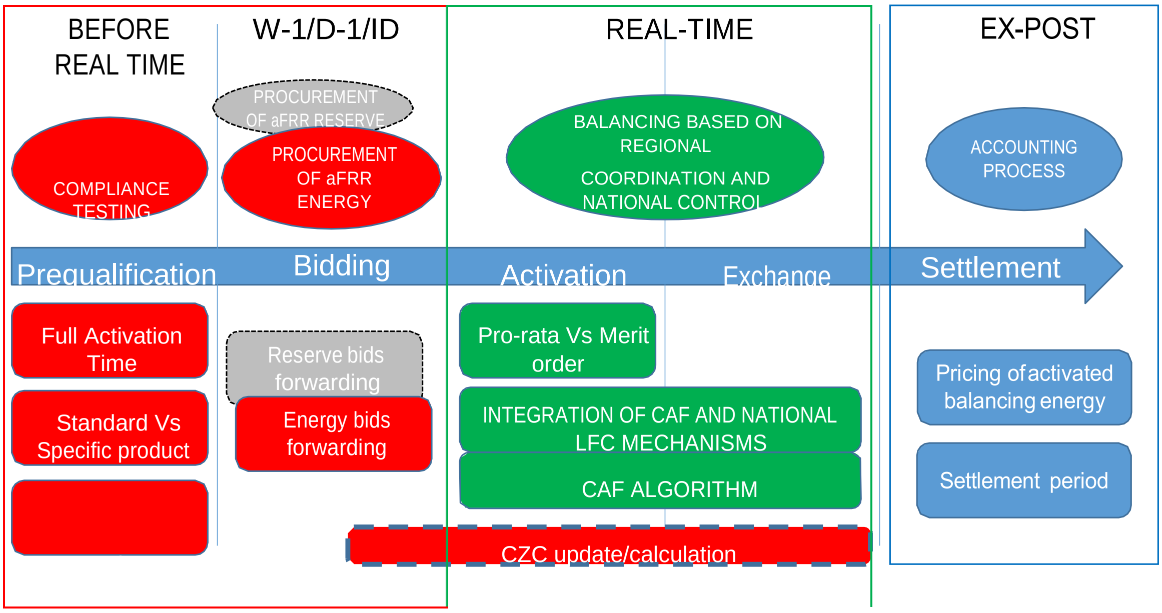


Figure 1: aFRR energy exchange process - phases

Key aspects of the Target Model are listed below:

- "TSO-TSO" as the standard and target model for the exchange of balancing services
- activation rule: merit order as currently in Austria and Hungary (opposed to pro-rata activation)
- Full activation time (FAT) of aFRR buds; currently max. 5 min in Austria, and 15 min in other three countries. Selection among the suitable FAT (5-15 min), and possible hybrid of standard and specific FAT bids, was left to be decided based on simulations.
- Integration models: "Control demand"-based integration, assumes open loop deviation of control area as the input in CAF; or "Control Target/Request"-based integration is based on control target or control request, i.e. ramp rate limited/unlimited output of aFRR controller. The selection among these two concepts is also left to be decided based on simulation results.

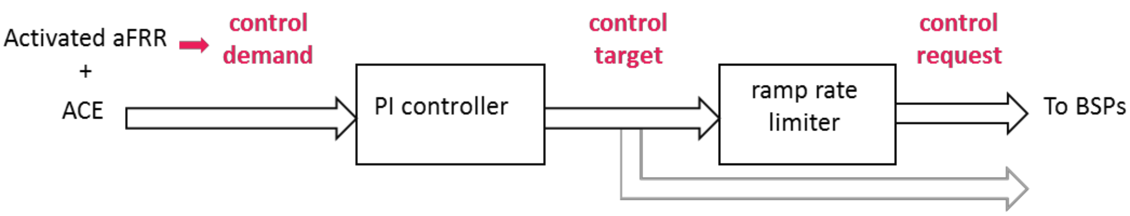


Figure 2: LFC and possible aFRR exchange demand sources: control demand, control target/request

- Cross-zonal capacity: Remaining capacity after the commercial day-ahead and intra-day processes are to be used for balancing exchanges. Both concepts of calculation and implementation ATC- based and Flow-based transmission capacity constraints are required to be supported.

