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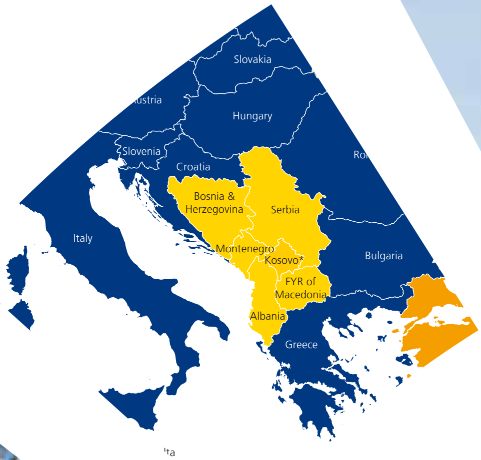

Final Report: Models of regional cooperation for balancing energy – Imbalance netting (Task 3)

EKC and IMP

March 2019

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Technical Assistance to the Implementation of Cross-border Electricity Balancing

Task 3: Models of regional cooperation for balancing energy – Imbalance netting

Final Report

March 2019

Project Team		
Zoran Vujasinović	EKC	Project leader
Dušan Vlaisavljević	EKC	Author
Dragana Orlić	EKC	Author
Nebojša Jović	EKC	Author
Ognjen Vuković	EKC	Author
Branko Leković	EKC	Author
Goran Jakupović	IMP	Software development
Nikola Stojanović	IMP	Software development
Digna Eglite		Legal expert

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1. INTRODUCTION

Task 3 is related to imbalance netting mechanism as determined by EB GL and SO GL requirements and its implementation among WB6 TSOs following the European rules of imbalance netting process and Inter-TSO settlement.

Section 1 gives definition of imbalance netting model, including optimization and settlement (e.g. specification, detail functional design, IT requirements at national and regional level, as well as data exchange processes). Based on defined model and corresponding algorithm, web-based software platform with user-friendly graphical interphase has been developed and described in Section 2.

Developed software platform has been implemented in pilot tests organized in 1 week (Monday 14.05.2018 00:00 – Sunday 20.05.2018 23:59) providing the results for benefit assessment. Dry-run activities and results of the pilot tests are described in Section 3.

Section 3 also gives the results of the benefits assessment for three different options of IN cooperation among WB6 TSOs:

- All TSOs in “WB6” option
- All TSOs, except NOS BIH, in “WB5” option
- EMS, CGES and MEPSO in “SMM” option

Summary of the results and recommendations related to implementation of IN mechanism among WB6 TSOs is provided at the end of this report, as well as in Task 5 report.

2. IMBALANCE NETTING MODEL

According to definition imbalance netting (IN) is the process agreed between TSOs of two or more LFC areas that allows avoiding the simultaneous activation of frequency restoration reserves (FRR) in opposite directions by taking into account the respective frequency restoration control errors as well as the activated FRR, and by correcting the input of the involved frequency restoration processes accordingly.

IN is the optimization platform initially developed among German TSOs, but, it was rapidly accepted and implemented in ENTSO-E community. The implementation project called International Grid Control Cooperation (IGCC) was launched in October 2010 as a regional project and, till today, has grown to cover 20 countries (23 TSOs) across continental Europe, including all those that need to implement the IN-Platform according to the EBGL.

This project, IGCC is, in February 2016, chosen by ENTSO-E to become the future European Platform for the imbalance netting process (IN-Platform) as defined by the guideline on electricity balancing (EBGL Art. 22).

The IGCC process is operated by Transnet BW, which is the Host TSO of IGCC. Balancing energy is settled in each ¼ hour and there is no entry fee charged to join this cooperation. Implementation costs are mainly related to the connection of the control systems, modification of control loops and business systems and should be borne by the Acceding TSO itself.

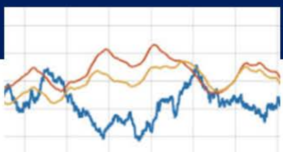
The pan-European IN target model is determined to be in line with the requirements set in EB GL and SO GL and at the same time secure, sustainable, replicable and applicable in the situations of congested borders. It includes proper configuration and correlation among the national balancing markets, cross-border transmission constraints, as well as their pan-regional integration.

Imbalance Netting Platform developed in this project has been designed according to the determined pan-European target model encompassing all relevant functionalities. The general concept is shown and described at the following scheme (Figure 1).

IMBALANCE NETTING PLATFORM SCHEMA

OPEN LOOP ACE PROCCESSING MODULE

Each TSO will upload realized Open loop ACE (P_{demand}) in AGC cycle resolution for agreed time period.

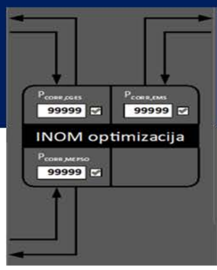


CZC MODULE

Each TSO will upload the cross zonal capacities as the network constraints to the imbalance netting energy exchange. Cross zonal capacities in form of **ATC** values will be supported within the platform.

ACTIVATION / SETTINGS IN MODULE

TSO will have possibillity to set the limitations for total energy exchange within imbalance netting process (IN LIMIT), to adjust TSO's participation in Imbalance Netting, to upload realized aFRR prices for analyzed time period and to run imbalance netting procedure on uploaded operational data .



IMBALANCE NETTING OPTIMIZATION FUNCTION (INOF)

Stateless simulation mode: ~~*f(t)*~~
(for offline assessment of benefits)

RESULTS MODULE

For each imbalance settlement period (ISP), detail overview of results for imbalance netting energy exchange volume will be available. The results will contain data on exchanged energy, cross border flows, ACE with and without imbalance netting, Pcorr, etc. Obtained results will serve as a input for impact analysis that will evaluate benefits of WB6 region balancing market integration.

SETTLEMENT MODULE

For each imbalance settlement period (ISP), imbalance netting volume for remuneration will be determined. Settlement price will be calculated according to the rules defined within Task 3 - imbalance netting model design (i.e. to be most suitable model for WB6 region in line with EU electricity GLs). In a final step, TSO-TSO payments will be calculated for each ISP using the previously determined volume and price.

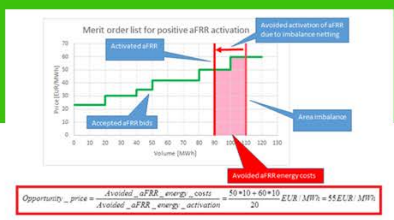


Figure 1: Imbalance Netting platform - schema

2.1 Basic principles of IN platform

The concept of Imbalance Netting (IN) is based on the avoidance of the opposite activation of balancing reserve (aFRR), by the TSOs participating in IN cooperation. The essence of this concept is the optimization of aFRR activation for all participating TSOs in real time, aimed at minimizing the activation of balance energy of an opposite direction.

Imbalance netting across LFC areas enables all participating TSOs to decrease the use of balancing energy while increasing system security.

Implemented imbalance netting operating principle is presented in the following diagram showing simple principles of avoiding counter activations of aFRRs enabling reduction of aFRR activations and corresponding costs:

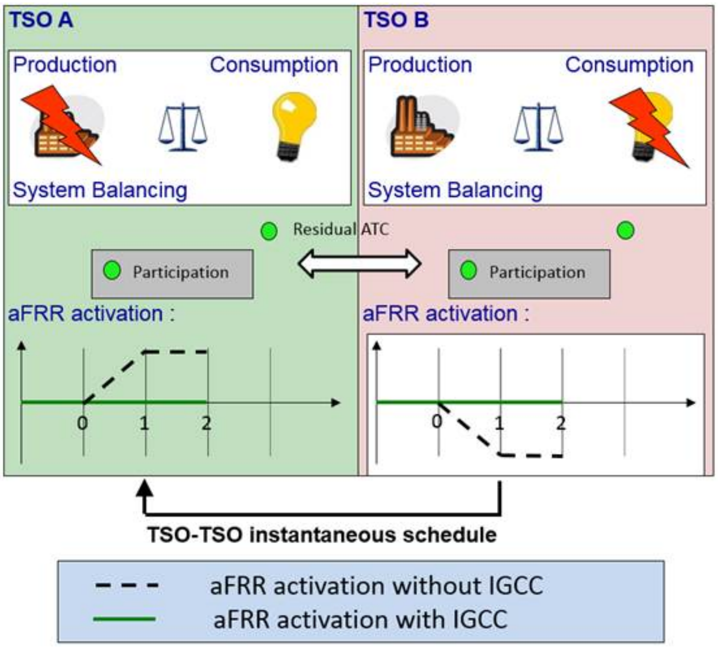


Figure 2: Principle of Imbalance Netting

The implementation of the Imbalance Netting process is based on the communication of the power-frequency controls of all participating TSOs, which enables online balancing of the different power imbalances. Reduction of the aFRRs activation is enabled through optimization module (aFRR-Optimization system) which is integrated in aFRR control loops of all participating TSOs providing optimized signal for secondary controllers (Figure 2).

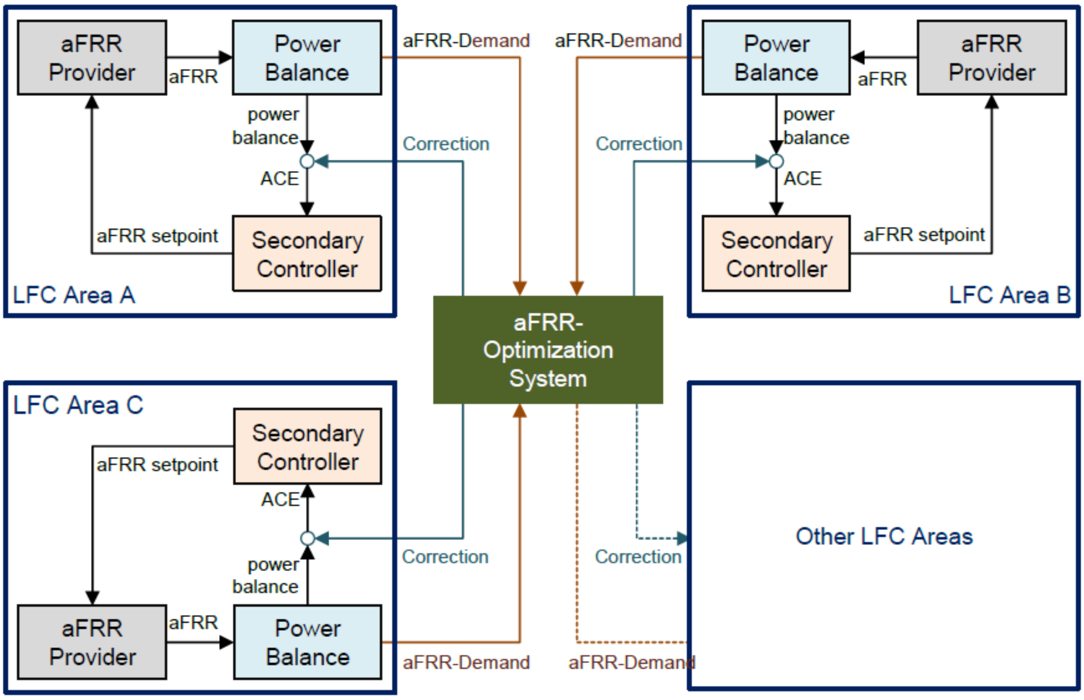


Figure 3: Implementation scheme of optimization module

The whole process of reduction of aFRRs activation includes several activities:

- Each participating TSO calculates the aFRR-Demand
- The aFRR-Demand and Limits are reported to the aFRR-Optimization System
- The aFRR-Optimization System calculates the Corrections respecting the Limits
- The Corrections are returned to the secondary controllers of each participating TSO after each optimization step

The aFRR-Optimization System calculates the Corrections with the aim to minimize the counter activation of the aFRRs and therefore the use of aFRR is optimized and corresponding costs are reduced.

