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Advanced load shaping using battery

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***Abstract*—System imbalance influences the economic aspects of electricity distribution. As system imbalance in well-regulated distribution system is of stochastic nature, it turns interesting due to system regulation to suit the demand with the supply such that the local imbalance in balancing group is minimized. In this contribution we study an approach of self-regulation of balancing group using an energy storage to rebalance own difference of demand and actual supply of the group. The aim is to minimize paid fees for system imbalance and benefit eventually negative fees if possible.**

Keywords*—*peak shaving, load shaving, system imbalance, balancing group, energy storage

I. INTRODUCTION

The issue of balancing the production, purchasing and consumption is a vital part of the life of every participant in the electricity market. The differences between the consumption and production of electricity in the grid can cause frequency fluctuations, which is undesirable for the power grid. Frequency fluctuations are primarily addressed by the Transmission System Operator (TSO) in each part of the network. The TSO has a range of resources commonly known as Ancillary services (AS) [1]. These services are provided by the independent providers, from whom the TSO orders them in the form of an auction.

The energy that TSOs buy in this way for the needs of electricity stability is also called regulating electricity (RE). RE therefore serves to compensate for the differences between energy produced, supplied, and consumed.

Legislation in the field of electricity market organization assists TSOs in fulfilling this task, thus defining the concept of market participant imbalance. Each electricity market participant must be held liable for their imbalance in one of two forms:

- market participant transfers responsibility for its imbalance to its electricity supplier, or
- is responsible for their imbalance itself.

The supplier who has thus taken over the responsibility for the imbalance of its customers’ needs to create a Balance Responsibility Party (BRP). It will thus become a subject of clearing and a market participant with an imbalance, which is organized by the Balance Settlement Authority (BSA).

As a result of the clearing process is the cost reflecting basically RE, the BRP should aim to minimize its imbalance to save these costs or even to benefit from them. This can be achieved in various ways. In this article, the section II brings the study of notions System imbalance and BRP imbalance and brings some basic analysis of SI behavior in Slovak republic (SK). The analysis tries to either confirm that SI in Slovak republic is of purely stochastic nature or it is worth for BRP try to predict SI to cope with its imbalance.

In the section III we study possibility to cope with BRP imbalance by load shaping using battery at the BRP. Using naive prediction model applied on real Local Distribution Network data we study the ideal battery needed and RoI of such model.

II. SYSTEM IMBALANCE

Imbalance means an energy volume calculated for a balance responsible party and representing the difference between the allocated volume attributed to that balance responsible party and the realized volume of that balance responsible party, within a given imbalance settlement period. All market participants should be financially responsible for imbalances they cause in the system, representing the difference between the allocated volume and the final position in the market. [2]

A. System imbalance vs. BRP imbalance

It is necessary to distinguish between the terms BRP imbalance and system imbalance (SI). The system imbalance is defined by law as the volume of regulated electricity generated by the TSO.

One can see BRP imbalance as the difference between planned consumption and supply in BRP and actual consumption and supply in BRP.

The combination of system imbalance and BRP imbalance can be in the following alternatives:

- BRP positive imbalance (surplus) with positive system imbalance (surplus)
- BRP negative imbalance (shortage) with negative system imbalance (shortage)
- BRP positive imbalance (surplus) with negative system imbalance (shortage)
- BRP negative imbalance (shortage) with positive system imbalance (surplus)

Total payment of the participant for imbalance is calculated by multiplying the system imbalance price and the BRP imbalance volume. In the rest of the paper, we will use positive payment prices, for payment paid to BRP and negative payment prices for payment paid from BRP to TSO.

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B. *Prediction of SI as benefit for BRP*

From the perspective of BRP this means either need for precise allocating and matching with the actual final position for every single balancing period or extra costs to cover TSO's costs of regulatory power. According to the formulas of imbalance settlement there is yet another approach based on prediction of the system imbalance accompanied with some of market or technical based strategies. Those of market-based strategies are briefly covered by [3].

Generally, market-based strategies rely on predictability of the imbalance. The imbalance should be of stochastic nature and hence unpredictable. There has been a lot of research on predicting the imbalance undercovering that long-term trends are caused by structural changes and acknowledging the presence of feedback from the imbalance price on the behavior of market parties [3].