VERIFICATION OF SIMULATION MODEL

For the purposes of aFRR simulations, the simulation model (DEMOX tool by EIMV Ljubljana) and its parametrization was validated, in order to confirm that further simulation results can be considered as relevant. During validation, individual TSO's LFC controller models and unit responses as well as its parameterisation has been tested to ensure that measured and simulated responses of existing controllers and units for all four TSOs match. The input data of such parametrisation and simulation were provided by the TSOs. If the responses of the simulation model are a reasonably good match with measurements, it can be assumed that the simulation environment is correctly validated and as such can be used in further simulations.

Two types of validation have been performed:

Validation of the load-frequency controller (LFC) parameters by comparing the input data of TSOs and output setpoint generated by the LFC with the measured setpoint. Measured ACE represents the model input.

Validation of BSP responses by comparing the input data of TSOs and the output data of activated aFRR of individual units, where BSP set points represent the model's input.

Validation has been performed using ACE, LFC controller and individual unit response data for period of one week of winter-2017 data. Since ELES and TEL use pro-rata activation, this activation principle has also been modelled in DEMOX to enable validation and comparability of measured/simulated responses.

The figure illustrates the verification results of ELES LFC controller and a unit participating in aFRR:

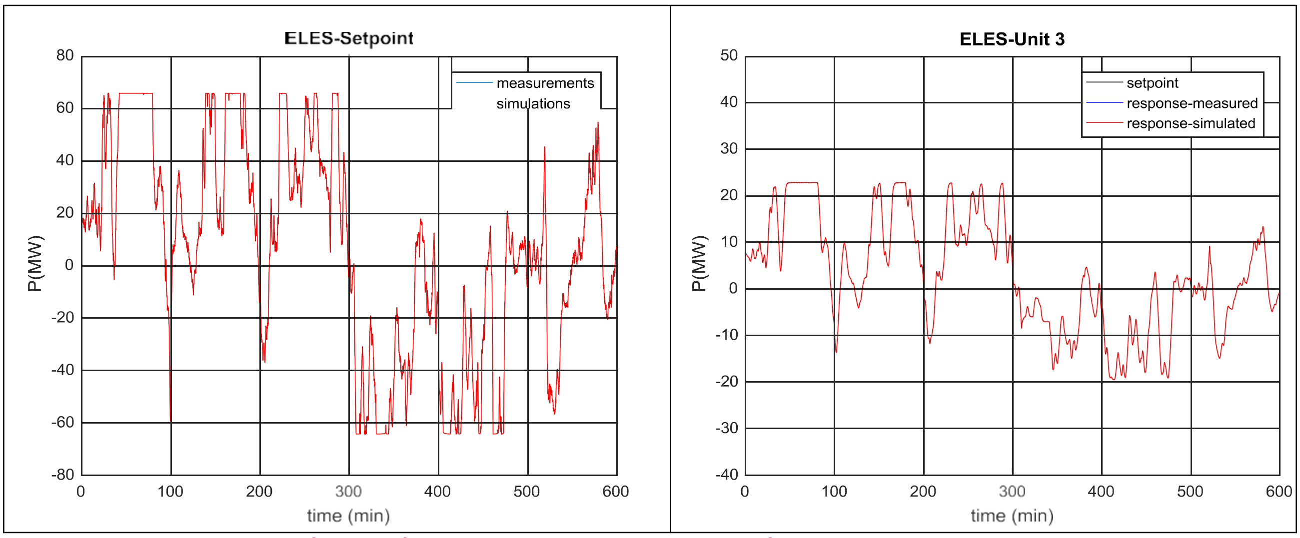


Figure 3: Verification of ELES LFC response, and response of a generation unit participating in aFRR control

Corresponding results were obtained for remaining three TSOs as well; based on this verification process of all four aFRR controller and BSP response models, it was concluded, that DEMOX realistically models TSO's LFC controller and unit responses, therefore simulations results were considered as relevant.

SETUP OF SIMULATIONS ANALYSES

Simulations have been performed on historic time-series of ACE open-loop signal and national merit order lists for four consecutive weeks (data for the period 6th – 31st March 2017) provided by the TSOs. The DEMOX platform handled the data and performed aFRR activation in accordance with different simulation cases. The resulting simulated ACE time-series (i.e open-loop ACE with subtracted activation of simulated aFRR response), is used to calculate LFC performance quality considering the same quality indices as given in regular ENTSO-E report "Regular Report of the Performance of the Primary and Secondary Load-Frequency control – Q1 2017", such as mean value of ACE and standard deviation of ACE on 1 hour, 15-minute and 5-minute time intervals.