Reduced costs are calculated ex-post, within a settlement module. The principle of “equal benefit” settlement is implemented with proportional distribution of total cost savings to participating TSOs.

2.2 Functional design

Imbalance netting platform includes two modules:

- The optimization module (real-time processes)
- The settlement module (ex-post processes)

2.2.1 Optimization

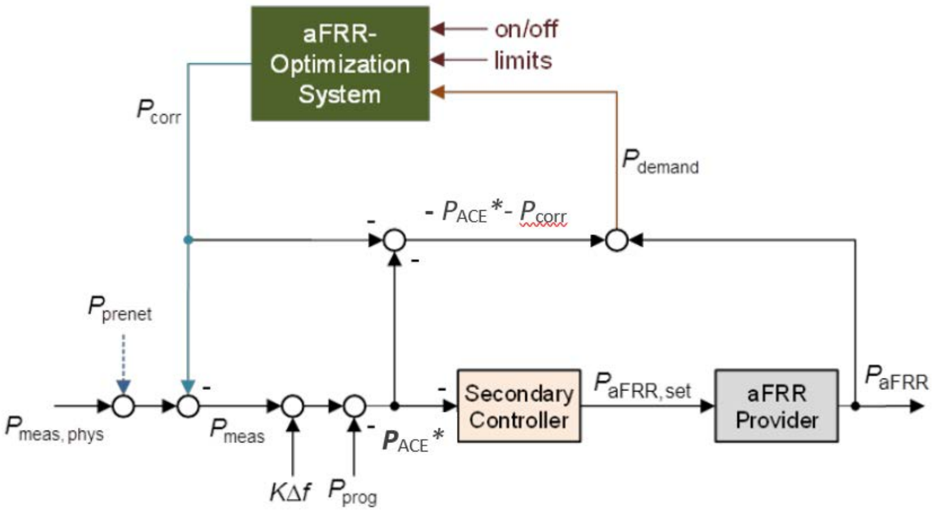


Figure 4: Integration of aFRR-Optimization System – Optimization module

The optimization module which includes the process of integration of the aFRR-Optimization System into the secondary control loop of a participating TSO is functionally determined as presented in *Figure 4*. It encompasses the following main sub-processes:

- **Initiation** – real-time activity (typically in P_{ACE} calculation time steps) in which each participating TSO calculates the P_{demand} according to the following formulae:

$$P_{ACE} = \Delta P + K\Delta f = P_{meas} - P_{prog} + K\Delta f$$

$$P_{ACE}^{*} = P_{ACE} - P_{corr} = P_{meas} - P_{prog} + K\Delta f - P_{corr}$$

Therefore,

$$P_{\text{demand}} = P_{\text{aFRR}} - P_{ACE}^{*} - P_{corr} = P_{\text{aFRR}} - P_{ACE} + P_{corr} - P_{corr}$$

$$P_{demand} = P_{aFRR} - P_{ACE}$$

where P_{aFRR} is activated aFRR (see table below with definitions), P_{corr} is the amount of power exchange of the participating TSO with other TSOs (and avoided aFRR activation.

- **Activation** - Real-time activity (typically within few seconds) in which each participating TSO submits its current P_{demand}, while the optimization module optimizes all submitted demands and sends back correction signals to obtain the most efficient economic solution under the given constraints:
  - Available Transfer Capacity (ATC) between the involved TSOs
    ATCs are submitted by participating TSOs as available cross-border capacities that can be used within imbalance netting process. Usually, these capacities present available capacities after ID market closure taking into account exchange of balancing energy, e.g. aFRR, mFRR, RR, or other reserves at the common border.
  - Limitations for total exchange of load frequency control power (FRR) of certain TSO
  - Adjustment of suspension conditions of IN (ON/OFF), adjustable by the contributing TSOs

- **Correction calculation** - Real-time activity (typically within few seconds) in which aFRR-Optimization System calculates Corrections (P_{corr}) in real time for each participating TSO which results in imbalance netting. The objective function is the Counteracting Activation Minimization Function.
  The price for cross-zonal capacity used for the imbalance netting process is 0 €/MWh. This is in lie with ENTSO-E document on CZC pricing proposal (8), where in Article 7.3 it is stated: "The price of cross-zonal capacity for the exchange of balancing energy from imbalance netting performed explicitly by the imbalance netting AOF is 0 €/MWh. Due to the fact that there is no harmonised pricing methodology with the go live of the imbalance netting platform, a proper valuation of the cross-zonal capacity is not possible. At the same time, the impact of cross-zonal capacity limitations is implicitly part of the respective settlement of the intended energy exchange."

- **Exchange** - Real-time activity in which participating TSOs exchange balancing energy (P_{corr}) through Imbalance Netting Cooperation, physically through existing interconnection lines and administratively through virtual tie-lines.

Table 1: Optimization module – Definitions and Sign Conventions

Symbol		Description
Pre-netted aFRR demand	P_{prenet}	The amount of aFRR-Demand netted in LFC block or Optimization Region (if any) before participation in the current IN cooperation
Measured power exchange	P_{meas}	Measured power exchange of the LFC Area in MW. Positive value: the LFC Area exports. Negative value; vice versa.
Frequency component of Area Control Error	$K\Delta f$	Frequency deviation is positive in case of actual frequency above scheduled frequency. Frequency deviation is negative in case of actual frequency below scheduled frequency.
Scheduled power exchange	P_{prog}	Scheduled power exchange of the LFC Area in MW. Positive value: the LFC Area exports. Negative value: vice versa.
Required aFRR activation	$P_{aFRR,set}$	Required activation of aFRR to control ACE of the participating TSO to zero in MW. Negative value: the LFC Area is long and negative aFRR needs to be activated in order to control the ACE to zero. Positive value: vice versa.
Activated aFRR	P_{aFRR}	Activated aFRR, measured, as determined by each LFC Area that controls the ACE of the LFC Area to zero in MW. Negative value: the LFC Area is long and negative aFRR is activated in order to control the ACE to zero. Positive value: vice versa.
Correction	P_{corr}	Power exchange of the participating TSO with other participating TSOs in MW. The Correction is calculated by the aFRR-Optimization System and has the opposite sign of the corresponding aFRR-Demand. The Correction value is treated as an agreed upon active power flow over a Virtual Tie-Line between two participating TSOs. Negative value: leads to power import of the participating TSO. Positive value: vice versa.

On this basis, the optimizing module calculates the portions of requests for load frequency control, which may be reduced by each TSO, due to activations of an opposite direction by other TSOs. When imbalances have a contrary tag (a certain TSO is "long", certain TSO is “short”), an optimizing function forms a virtual exchange by means of which these balances are compensated. Virtual exchange is defined using the concept of "Virtual Tie Line"(VTL).

The contribution of TSOs which have the same direction of a demand at certain moment are proportionally distributed, in accordance with their demand (P_{demand}). Optimizing module simulates forwarding of corrective signal (i.e. the power of exchange of balance energy between TSOs) of all involved TSOs to LFC, in each operating cycle. Based on this, the total exchange of balancing energy is calculated for each defined Imbalance Settlement Period (ISP).

2.2.2 Settlement

The settlement module encompasses ex-post processes in which activated energy, as well avoided activations and costs are being calculated. The principle of sharing gained benefits in a fair manner between participating TSOs is applied.

The settlement module includes the following processes:

- **Energy settlement calculation** – ex-post activity in which import and export ($E_{Imp(t,m)}$ and $E_{Exp(t,m)}$) are summarized for each participating TSO, each ISP and each direction

- **Provision of Opportunity prices** – ex-post activity in which each participating TSO submits its opportunity prices ($CImp(t,m)$ and $CExp(t,m)$) for each ISP and each direction (upward/downward)

  These prices usually:

  - reflect the value of netted imbalances, i.e. avoided aFRR energy costs due to the avoidance of aFRR activation;
  - present aFRR energy prices.

  The opportunity price should be based on the amount of costs saved by avoiding the use of control energy because of participation in IN platform. The methodology for calculating the opportunity prices largely depends on the pricing model for balancing energy in each control area and is therefore performed by each TSO individually.

  In case of "positive" aFRR request, balancing energy is needed by the TSOs; the opportunity price corresponds with the quotient of avoided energy costs/energy volume, for positive activated aFRR per settlement period. In case of "negative" aFRR request, balancing energy can be provided by the TSOs; the opportunity price corresponds with the quotient of avoided energy costs/energy volume, for negative activated aFRR per settlement period.

- **Settlement price calculation** – ex-post activity in which settlement price is calculated as the weighted average of all opportunity prices

  Based on opportunity prices for each TSO and the total exchange of balancing energy obtained from the optimization module, the settlement price is calculated as the average of all opportunity prices within the respective cooperation, weighted with the respective exchanged volumes of balancing energy per TSO:

$$C_{Settl(t)} = \frac{\sum_{m=1}^{M} E_{Exp(t,m)} * C_{Exp(t,m)} + \sum_{m=1}^{M} E_{Imp(t,m)} * C_{Imp(t,m)}}{\sum_{m=1}^{M} E_{Exp(t,m)} + \sum_{m=1}^{M} E_{Imp(t,m)}}$$

Variable	**Description**	**Unit**	**Sign Convention**
M	Number of participating TSOs	-	-
m	participating TSO	-	-
t	Settlement period	-	-
$E_{Imp(t,m)}$	import of participating TSO m	MWh	Always positive
$E_{Exp(t,m)}$	export of participating TSO m	MWh	Always positive
$C_{Imp(t,m)}$	Opportunity Price for import of participating TSO *m*	€/MWh	Positive, if the participating TSO m pays for activation of positive aFRR. Negative, if the participating TSO m is paid for activation of positive aFRR.
$C_{Exp(t,m)}$	Opportunity Price for export of participating TSO *m*	€/MWh	Positive, if the participating TSO m is paid

			for activation of negative aFRR. Negative, if the participating TSO m pays for activation of negative aFRR.
$C_{Settl(t)}$	Settlement price	€/MWh	Positive or negative

- **Settlement amount calculation** – ex-post activity in which settlement amount (S) in Euros is calculated for each participating TSOs for each settlement period

$$\boldsymbol{S}_{(t,m)} = (E_{Imp(t,m)} - (E_{Exp(t,m)}) * \; C_{Settl(t)}$$

- **Cost reduction calculation** – ex-post activity in which cost savings are calculated for each participating TSOs
  Based on the spread between the opportunity and settlement prices, as well as exchange energy quantities, reduction of costs is calculated for each participating TSO, using the following formula:

$$\boldsymbol{B}_{(t,m)} = (E_{Imp(t,m)} * \; C_{Imp(t,m)} - E_{Exp(t,m)} * \; C_{Exp(t,m)}) - \; S_{(t,m)}$$

Benefits for each participating TSO are calculated for each settlement period and summarized for each reporting period (usually month).