The following simulation cases have been analysed:

Table 1 – Simulation Cases and its comparisons

SI, RO: pro-rata activation		All: merit-order activation	
BASE CASE STATUS QUO (SI,HU,RO: 15 min FAT)	VS.	REFERENCE CASE A (5 min FAT)	VS.
		REFERENCE CASE B 5 & 10 min FAT	
CZC = 0 *No regional cooperation*		*CZC = 0* *No regional cooperation*	

CASES	Integration approach	Pre-netting	Products
FF INTEGRATION CASE 1	Control Demand	No	STANDARD (FAT 5 min)
FF INTEGRATION CASE 2	Control Target	Yes	STANDARD (FAT 5 min)
FF INTEGRATION CASE 3			STANDARD + SPECIFIC (FAT 5 min) + (FAT 10 min)
CZC ≠ 0 *ATC-based, and Flow-based*			

- BASE CASE (STATUS QUO, NO REGIONAL COOPERATION)

Here the current parameter settings of TSOs' LF controllers, the current bid activation schemes (pro-rata for ELES and TEL and merit order for APG and MAVIR) as well as validated aFRR providers' have been used. This scenario is used as a base case scenario for creation of transition reference scenarios REFERENCE CASE A and REFERENCE CASE B in which TSO's LFC controller parameters and aFRR unit responses are harmonized to fulfil the analysed FF target model requirements, namely merit order bid activation schemes and FAT requirements. The cross-zonal capacities for each border are set to zero to simulate no regional cooperation.

- REFERENCE CASE A (HARMONIZED STANDARD PRODUCT, NO COOPERATION)

Within this case, the following changes have been made compared to base case scenario: Pro-rata bid activation schemes for ELES and TEL have been changed to simple merit order scheme; Generator unit responses for ELES, TEL and MAVIR are adjusted to fulfil harmonized standard product (FAT = 5 minutes); Generator unit responses and LF controller settings are tested and adjusted (if necessary) to fulfil ENTSO-E Policy 1 requirement that secondary control must perform its action to bring ACE back to 0 after disturbance within 15 minutes; Stepwise activation of BSPs has been implemented instead of actual ramp- rate limited (continuous) activation.

The reason of implementation of Reference case A is to provide a reference for the evaluation of different FF integration solutions (i.e. FF integration case scenario 1 and 2). It represents a base case with no cross- border cooperation, however with standardised MOL based aFRR activation and standardised unit responses (FAT 5).

- REFERENCE CASE B (STANDARD& SPECIFIC PRODUCTS, NO COOPERATION)

Within this case, the following changes have been made compared to base case scenario: Pro-rata bid activation schemes for ELES and TEL have been changed to simple merit order scheme; Generator unit responses for ELES, TEL and MAVIR are adjusted to fulfil requirements for standard and specific products (standard product is FAT = 5 minutes, specific product is FAT = 10 minutes). APG applies Standard Product only (5 min FAT); Generator unit responses and LF controller settings are tested and adjusted (if necessary) to fulfil ENTSO-E Policy 1 requirement that secondary control must perform its action to bring ACE back to 0 after disturbance within 15 minutes; Stepwise activation of BSPs has been implemented instead of actual ramp-rate limited (continuous) activation.

The reason of implementation of Reference case B is similar as for Reference case A. General modifications of both reference cases are equal, with the exceptions some units in B have FAT 10 min instead of FAT 5 min. Because of this, performance of ref. case B slightly deviates from a ref.case A.

- FF INTEGRATION CASE 1 (CONTROL DEMAND ACTIVATION SCHEME, HARMONIZED STANDARD PRODUCT, REGIONAL COOPERATION)

The FF Integration Case 1 is derived from Reference Case A and has enabled regional cooperation using **control demand** activation scheme. Both ATC and Flow-based cross zonal network constraints have been analysed. The resulting LF controller performance indices for each TSO as well as overall quality parameters have been compared with REFERENCE CASE A and other examined FF integration cases to select the most suitable model for Future Flow project. Imbalance Netting process is implicitly embedded within the Control Demand optimisation.

- FF INTEGRATION CASE 2 (CONTROL TARGET ACTIVATION SCHEME, HARMONIZED STANDARD PRODUCT, REGIONAL COOPERATION)

The FF Integration Case 2 is similar to The FF Integration Case 1, except that control demand activation scheme is substituted with **control target** activation scheme. At both FF Integration Cases 2 and 3, related to Control Target Activation Scheme, explicit Imbalance Netting ("Pre-netting") is considered and simulated. Both ATC and Flow-based cross zonal network constraints have been analysed.