Summary of the benefits for all participating TSOs gives the benefit of the IN cooperation:

$$\boldsymbol{B}_{(t)} = \sum_{m=1}^{M} \boldsymbol{B}_{(t,m)}$$

The settlement principle assumes no negative benefit for any of the participating TSOs. Different market designs among participating TSOs leads to higher spreads between the Opportunity Prices and, in some cases, provoke negative benefits for some participants, however with the positive benefit for the entire IN cooperation. To overcome this situation, an ex-post adjustment of settlement amounts is introduced, where the settlement amount is adjusted in the following way:

- Participating TSO with negative benefits distribute their negative individual benefits to participating TSOs with positive benefits in order to shift their negative benefits to zero.
- Participating TSO with positive benefits reduce their positive benefits by the amount of negative benefit proportionally to their share in the total sum of positive benefit.

With this approach, the principle of no negative benefit for all participating TSOs is respected.

2.3 Examples of the P_{corr} calculations by IN algorithm

This chapter provides a couple of examples of calculations, particularly examples for optimisation without and with limits, providing better understanding of the IN principle.

Case without ATC limitations

LFC Block	A	B	C	D
aFRR-Demand [MW]	200	800	-50	-450
Share of Total Positive Demand [pu]	200/(200+800) = 0.2	800/(200+800) = 0.8	n/a	n/a
Share of Total Negative Demand [pu]	n/a	n/a	-50/(-50+(-450) = 0.1	-450/(-50+(-450) = 0.9
Correction - Optimisation Target [MW]	-0.2·500 = -100	-0.8·500 = -400	0.1·500 = 50	0.9·500 = 450
Correction Value (Optimisation Result) [MW]	-100	-400	50	450
Remaining aFRR-Demand [MW]	200+(-100) = 100	800+(-400) = 400	-50+50 = 0	-450+450 = 0
Deviation from Target [MW]	-100-(-100) = 0	-400-(-400) = 0	50-50 = 0	450-450 = 0
Deviation/aFRR-Demand (Absolute Value) [pu]	| 0/200 |= 0	| 0/800 | = 0	| 0/50 | = 0	| 0/450 | = 0

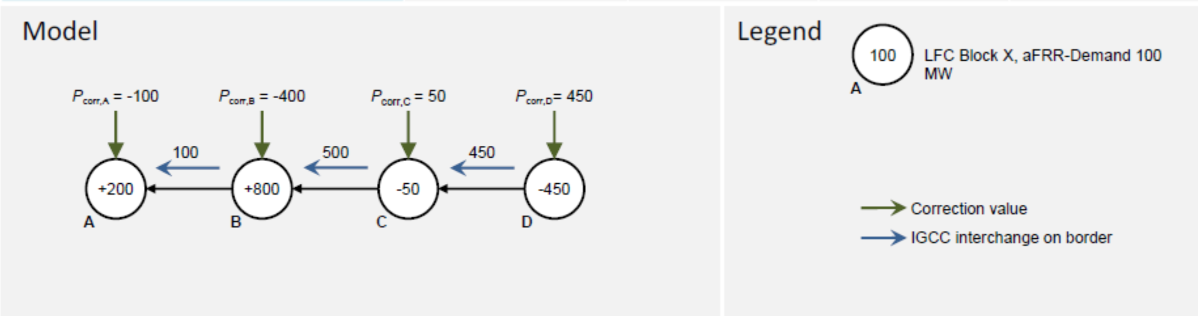


Figure 5: Example without consideration of restrictions

Figure 5 illustrates the calculation of the Correction values **without Limits**:

- LFC Areas A and B are short (1000 MW in total) while LFC Areas C and D are long (-500 MW in total)

- The optimization target is to fully net the aFRR-Demands of C and D and to distribute the netting for A and B according to the respective shares of the overall positive aFRR-Demand
- Since there are no Limits, the optimization target can be reached (the deviation from the optimization target is zero)

Case with ATC limitations

LFC Block	A	B	C	D
aFRR-Demand [MW]	200	800	-50	-450
Share of Total Positive Demand [pu]	200/(200+800) = 0.2	800/(200+800) = 0.8	n/a	n/a
Share of Total Negative Demand [pu]	n/a	n/a	-50/(-50+(-450) = 0.1	-450/(-50+(-450) = 0.9
Correction - Optimisation Target [MW]	-0.2·500 = -100	-0.8·500 = -400	0.1·500 = 50	0.9·500 = 450
Correction Value (Optimisation Result) [MW]	-30	-120	50	100
Remaining aFRR-Demand [MW]	200+(-30) = 170	800+(-120) = 680	-50+50 = 0	-450+100 = -350
Deviation from Target [MW]	-100-(-30) = -70	-400-(-120) = -280	50-50 = 0	450-100 = 350
Deviation/aFRR-Demand (Absolute Value) [pu]	| -70/200 | = 0.35	| -280/800 | = 0.35	| 0/(-50) | = 0	| 350/(-450) | = 0.78

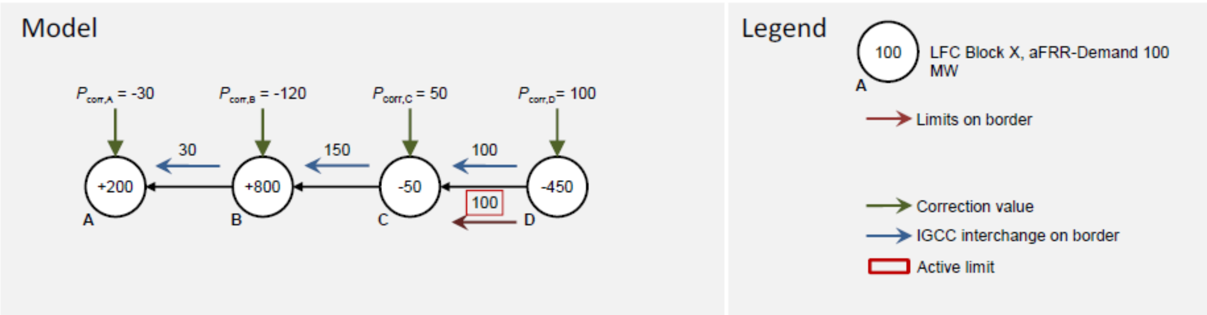


Figure 6: Example with consideration of restrictions

Figure 6 shows the scenario **with a more restrictive limit** on the concerned border between B and C:

- The exchange in the direction from D to C is limited to 100 MW
- Therefore, only 100 MW can be exported from D to C, B and A
- Since the overall amount of short-aFRR demand is 1000 MW, C exports its complete long aFRR demand of 50 MW.
- A and B receive the respective shares of the overall export of 150 MW: A receives 30 MW and B receives 120 MW.

In this example, the optimisation targets cannot be reached.

Case with one active limitation without an impact on correction values

LFC Block	A	B	C	D
aFRR-Demand [MW]	200	800	-50	-450
Share of Total Positive Demand [pu]	200/(200+800) = 0.2	800/(200+800) = 0.8	n/a	n/a
Share of Total Negative Demand [pu]	n/a	n/a	-50/(-50+(-450) = 0.1	-450/(-50+(-450) = 0.9
Correction - Optimisation Target [MW]	-0.2·500 = -100	-0.8·500 = -400	0.1·500 = 50	0.9·500 = 450
Correction Value (Optimisation Result) [MW]	-100	-400	50	450
Remaining aFRR-Demand [MW]	200+(-100) = 100	800+(-400) = 400	-50+50 = 0	-450+450 = 0
Deviation from Target [MW]	-100-(-100) = 0	-400-(-400) = 0	50-50 = 0	450-450 = 0
Deviation/aFRR-Demand (Absolute Value) [pu]	| 0/200 |= 0	| 0/800 | = 0	| 0/(-50) | = 0	| 0/(-450) | = 0

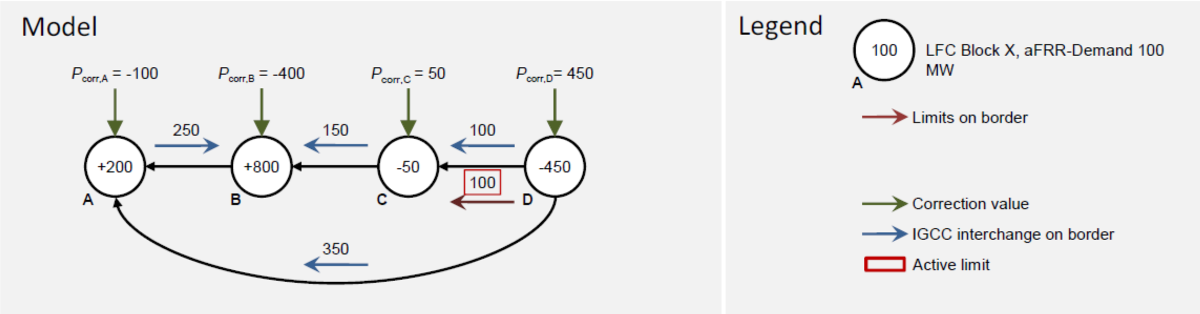


Figure 7: Example with one active limitation without an impact on correction values

Figure 6 shows the scenario with additional border between D and A. Although the limitation between D and C of 100 MW still exists, the border between D and A can be used to exchange the additional 350 MW. In this example, the optimisation targets is reached.

2.4 IT requirements and data exchange

Existing aFRR IT infrastructure (data exchange channels and protocols, controllers, SCADA modules) are suitable for initial setup of Imbalance Netting, both on the level of Control Blocks or wider among IGCC members. IT requirements related to implementation of IN platform includes:

- Determination of “host” TSO (TSO in which aFRR-Optimization system is installed)
- Application of current data exchange protocols and usage of existing IT structures
- Communication between “host” TSO and each participating TSO via two redundant communication lines that enables communication and exchange of messages, measurements and GI requests in both directions
- All data exchange (sent or received) with “host“ TSO and aFRR-Optimization system must be transferred using ICCP (Inter-control Center Communication Protocol), that satisfies the requirements of IN cooperation in relation to IN cycle and time delay
- Continuous automatic exchange of signals via SCADA systems
- Handling of big data volumes

- Exchange of data in different time steps:
  - data ex-ante: ATC values and other Limits,
  - in real-time: P_{demand}, P_{corr} and
  - ex-post: Opportunity prices, Settlement prices, Settlement volumes, Benefits

Participating and "host" TSO exchange at least the following data:

From	**To**	**Data**
Participating TSO	Host TSO	Applicable Limits
Participating TSO	Host TSO	Participation Status Request
Participating TSO	Host TSO	aFRR-Demand (P_{demand})
Host TSO	Participating TSO	Correction (P_{corr})
Host TSO	Participating TSO	Participation Status
Host TSO	Participating TSO	Applicable Limits of other participating TSOs
Host TSO	Participating TSO	aFRR-Demand of other participating TSOs

Based on presented principles, an INOM software platform has been developed. The basic description of the platform is given in the next chapter.

3. SOFTWARE: INOM PLATFORM

In this chapter, the software platform developed within this project has been briefly described.

Cross-border Electricity Balancing simulator is joint tool for both INOM and mFRR platforms (simulators):

- Imbalance Netting Optimization Module (INOM) dedicated to IN process
- mFRR platform dedicated for optimization of the balancing energy (mFRR and RR) exchange

It is a web application, accessible through most of the available web browsers (IE, Edge, Firefox, Chrome, Opera). It is HTML only, meaning it does not require additional plugins installation. After logging on with credentials, user accesses INOM platform pages, although all pages are accessible from the main menu. Main menu is positioned at the top-left part of the page.

INOM main screen (*Figure 8*) displays all real-time Imbalance Netting data, grouped by TSO. This "Real-time" data is not a current data, but data at the simulated moment. This simulated moment (Simulated Time) is displayed in the top-right corner of the page. Simulated time is running at the same pace as actual time, only in a previously set time interval.

For each TSO, data include P_{demand}, P_{corr}, $P_{demandc}$ (powers after corrections) and ATC values.

It is also possible to toggle Imbalance Netting participation of TSO on or off.

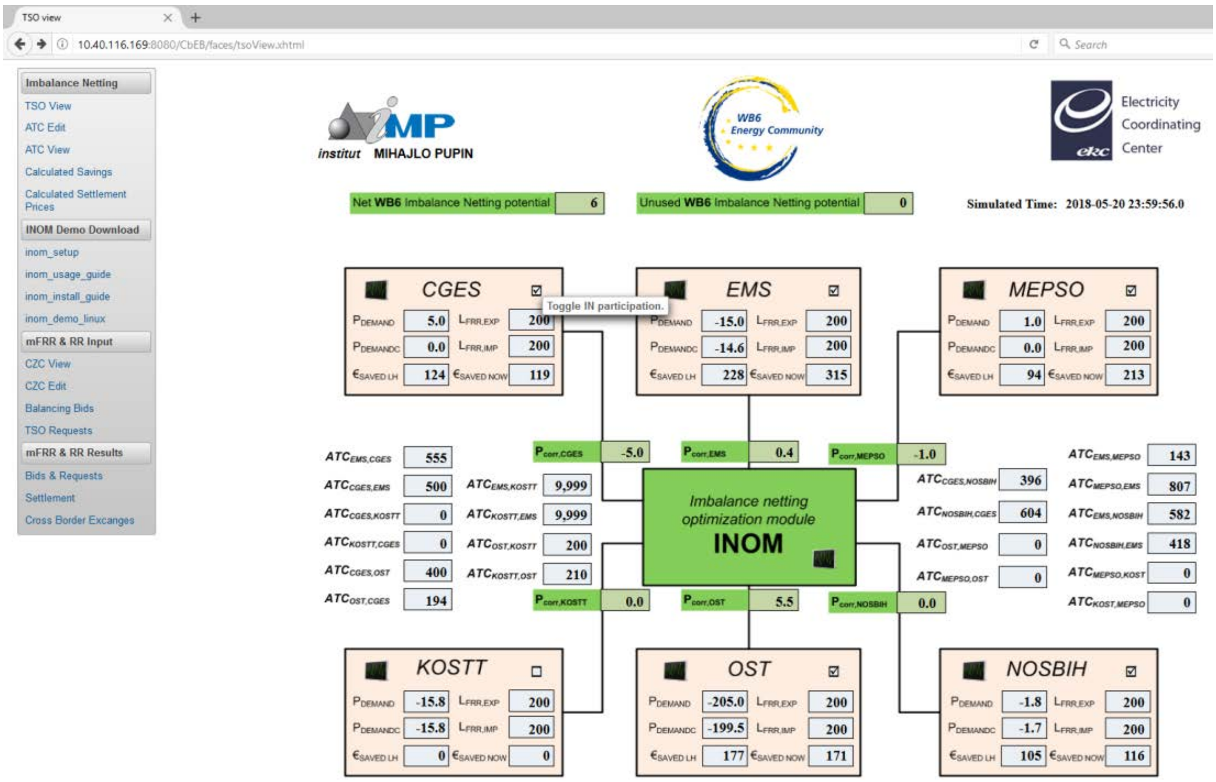


Figure 8: INOM Main Screen

At each TSO's box, there is a link to the page with the last 15 minutes P*demand* before and after Imbalance Netting correction (Figure 2).

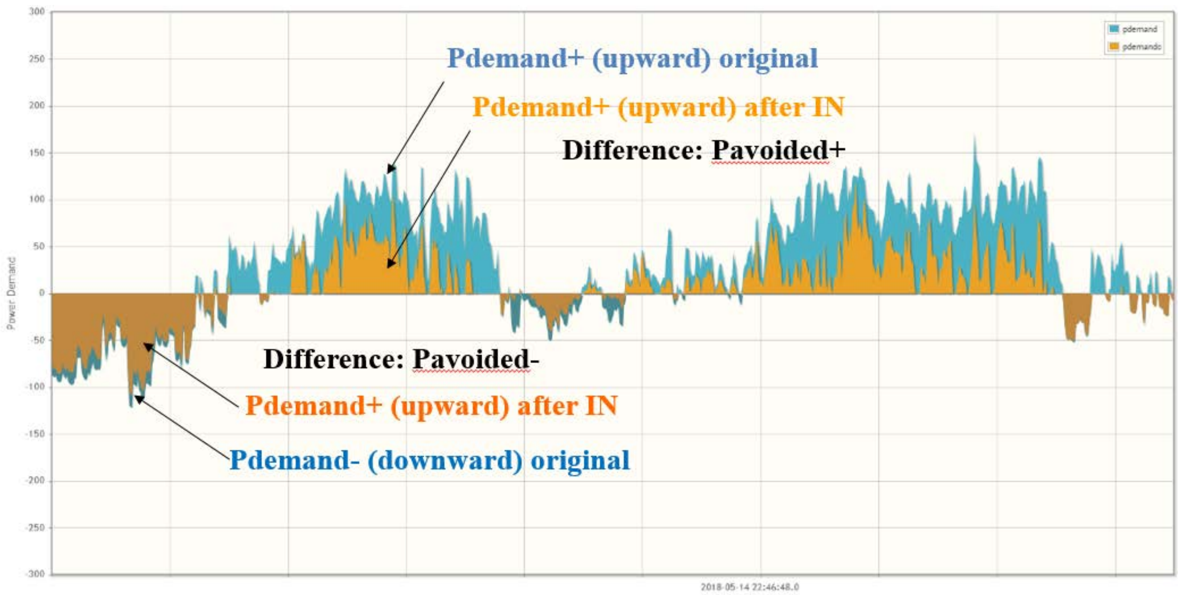


Figure 9: INOM platform screenshot with calculated values

User can access (over hyperlink) the joint diagram for all 6 TSOs (1 hour long). This diagram presents a process in real time, thus is maybe the most illustrative representation of Imbalance netting process. In *Figure 10*, one screenshot of the continual IN process is presented.

Figure 10: INOM Graphical Representation for all TSO-s

ATC values are input data for simulation process, and through the main menu user can access pages to overview and edit these values.

Date: 2018-05-14 TSO 1: NOSBIH TSO 2: CGES

Show ATC-s

Imbalance Netting
- TSO View
- ATC Edit
- ATC View
- Calculated Savings
- Calculated Settlement Prices

ATC-s for 2018-05-14

Hour	NOSBIH -> CGES		CGES -> NOSBIH	
	Value	Manual	Value	Manual
1	882	no	118	no
2	882	no	118	no
3	882	no	118	no
4	882	no	118	no
5	882	no	118	no
6	882	no	118	no
7	894	no	106	no
8	799	no	201	no
9	799	no	201	no
10	799	no	201	no
11	799	no	201	no
12	799	no	201	no
13	794	no	206	no
14	794	no	206	no
15	794	no	206	no
16	794	no	206	no
17	787	no	213	no
18	787	no	213	no
19	792	no	208	no
20	792	no	208	no
21	812	no	188	no
22	812	no	188	no
23	882	no	118	no
24	882	no	118	no

Figure 11: INOM ATC editor

Economic effects realized through aFRR activation cost reduction can be seen at Calculated savings page (*Figure 12*). It is grouped by each TSO and displayed in table, for each ISP.

Imbalance Netting
- TSO View
- ATC Edit
- ATC View
- Calculated Savings
- Calculated Settlement Prices

Calculated Settlement Prices for 2018-05-14

Hour	Settlement Price
1	27.74 €
2	28.23 €
3	25.94 €
4	20.86 €
5	18.49 €
6	22.86 €
7	30.14 €
8	34.37 €
9	27.3 €
10	27.32 €
11	28.83 €
12	29.64 €
13	30.54 €
14	35.84 €
15	26.18 €
16	25.63 €
17	33.56 €
18	37.47 €
19	34.9 €
20	29.84 €
21	41.69 €
22	31.89 €
23	34.37 €
24	34.94 €

Average price:
29.94 €

Calculated savings for NOSBIH, for date 2018-05-14

Hour	Saving
1	227.75 €
2	3.79 €
3	20.22 €
4	40.31 €
5	217.33 €
6	119.14 €
7	169.97 €
8	2.84 €
9	36.69 €
10	136.72 €
11	75.73 €
12	46.14 €
13	50.8 €
14	85.54 €
15	91.65 €
16	74.46 €
17	40.5 €
18	108.62 €
19	7.74 €
20	84.41 €
21	135.17 €
22	-19.92 €
23	110.42 €
24	92.08 €

Total Saving:
1,958.1 €

Figure 12: Calculated Settlement Prices and Calculated Savings

4. IMBALANCE NETTING ANALYSES

This section will provide and analyse results of Imbalance Netting simulation, performed on the basis of TSOs' data for period 14-20th of May 2018, within INOM demo platform, as follows:

- Input data
- Interpretation of the results – technical and economic aspect perspective
- Establish and analyse causative relationship concerning savings caused by imbalance netting mechanism

Following imbalance netting blocks were considered:

- Western Balkan Six (WB6) – all WB6 TSOs
- Western Balkan Five (WB5) – Five WB6 TSOs (NOS BiH excluded)
- SMM block – EMS, CGES and MEPSO

The results and consequential savings by each TSO are determined by:

- Pdemand**,**
- Opportunity prices,
- ATC constraints, as well as potential composite constraints.