- FF INTEGRATION CASE 3 (CONTROL TARGET ACTIVATION SCHEME, STANDARD AND SPECIFIC PRODUCTS, REGIONAL COOPERATION)

The FF Integration Case 3 is derived from Reference Case B and has enabled regional cooperation using **control target** activation scheme. FF integration test 3 is similar to FF integration test 2, except that some units use specific (FAT 10 min) products instead of standardised (FAT 5 min one). Both ATC and Flow-based cross zonal network constraints have been analysed.

CROSS ZONAL CAPACITIES

The two different approaches of CZC are applied in parallel: ATC-based and Flow-based (FB). Having in mind the TSO practice and the time and efforts needed for TSOs to manage and prepare the CZC to be suitable and ready for the real-time balancing process:

o ATC-based capacities are analysed as capacity remaining after the Intra-day commercial trade

o Flow-based capacities are analysed as recalculated on the basis of Intra-day network models for each following timestamp

ATC values (as remaining after Intra-day) naturally provide more conservative constraints to the balancing exchanges, since original NTC values are currently calculated at two-days ahead time horizon in the best case, and therefore capture more conservative forecasting assumptions.

On the other hand, being calculated as late as possible, FB values can be more relaxed in sense of forecasting the network situations roughly half an hour before its application. In the simulated cases, they led to the uncongested situations.

SIMULATION PROCESS AND RESULTS

- BASE CASE – STATUS QUO

The main objective of this simulation is to obtain the aFRR control reference performance indicators for each participating TSO, as well as for the observed region as a whole. These indicators will be used as a basis once the LFC controller parameters and aFRR unit responses are modified to comply with the analysed FF target model requirements.

The main performance indicators for each TSO in base case regime are given in the following Figure.

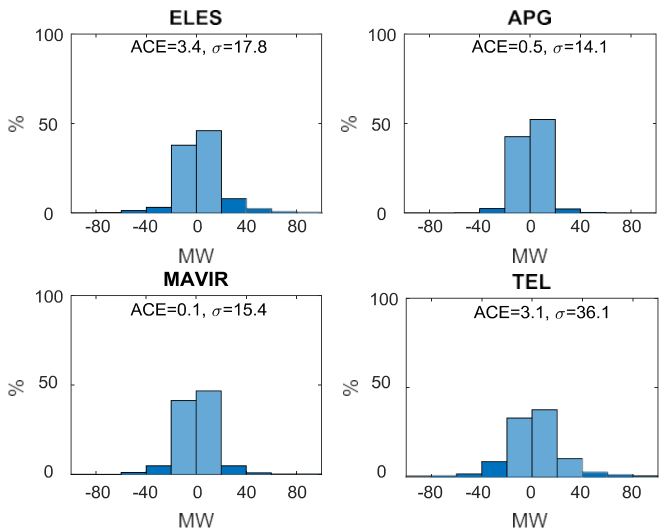


Figure 4: Average Area Control Error per 15 minute ΔP [MW] - Class width 20 MW

It is concluded that obtained values for analysed period (March 2017) are very similar to real performance indicators taken from ENTSO-E LFC Report 2017 Q1. This additionally proves the validity of the DEMOX simulation tool and settings.

- REFERENCE CASE A – STANDARD PRODUCT

The main objective of this case is to obtain new reference case scenario once the LFC controller parameters and aFRR unit responses are harmonized to comply with the analysed FF integration model with standard product. The reference case A is later used a reference for comparison with FF integration case 1 and 2.

In order to correctly simulate the behaviour of FF integration solution with standard product (FAT = 5 minutes), the following changes in control strategy, activation principles and aFRR provider's technical capabilities are applied in the model:

- ELES and TEL are migrated from current pro-rata activation mechanism to simple merit order list activation
- Implementation of stepwise activation principle for ELES, MAVIR and TEL
- The aFRR provider's ramping capabilities in ELES, TEL and MAVIR are adjusted to comply with FAT of 5 minutes (in case of non-available data for ramping capabilities, the conservative approach is used)
- The aFRR control mechanism (LF controller parameters and aFRR unit responses) have to be reparametrized to be in line with requirements to bring ACE back to zero within 15 minutes (smaller step disturbance and larger step disturbance).

After these adjustments of control settings and parameters, the ACE quality performance indicators for reference case A are calculated and compared with base case, taking into account input open-loop signals for March 2017 and cross border capacities set to zero.