In order to evaluate the performance of the effects of the balancing market, a set of performance criteria is considered:

- Savings made by each party, by each specific TSO
- Upward power avoided as a % of upward power demanded that is corrected
- Downward power avoided as a % of downward power demanded that is corrected
- Efficiency Rate as a fraction of Power Avoided divided by Sum of power demanded)

4.1 Test Information

4.1.1 Data: Pdemand

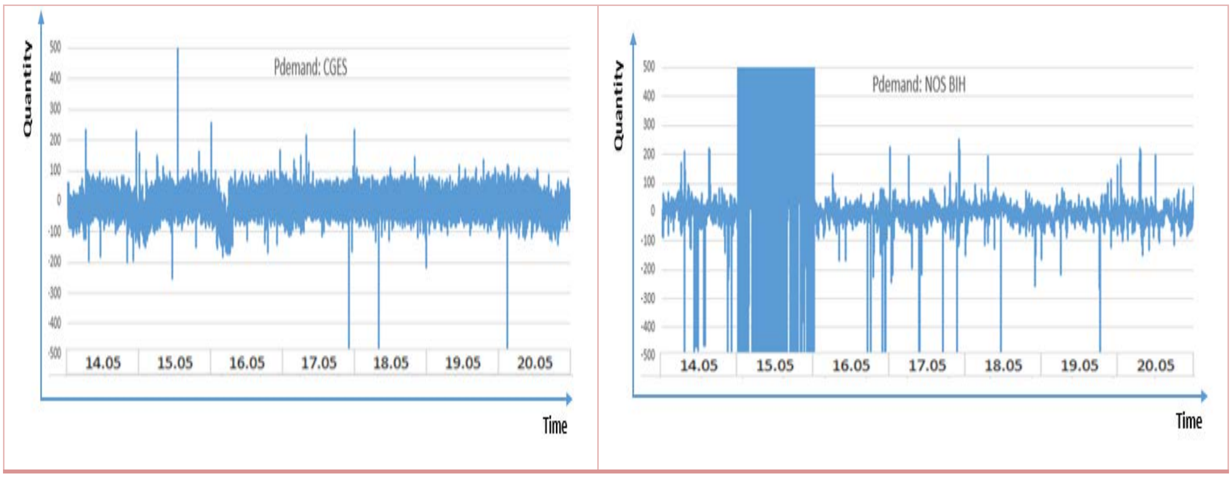
Pdemand, as an input to the INOM demo platform, has been calculated on the basis of Open Loop ACE by the TSOs. Optimization is done on the methodological basis explained in Chapter 2.2.1.

$$P_{demand} = P_{aFRR} - P_{ACE} = -P_{OL\,ACE}$$

Table 2: Imbalance Netting Test Information Sheet: Pdemand

Imbalance Netting Test Information Sheet: Pdemand		
Time Span	1 week: Monday 14.05 00:00 – Sunday 20.05 23:59	
Pdemand	**CGES**	Based on Open Loop ACE in 5-seconds time resolution, converted by interpolation to 4 seconds time resolution
	MEPSO	Based on Open Loop ACE in 5-seconds time resolution, interpolation conversion to 4 seconds time resolution
	EMS	Randomized 4-seconds dataset based on hourly ACE value
	OST	Based on Open Loop ACE in 4s time resolution
	KOSTT	Based on Open Loop ACE in 4s time resolution
	NOSBIH	Based on Open Loop ACE in 4s time resolution
Note	Date 15.05 results ignored due to unrealistic Pdemand of NOSBIH which interferes with the obtained results	

Graphical demonstration of each TSO signal is shown in the figure below:



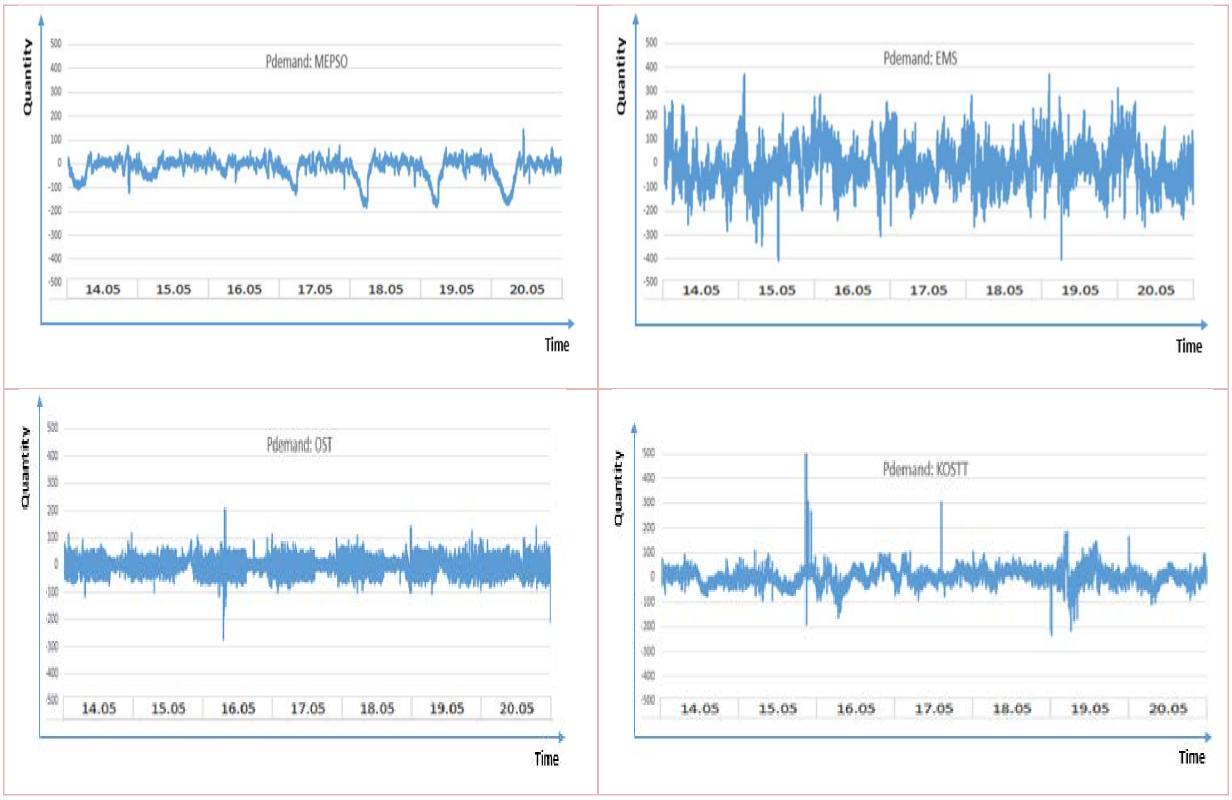


Figure 13: Power Demanded Signal of each TSO

4.1.2 Data: Opportunity prices

Obtained or estimated opportunity prices were used in the calculation of IN settlement price, according to the principles explained in Chapter 2.2.2.

Table 3: Imbalance Netting Test Information Sheet - Opportunity prices

Imbalance Netting Test Information Sheet: Opportunity prices		
Time Span	1 week: Monday 14.05.2018 00:00 – Sunday 20.05.2018 23:59	
Pdemand	**CGES**	Provided data for aFRR upward and downward
	MEPSO	Provided data for aFRR upward and downward
	EMS	Average price for aFRR upward and downward in period from January to April
	OST	Provided data for aFRR upward and downward (1.5*HUPX and 0.05*HUPX)
	KOSTT	Provided data for aFRR upward and downward (1.5*HUPX and 0.05*HUPX)
	NOSBIH	Provided data for aFRR upward and downward (1.5*HUPX and 0.05*HUPX)

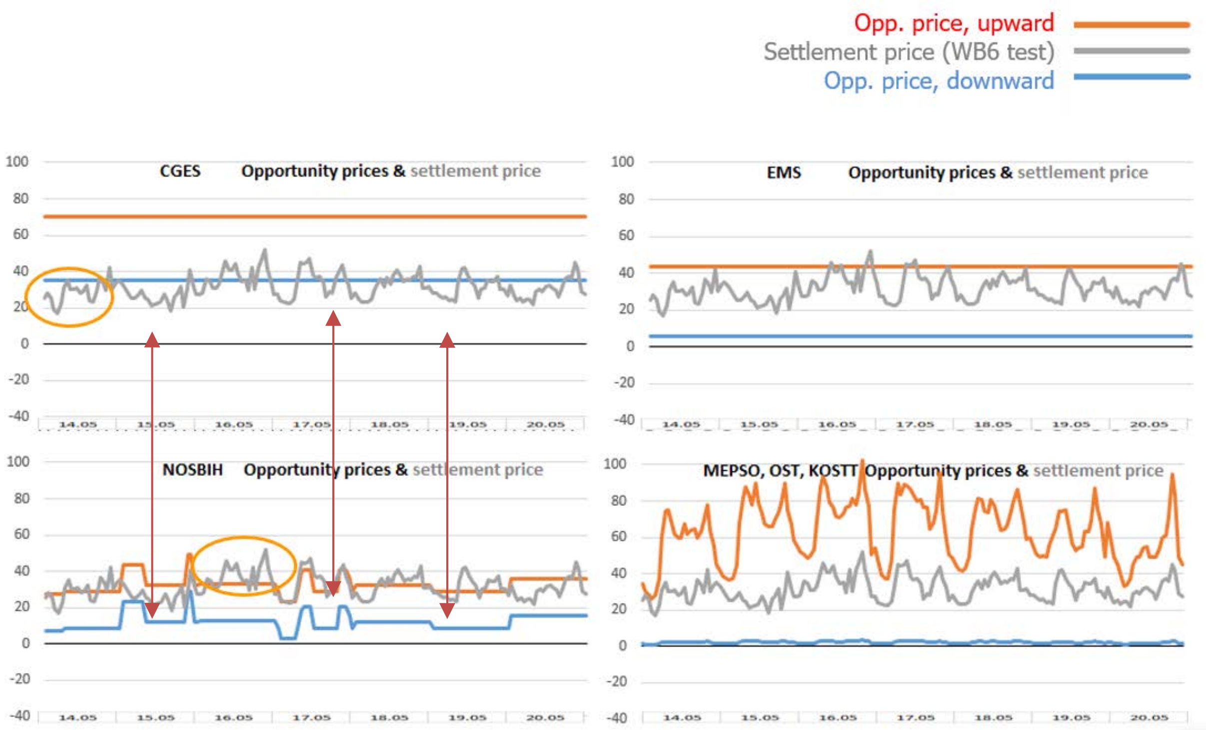


Figure 14: Opportunity Prices of all TSOs, and IN Settlement Price from WB6 test

Figure 14 demonstrates upward and downward opportunity prices as well as settlement price (from WB6 test – as the mostly integrated market with the lowest settlement price). It is of interest to observe the following:

Perfect conditions for obtaining saving of each TSO in each period is when the settlement price stays in the boundary region determined by two envelopes denoted by upward opportunity price and downward opportunity price.