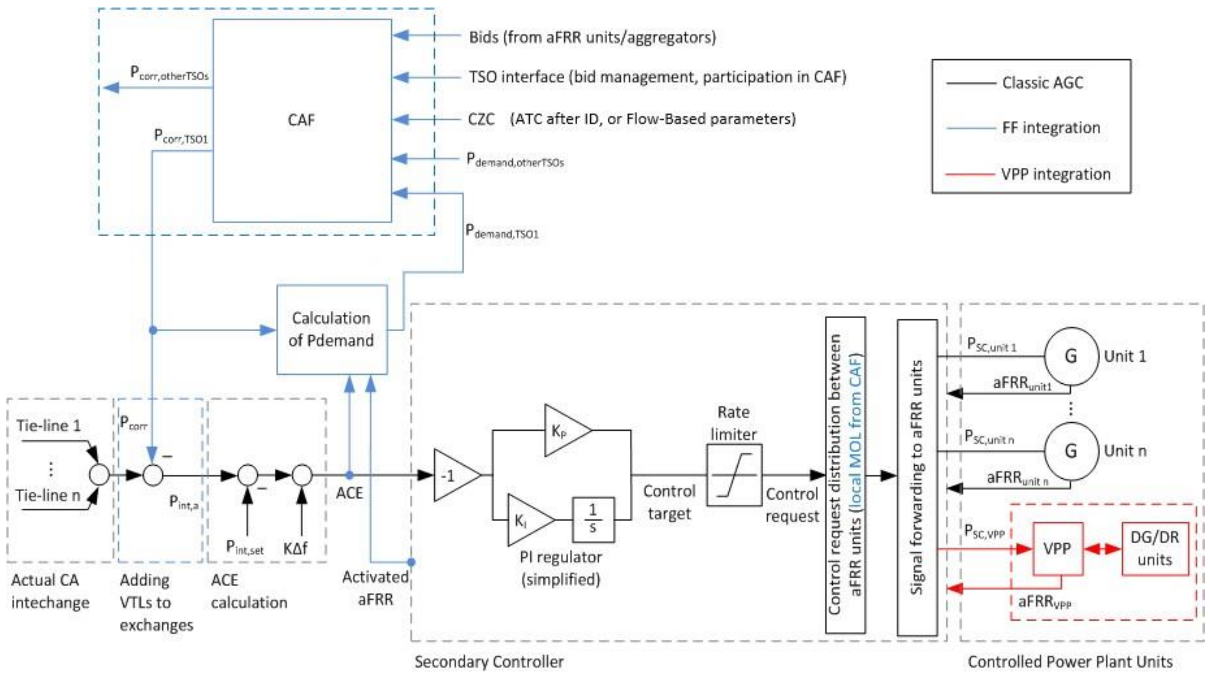
- REFERENCE CASE B – STANDARD AND SPECIFIC PRODUCT

Similar as for Reference Case A with standard product, the main goal of this simulation case is to prepare new reference scenario that will serve as a basis for further FF target case simulation with combined standard and specific products. It is assumed that standard product is with FAT of 5 minutes, while specific product considers FAT of 10 minutes.

- FF INTEGRATION CASE 1 – CONTROL DEMAND WITH STANDARD PRODUCT

First simulated option with regional cooperation is Integration Case - Control Demand with Standard Product.

Figure 5: Control Demand integration, (for FF Integration Case 1)



The adjusted LFC controller parameters and aFRR unit's settings from Reference Case A has been applied also for this scenario, while available cross zonal capacities are taken from realized ATC values on observed borders after intra-day auction process for March 2017.

The main criteria for evaluation of feasibility of this integration case is a quality of ACE control performance indicators, i.e. ACE mean values and ACE standard deviation values have been compared against the same values for Reference Case A, to identify the influence of FF cooperation on national ACE quality parameters as well as on overall ACE quality indices for observed 4 TSOs.

Based on comparison with Reference Case A, it can be concluded that overall ACE control performance indicators have been significantly improved and that local ACE control quality for ELES, APG and MAVIR is also being improved, while TEL parameters are approximately on the same level with slight improvement.

- FF INTEGRATION CASE 2 – CONTROL TARGET WITH STANDARD PRODUCT

The FF Integration Case 2 control target with standard product is analysed as a second potential option of regional cooperation. The results of ACE control performance indicators are compared against the same indicators for Reference Case A as well as against Future Flow Integration Case 1. Comparing calculated indicators with the same ones for Reference Case A, overall ACE quality performance for each TSO has been significantly improved. However, comparing the same indicators with previously analysed FF Integration Case 1 – Control demand, there is slight deterioration of overall ACE quality parameters, as well as for ELES, APG and MAVIR, while for TEL the small improvement in ACE quality can be envisaged.

The observed overall deterioration of ACE control quality is a consequence of the fact that in this FF Integration Case, CAF deals with local LFC controller output signals that are already pass through filters and PI controllers. Hence, although volatility has been reduced, the signal is considerably delayed and as result cross border exchange is less efficient and optimization benefits are smaller in contrast with FF Integration Case 1 where CAF optimizes non-filtered, “raw” local ACE signals.

- FF INTEGRATION CASE 3 – CONTROL TARGET WITH STANDARD AND SPECIFIC PRODUCT

The FF Integration Case 3 control target with standard product is analysed as a third potential option of regional cooperation. The adjusted LF controller parameters and aFRR unit’s settings from Reference Case B has been applied for this scenario. The results of ACE control performance indicators are compared against the same indicators for Reference Case B as well as against FF Integration Case 1 and FF Integration Case 2. Comparing calculated indicators with the same one for Reference Case B, overall ACE quality performance for each TSO has been significantly improved. However, comparing the same indicators with previously analysed FF Integration Case 1 – Control demand with standard product and FF Integration Case 2 – Control target with standard product, obviously there is slight deterioration of overall ACE quality parameters, due to combination of aFRR unit portfolios with 5 minute FAT and with 10 minute FAT.

SELECTION OF A TARGET MODEL

The objective of the simulation process is to decide which model of cooperation among the three Integration Cases analysed, should be implemented within Future Flow project by analysing the impact of all FF models on ACE control quality performance.

During the selection of a target model, the technical performances (such as ACE quality) are evaluated numerically, while also other indicators are considered qualitatively, such as aFRR market liquidity, complexity of implementation, volatility, etc.

The ACE control quality parameters, given as an envelope, for each analysed case and for each TSO are shown on the Figure 6, while overall ACE quality indices for all TSOs are given on Figure 7.

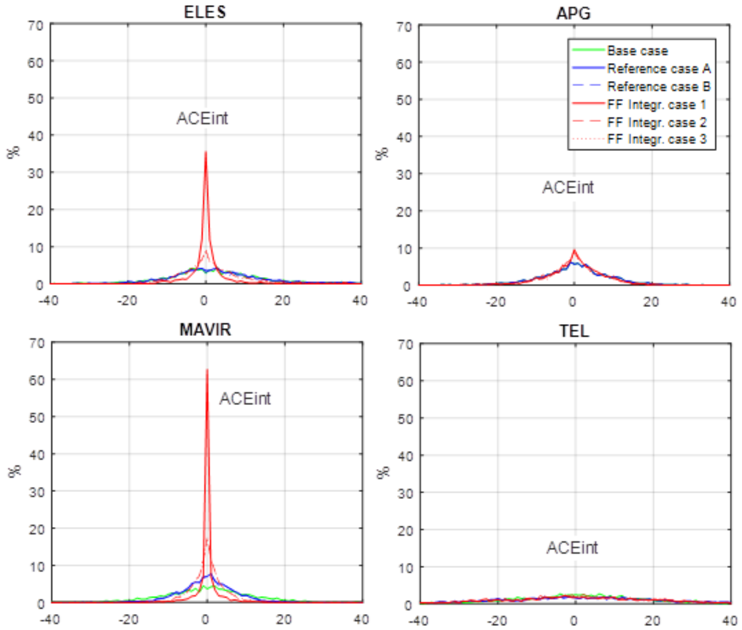


Figure 6: Envelope of 15-min average Area Control Error for each analysed case per TSOs