Upward Opportunity Price > IN Settlement Price > Downward Opportunity Price

In the *Figure 14*, it is shown that MEPSO, OST and KOSTT settlement prices were always in the boundaries determined by upward and downward opportunity price, since they are directly defined in relation with the HUPX DAM prices.

From the *Figure 14*, it can be observed that for CGES the settlement price is often lower than the downward opportunity price. As a result, in these periods it appears that for CGES it would be more beneficial to apply domestic downward than to perform Imbalance Netting. Also, in NOS BiH in some periods the upward opportunity price is higher than the settlement price.

Nevertheless, the IN mechanism ensures the savings for each of the TSOs in the entire observed period, even if it is not so in each timestamp.

4.1.3 Data: Transmission limits

As the transmission limits, the following is imposed:

- Overall aFRR exchange limit for each TSO is set to 200 MW (assumed, estimated value)
- The hourly ATC values at all borders/directions (considering EMS&KOSTT as the single biding zone with unlimited transfer capacity), are provided by the TSOs, as the remaining portion of NTC after previous allocation and nomination rounds (Day-ahead and Intra-day);

After the nominations of transmission rights, the TSOs evaluate the netting among counter-transactions, therefore the remaining ATC is quite high at some borders. Consequently, no congestions i.e. limitations to the IN potential appeared.

from_Bidding Zone	to_Bidding Zone	ATC average
CGES	EMS&KOSTT	431
CGES	NOSBIH	295
CGES	OST	400
EMS&KOSTT	CGES	554
EMS&KOSTT	MEPSO	187
EMS&KOSTT	NOSBIH	541
EMS&KOSTT	OST	210
MEPSO	EMS&KOSTT	763
NOSBIH	CGES	705
NOSBIH	EMS&KOSTT	459
OST	CGES	103
OST	EMS&KOSTT	100

Figure 15: ATC values between different Bidding Zones

4.2 Results of the Tests

Tests have been conducted for all TSO in the three aforementioned blocks.

- Test 1: “WB6”
- Test 2: “WB5” (without NOS BIH)
- Test 3: “SMM” (EMS, CGES, MEPSO)

Optimisation module of imbalance netting mechanism conducted the optimisation and the settlement module calculated the prices and savings made by each TSO.

4.2.1 EMS savings

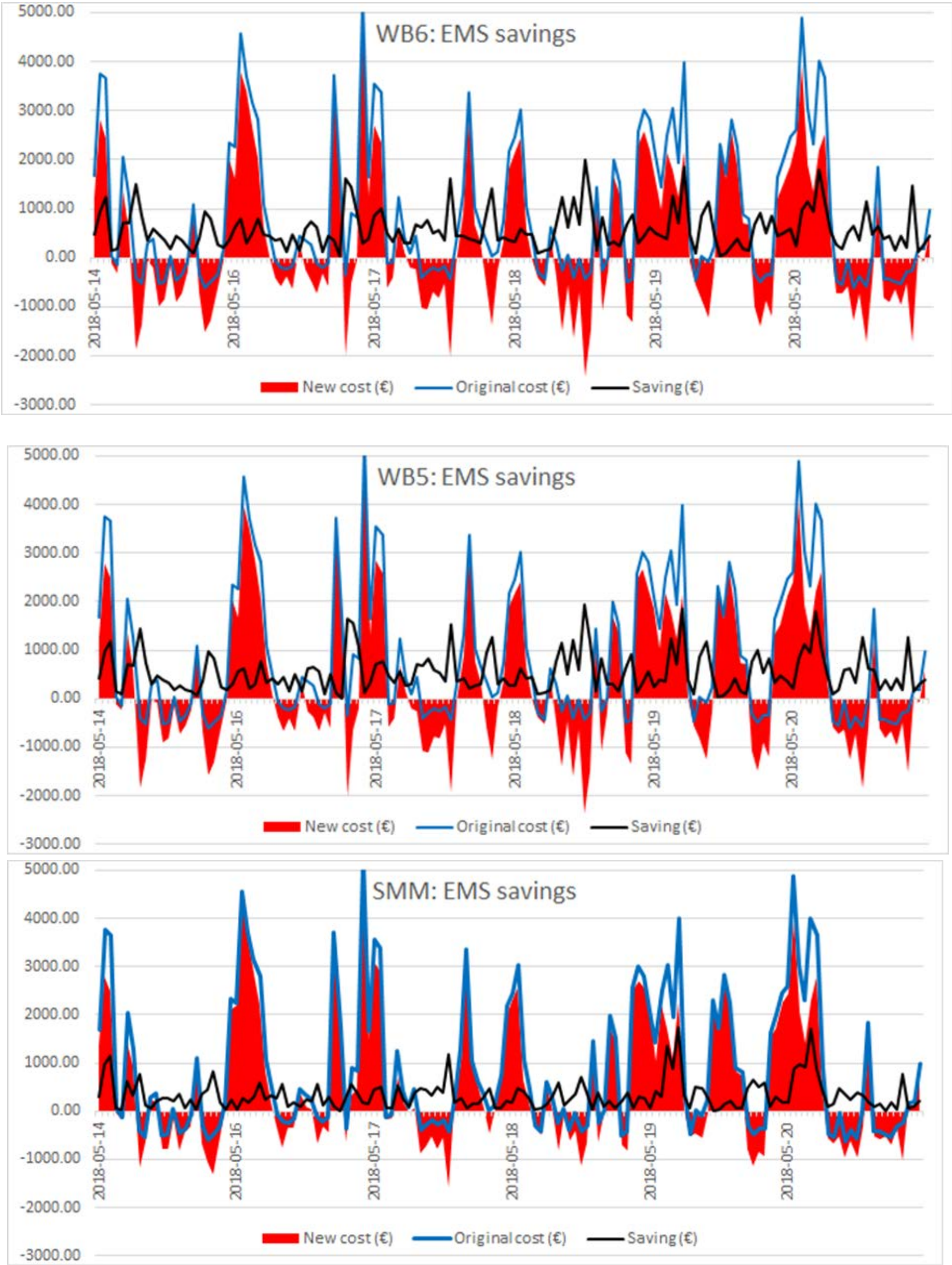


Figure 16: EMS savings in the performed IN tests

EMS recorded positive savings in each settlement period, as well as the highest level of savings in total for the testing period, (under the assumption/based on the data in observed week) provided that opportunity prices are competitive and that the settlement price is generally between downward and upward opportunity prices. This result is also related to the size of the system, as the biggest among the observed ones, and therefore having higher volatility of ACE.

4.2.2 CGES savings

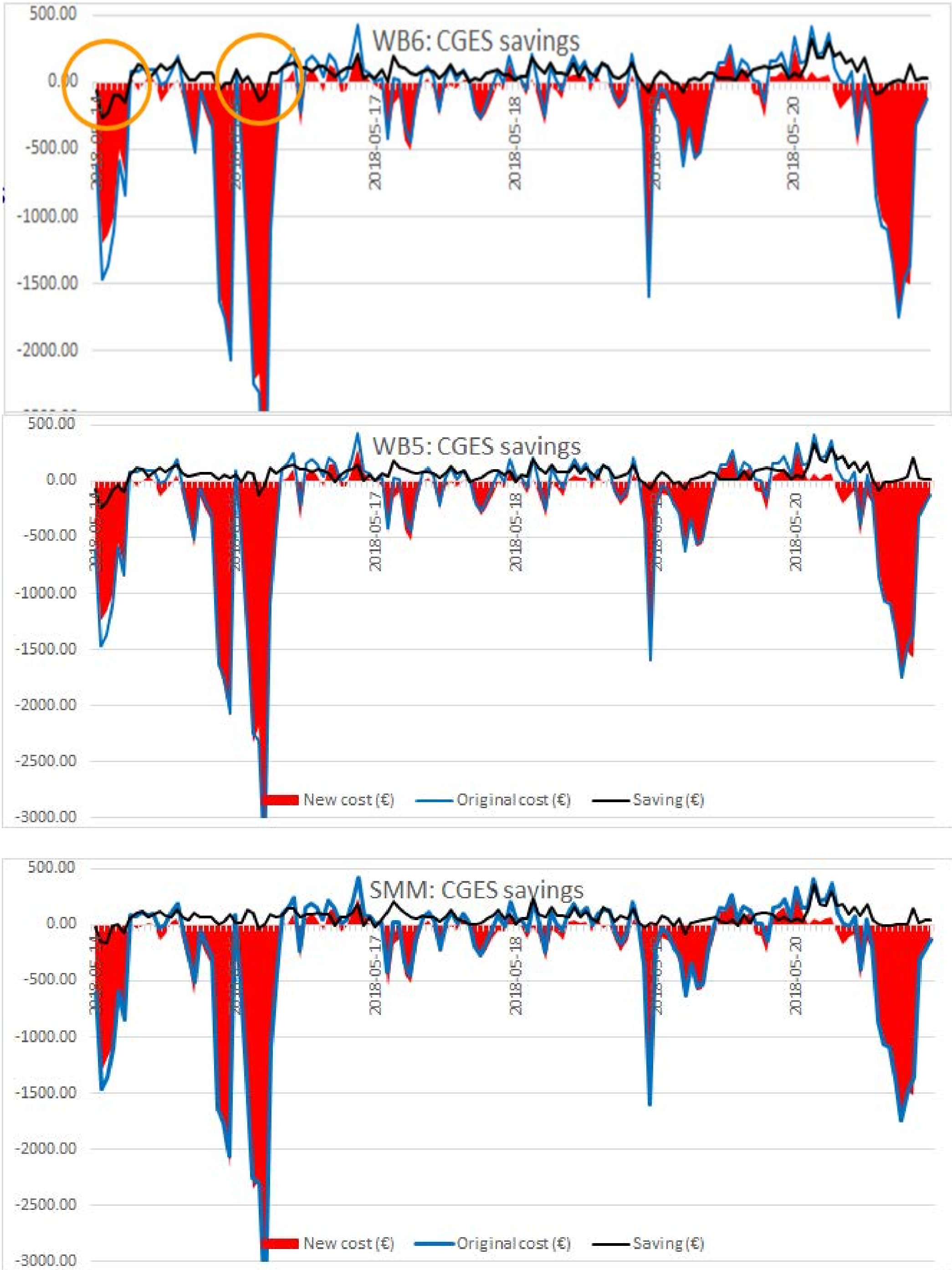


Figure 17: CGES savings in the performed IN tests

Montenegrin TSO records general savings in the imbalance settlement mechanism with occasional negative savings in some periods due to settlement prices lower than downward opportunity price in these periods.