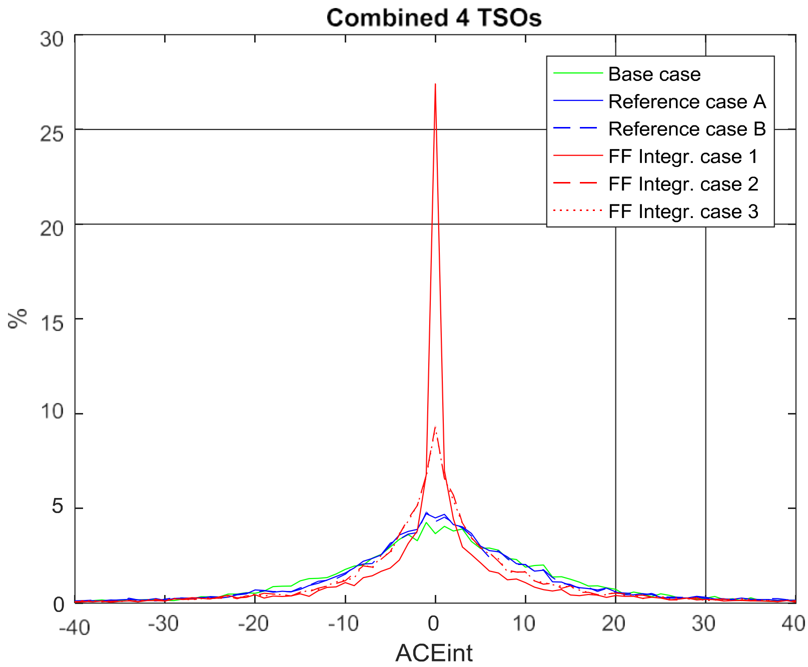


Figure 7: Envelope of 15-min average Area Control Error for each analysed case - all 4 TSOs combined

The following findings and recommendations summarize the analyses performed in simulation process, considering the available input data, namely open-loop signals, local merit order lists and available cross border capacities, all from March 2017:

- ACE Quality - All analysed FF Integration Cases show significant improvement of overall ACE control quality compared to status quo situation without regional cooperation. The FF Integration Case based on Control Demand activation with Standard Product shows better ACE control quality indices than other two FF Integration Cases
- Complexity of Integration - FF Integration case 1 can be easily integrated into existing LFC. The local controller needs to support calculation of demand (sum of ACE and already activated aFRR) and has to be able to receive single correction signal and add it to ACE. On the other hand, integration of FF integration cases 2 and 3 is much more complex as local PI controller output has to be decoupled from module that forwards signal to aFRR BSPs
- Failback Procedures - For control demand based approach, failback procedures are simple; if the signal from CAF is lost, local controller continues to operate locally without any automatic or manual intervention or mitigation measures. On the other hand, Control target based integrations (FF integration cases 2 and 3) are largely impacted if connection with CAF is lost, as the output of

local controller's distribution function is not connected to signal forwarding function anymore

- Market Liquidity - Control demand-based approach with harmonized 5-minute FAT shows the best ACE control performance indicators, it should be noted that lowering standard product's FAT size from current level (15 min) in Slovenia, Hungary and Romania can impact the aFRR market liquidity

Based on the technical performances of possible integration cases as well as other indicators considered qualitatively, the FF Integration Case 1 (Control Demand, with Standard Product) has been selected as proposed target solution for FF cross-border aFRR activation. The decisive factor is mostly superior control performance that prevails over considerations of possibly lower aFRR market liquidity.

TARGET MODEL: ECONOMIC BENEFITS

Techno-economic assessment with evaluation of cost savings for selected target model implementation is performed. Selected target model, i.e. FF Integration Case 1 (based on control demand and 5min FAT standard product) is compared with the Reference case A (standardized 5min FAT product in each country but with no cross-border cooperation).

Analysis is conducted using the obtained simulation results on March 2017 data for these two cases. Imbalance settlement period for calculation of costs & prices is defined to 15min. In terms of balancing energy pricing and costs calculation, two potential principles for harmonized price determination within FF cooperation were analysed:

- pay-as-bid method - all BSPs within a control area receive settlement price that they asked
- local marginal pricing - all BSPs within a control area receive settlement price set by the most expensive activated bid within that control area

In order to provide neutral comparison of benefits gained from introducing the cross border aFRR mechanism, both Reference case A and FF Integration Case 1 envisage harmonized price principle for TSO-BSP settlement within FF countries.

Changes of total aFRR costs on the level of FutureFlow regional cooperation with target model implementation are presented in the figure below (Figure *8*). The economic benefits are calculated for both ATC and flow-based network constraints.