This effect is opposite than for TSOs where there is settlement price between the opportunity prices, such as EMS and NOS BiH.

For example, at day 1 (14/05/2018), for the bigger IN region (WB6>WB5>SMM), the settlement prices are lower; that creates higher “loss” for CGES, i.e. more hours where settlement price is lower than their downward opportunity price.

	Date	2018-05-14																							
	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
WB6	SP (€)	25.6	27.8	25.4	18.8	17.2	22.6	30.7	35.5	30.5	30.1	30.8	28.4	28.6	32.5	23.8	23.0	29.8	36.4	33.8	29.8	41.9	30.3	33.7	34.9
WB5	SP (€)	27.2	28.5	26.2	19.0	17.9	25.5	32.0	39.4	40.4	37.9	35.3	33.9	33.2	33.1	34.1	35.4	36.6	39.3	36.3	38.0	43.4	37.6	38.3	35.8
SMM	SP (€)	31.0	30.2	27.5	26.6	25.2	26.6	29.8	40.0	37.4	33.8	37.1	34.8	34.5	37.8	35.1	37.3	40.3	42.7	36.9	37.9	44.1	37.7	39.3	37.5
	Marked: hours when Settlement price is lower than CGES downward opp. price																								
	CGES down o.p.	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
	CGES up o.p.	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70

4.2.3 MEPSO savings

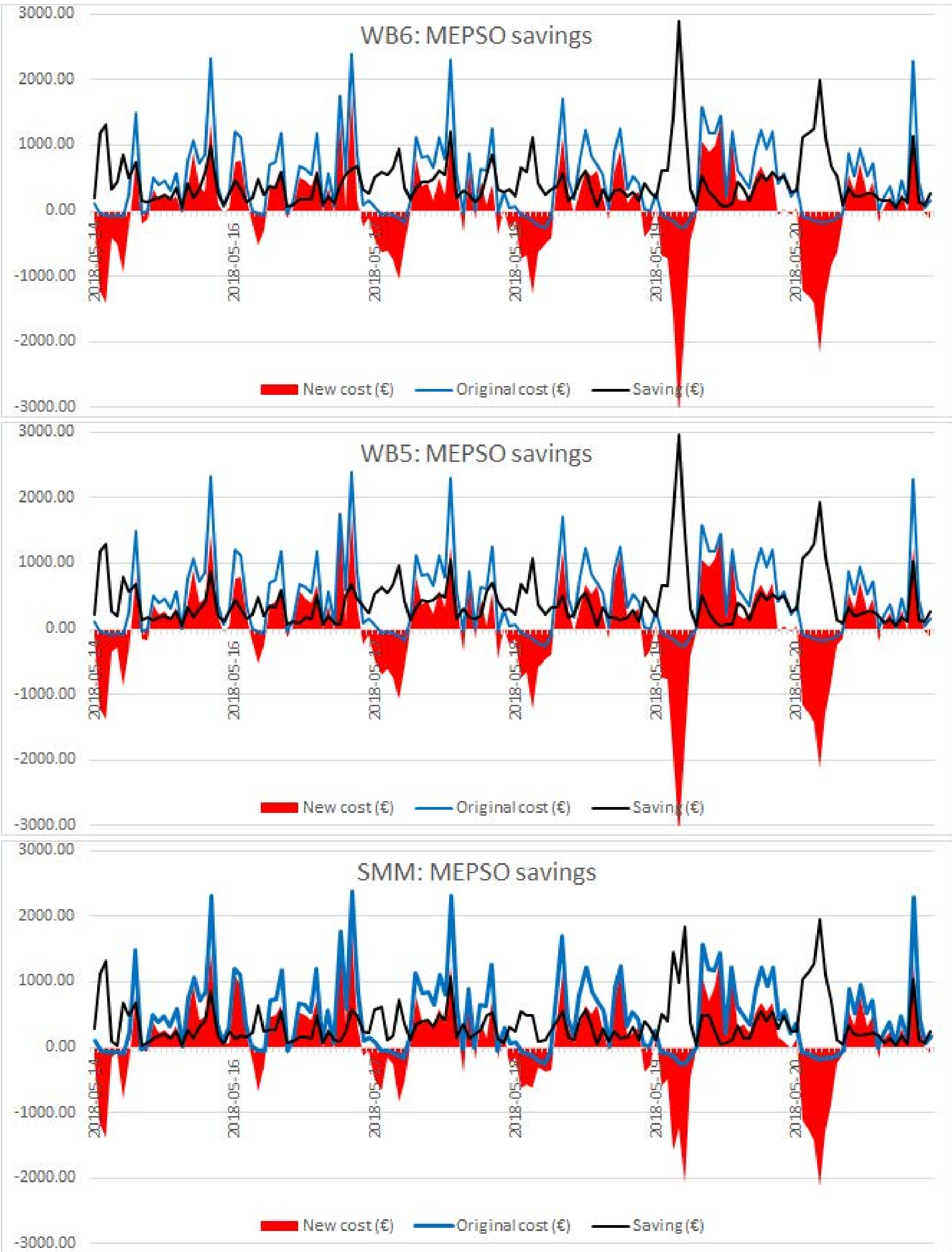
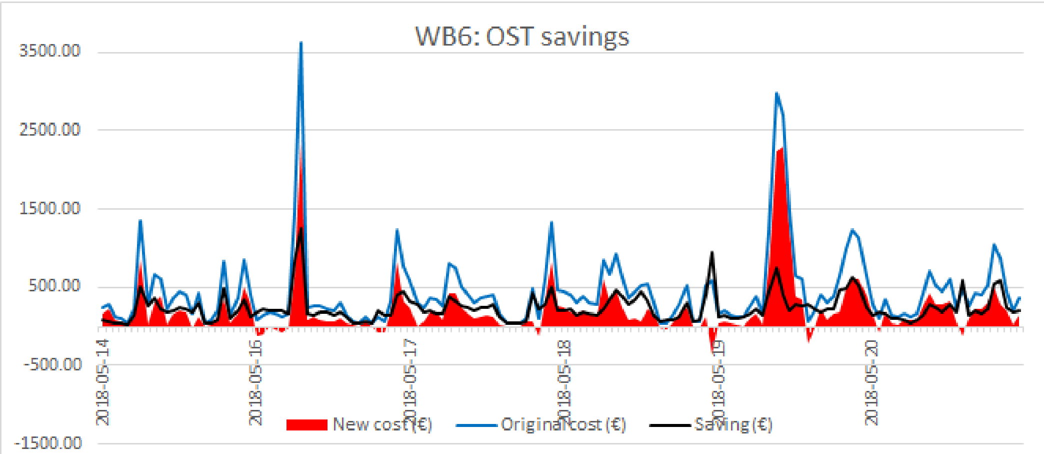


Figure 18: MEPSO savings in the performed IN tests

Since imbalance netting settlement prices stay between upper and downward opportunity price, savings are significant and stable. As expected, MEPSO savings is higher in the concept of WB6 and WB5 market, than at SMM test case.

4.2.4 OST savings



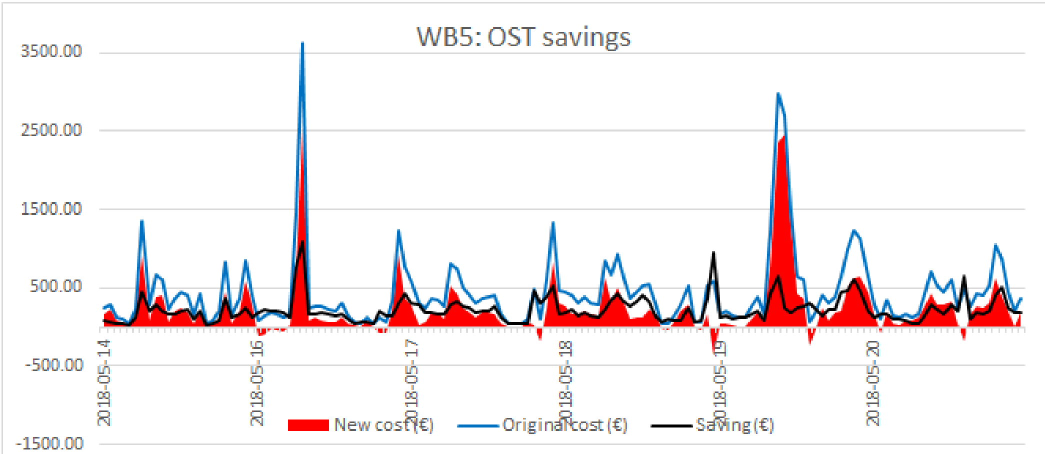


Figure 19: OST savings in the performed IN tests

Imbalance netting settlement prices stays between upper and downward opportunity price, so OST savings are significant and stable.

4.2.5 KOSTT savings

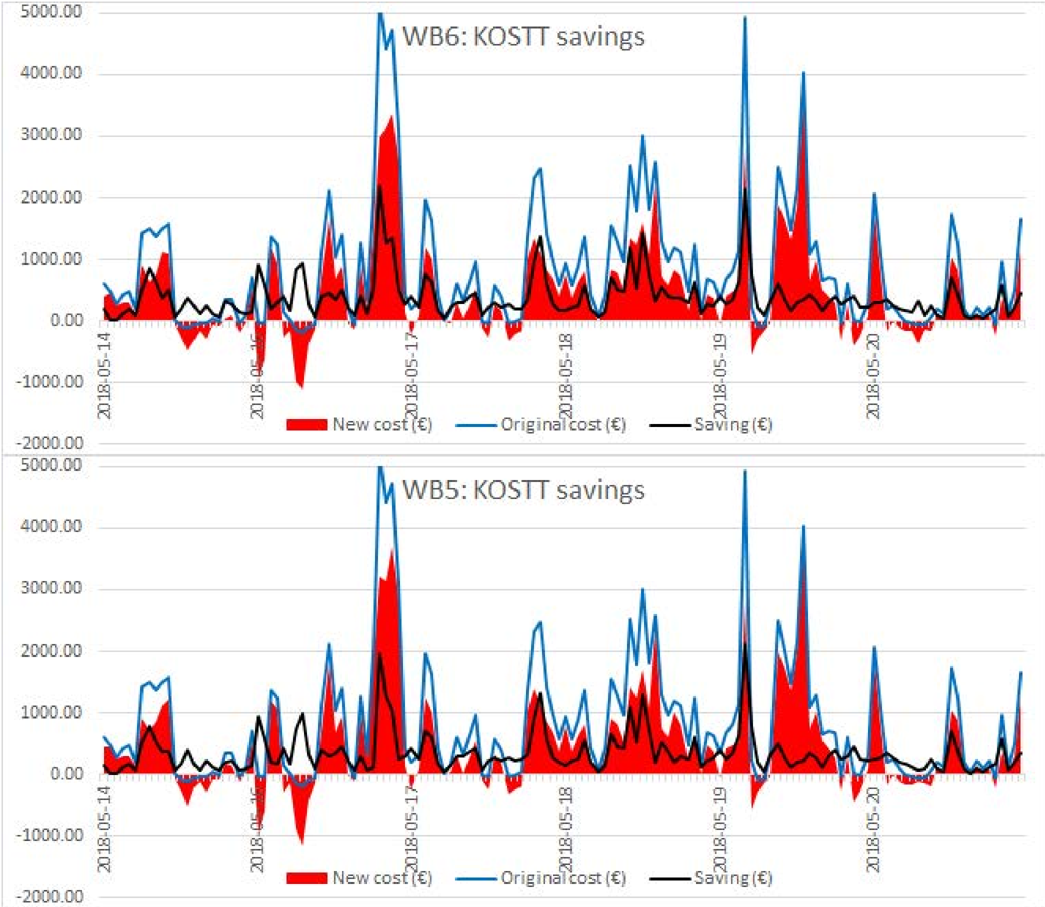


Figure 20: KOSTT savings in the performed IN tests

Since settlement prices stays between the opportunity prices, KOSTT savings are significant and stable as well.

4.2.6 NOS BIH savings

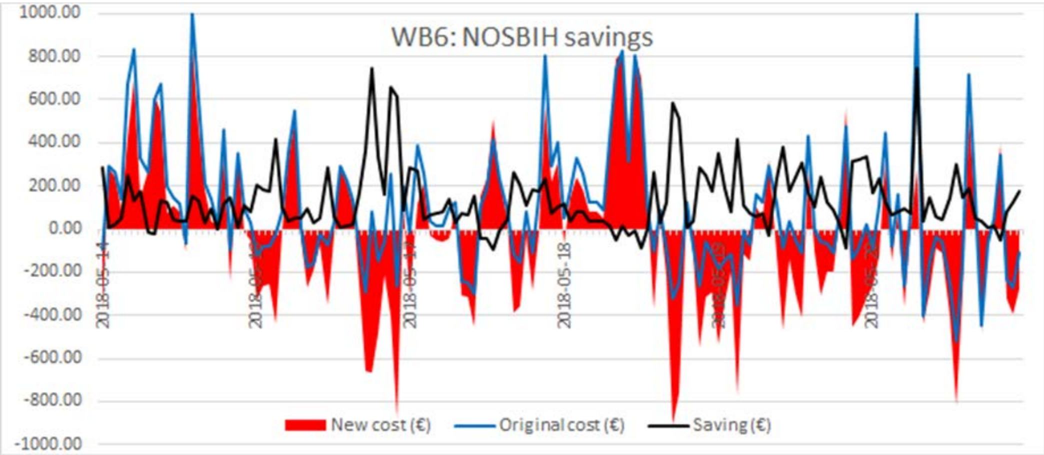


Figure 21: NOS BIH savings in the performed IN test WB6

Although there are periods where settlement price is higher than the domestic upward opportunity price, it is shown that NOSBIH makes high overall savings.

4.3 Summary of the results

The following data summarizes the outcomes of performed IN tests.

Table 4: Summarized results of the tests

WB6 Summary (6 days)

	Upward				Downward			
	Pdemand+ sum	Pavoided+ sum	**Pavoided+ average MW**	**%avoiding+**	Pdemand- sum	Pavoided- sum	**Pavoided- average MW**	**%avoiding-**
EMS	3640	2003	**13.9**	**55%**	5585	1788	**12.4**	**32%**
CGES	445	308	**2.1**	**69%**	1853	870	**6.0**	**47%**
MEPSO	1019	736	**5.1**	**72%**	3448	1511	**10.5**	**44%**
KOSTT	1972	1355	**9.4**	**69%**	1439	527	**3.7**	**37%**
NOSBIH	1110	820	**5.7**	**74%**	1753	862	**6.0**	**49%**
OST	1053	743	**5.2**	**71%**	846	407	**2.8**	**48%**
		average	6.9	68%			6.9	43%

WB5 Summary (6 days)

	Upward				Downward			
	Pdemand+ sum	Pavoided+ sum	**Pavoided+ average MW**	**%avoiding+**	Pdemand- sum	Pavoided- sum	**Pavoided- average MW**	**%avoiding-**
EMS	3640	1758	**12.2**	**48%**	5585	1557	**10.8**	**28%**
CGES	445	290	**2.0**	**65%**	1853	821	**5.7**	**44%**
MEPSO	1019	688	**4.8**	**67%**	3448	1455	**10.1**	**42%**
KOSTT	1972	1261	**8.8**	**64%**	1439	488	**3.4**	**34%**
NOSBIH								
OST	1053	712	**4.9**	**68%**	846	386	**2.7**	**46%**
		average	6.5	62%			6.5	39%

SMM Summary (6 days)

	Upward				Downward			
	Pdemand+ sum	Pavoided+ sum	**Pavoided+ average MW**	**%avoiding+**	Pdemand- sum	Pavoided- sum	**Pavoided- average MW**	**%avoiding-**
EMS	3640	1549	**10.8**	**43%**	5585	743	**5.2**	**13%**
CGES	445	286	**2.0**	**64%**	1853	669	**4.6**	**36%**
MEPSO	1019	696	**4.8**	**68%**	3448	1118	**7.8**	**32%**
KOSTT								
NOSBIH								
OST								
		average	5.9	58%			5.9	27%

Observing the WB6, WB5 and SMM tests, the average Pavoided per hour, in EMS, CGES, MEPSO is as follows:

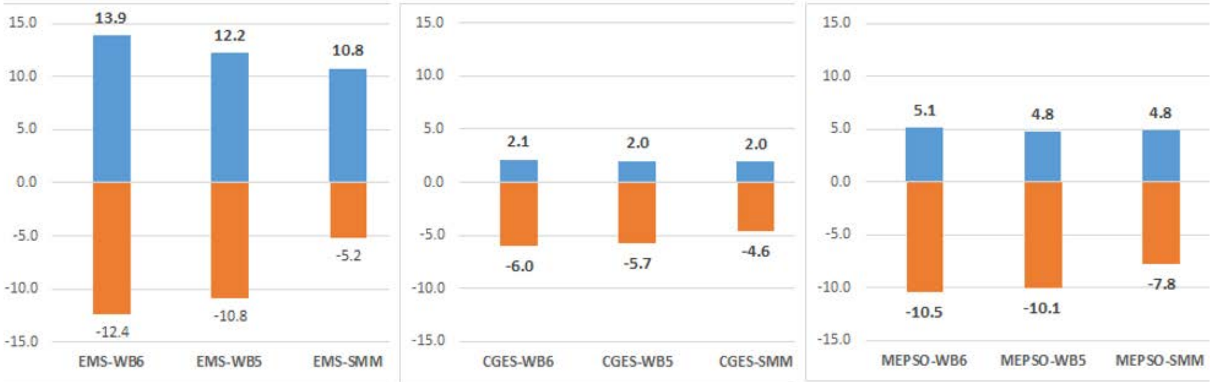


Figure 22: Level of P-avoided per hour provided by EMS, MEPSO and CGES

Roughly assessing the annual level of savings, based on the results of the performed analyses for 6 days, the following estimation can be made:

Table 5: Total savings for analysed 6 days, and estimation of yearly savings

Savings, EUR	WB6	WB5	SMM
EMS	83,219	77,808	47,679
CGES	9,030	9,368	10,090
MEPSO	63,323	59,532	50,904
KOSTT	54,630	49,549	
NOSBIH	19,437		
OST	34,425	31,732	
Sum, 6 days	**264,064**	**227,989**	**108,673**
EMS, ≈year	5,062,489	4,733,320	2,900,473
CGES, ≈year	549,325	569,887	613,808
MEPSO, ≈year	3,852,149	3,621,530	3,096,660
KOSTT, ≈year	3,323,325	3,014,231	
NOSBIH, ≈year	1,182,418		
OST, ≈year	2,094,188	1,930,363	
Estimation, year	16,063,893	13,869,331	6,610,941

4.4 Conclusions and recommendations

Out of the Imbalance Netting simulations and analyses, the following can be concluded:

- Imbalance Netting is beneficial in every aspect
- The higher the number of TSOs in the imbalance netting mechanism, the higher is the social welfare as whole of the imbalance netting parties
- Order of magnitude of annual savings at WB6 level would be 16 mEUR.

When settlement price is between upward and downward opportunity prices, the savings are high and positive. There are periods where the settlement price goes out of the range between downward and upward local opportunity price in CGES and NOS BiH (lower than downward opportunity price in CGES; higher than upward opportunity price in NOS BiH), but despite of such periods, overall benefits and savings are evident for each TSO.

Since IN mechanism is such that main inputs cannot be controlled, such as Pdemand (and its correlation among TSOs) and ATC constraints, it is important to introduce competitive balancing market which results in competitive opportunity prices which are then used in Imbalance Netting process.

Existing aFRR IT infrastructure (data exchange channels and protocols, controllers, SCADA modules) are suitable for initial setup of Imbalance Netting, both on the level of Control Blocks or wider among IGCC members. IT requirements related to implementation of IN platform includes the list as defined in chapter 1.4.

Implementation roadmap in Task 5 Report provides comprehensive description of implementation steps on the level of the region and at Continental European level as well. Here to briefly summarize:

- All TSOs should approach towards IGCC mechanism;
- In parallel, the pre-netting within each LFC block (SMM and SHB), subordinated to IGCC should be applied.
- Optionally, one additional pre-netting among LFC blocks can be implemented.

5. REFERENCES

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(2) Explanatory Document to All TSOs' proposal for the implementation framework for a European platform for the imbalance netting process in accordance with Article 22 of EB GL, ENTSO-E, June 2018
(3) Stakeholder document for the principles of IGCC, IGCC stakeholders, September 2016
(4) Opportunity prices, IGCC stakeholders, 2016
(5) ENTSO-E Operational Handbook, Policy 1, Policy 2
(6) Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a Guideline on Electricity Balancing (EB GL)
(7) Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a Guideline on Electricity Transmission System Operation (SO GL)
(8) Explanatory Document to all TSOs' proposal for a methodology to determine prices for the balancing energy and cross-zonal capacity used for exchange of balancing energy or for operating the imbalance netting process in accordance with Article 30 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing
(9) Doorman, G. d. (2011). Balancing Market Design. Sintef.