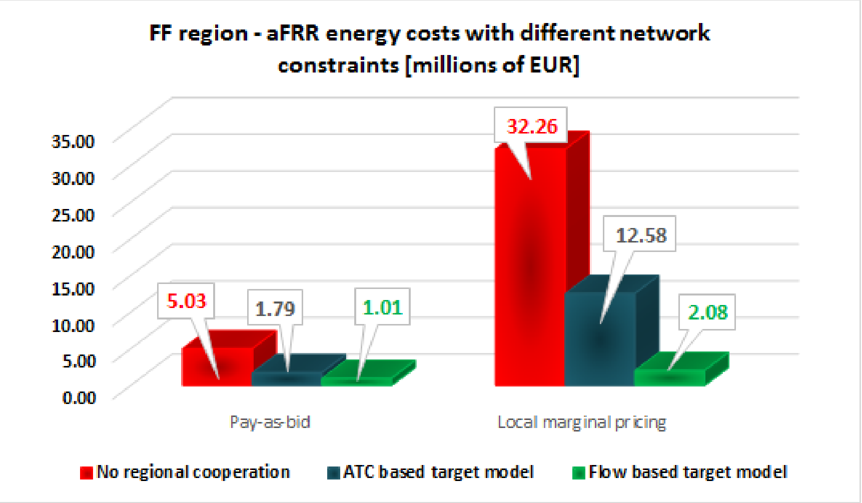


Figure 8: aFRR energy costs for FutureFlow regional cooperation

It can be concluded that for both pricing schemes and ATC network constraints, benefits from introducing the regional cooperation under the selected target model are rather high, with potential cost reduction of more than 60%. It is important to point out again, that observed potential savings incorporate joint benefits of both imbalance netting and cross-border CMOL activation, since selected target model based on FF Integration Case 1 envisages that imbalance netting process is implicitly embedded within the Control Demand optimisation. In this way also, more efficient usage of CZCs is enabled. Imbalance neeting effect produces 22.6% decrease of aFRR activation in target model compared to reference case without cross- border cooperation.

Analysing the overall balancing energy costs, after the potential implementation of cross border regional cooperation based on selected target model, notably higher costs are observed under the local marginal pricing compared to pay-as-bid system (12.58 million of Euros versus 1.78 million of Euros for ATC constraints). These costs do not imply higher expenses for the TSOs, but rather the higher costs and penalization for imbalanced BRPs on one hand, and higher revenues for BSPs that provided aFRR energy on the other. However, since 3 out of 4 countries are currently using pay-as-bid mechanism and that analysis indicated very sharp price & costs changes in the case of marginal pricing, pay-as-bid method could be recognized as the more suitable mechanism in the first step of regional cooperation establishment for FF countries. In such sense, obtained balancing energy costs could be moderate, and price shock effect towards the BRPs would be avoided. After the successful establishment of the regional aFRR energy market, increase in market competition and decrease in market concentration is expected. This would benefit self-regulation of the prices, in a manner that range of BSPs offered prices from different control zones would decrease, and that settlement prices across the region would gradually converge. Therefore, this initial phase of regional cooperation based on pay-as-bid pricing, will enable also a smoother transition towards potential introduction of marginal pricing, which is in line with Electricity balancing GL, and which enables higher level of market fairness.

With introduction of flow-based constraints, which in this case resulted in unconstrained situation, higher potential for cross border trading in enabled, therefore more cheaper bids from one area are activated on account of more expensive ones in another area. In the case of FF region, introduction of flow-based constrains provides significant boost in cost reduction of aFRR energy, especially in the case of local marginal pricing scheme.

CONCLUSIONS

In this paper the potential cross-border aFRR energy exchange among the TSOs of Austria, Hungary, Slovenia and Romania is analysed under the FutureFlow project cooperation. The main objective was to decide which model of cooperation among the three considered integration cases should be implemented within Future Flow project by analysing the impact of all proposed models. The main indicator was ACE control quality performance, but other indicators such as aFRR market liquidity, complexity of implementation and volatility are also taken into account.

The following findings and recommendations summarize the analyses performed in balancing simulations process, considering the available input data, namely open-loop signals, local merit order lists and available cross border capacities, all from March 2017:

- All analysed FF Integration Cases show significant improvement of overall ACE control quality compared to status quo situation without regional cooperation.
- Based on the technical performances of possible integration cases as well as other indicators considered qualitatively, the FF Integration Case 1 (Control Demand, with Standard Product) has been selected as proposed target solution for FF cross-border aFRR activation. The decisive factor is mostly superior control performance that prevails over considerations of possibly lower aFRR market liquidity. Additional increase of performance appears with the situation of sufficient CZC without congestion, i.e. with application of Flow-based parameters in this case.
- Economic benefits from introducing the regional cooperation under the selected target model are rather high, with potential cost reduction of more than 60%. Observed potential savings incorporate joint benefits of both imbalance netting and cross-border CMOL activation, since selected target model based on FF Integration Case 1 envisages that imbalance netting process is implicitly embedded within the Control Demand optimisation.

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