C. *Potential predictability of SI in Slovak republic*

To cope with the strategies, we have done a brief introductory investigation of the system imbalance in SK behavior in period of 2019 to 2021.

In the Slovak Republic, the BSA is OKTE. According to the valid regulations, OKTE evaluates the imbalance of each settlement period (ISP), which is defined in SK for 15 minutes. Based on this evaluation, it rewards and penalizes individual participants. OKTE as BSA provides freely the SI data at its website [4].

We have chosen the period of 2019 to 2021 because the formula of imbalance price settlement applied by OKTE has been kept unchanged except the multiplication coefficient in regulatory power price.

Raw data of 2020 and 2021 are illustrated on Fig. *1*.

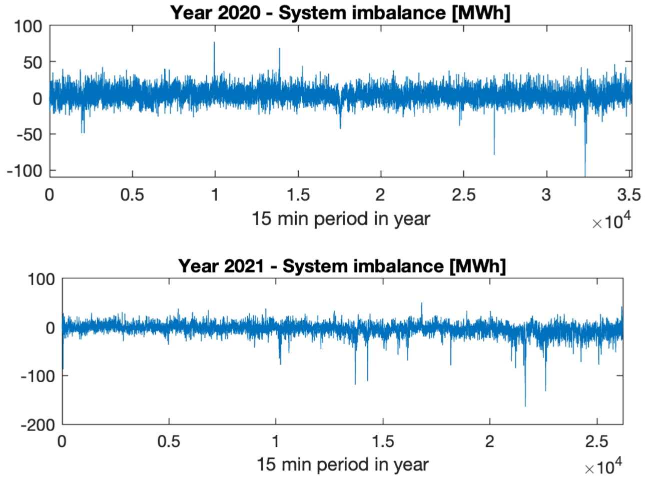

Fig. 1. System Imbalance in SK

Histogram of SI from year 2020 (Fig. 2) shows mean value of 3 kWh, which means that network was in slight surplus. It is in line with Covid-19 restrictions and lockdowns.

On the other hand, histogram of SI from year 2021 (Fig. 3) shows mean value of -4 kWh, which means that network was in shortage

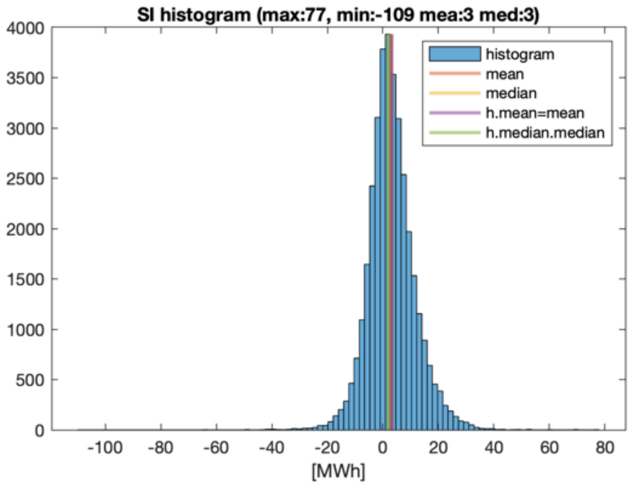

Fig. 2. System Imbalance Year 2020 – Histogram

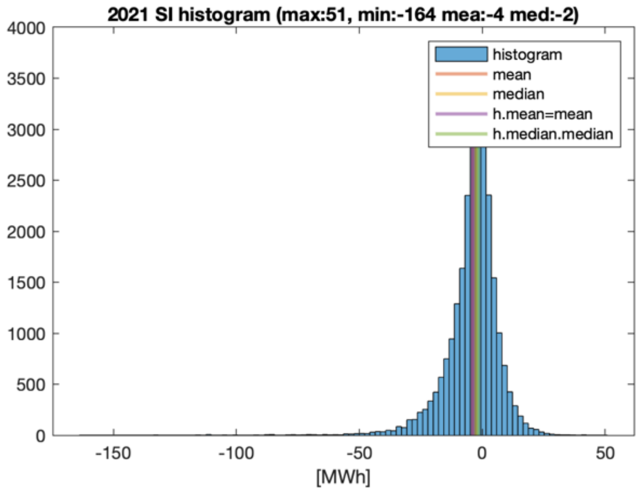

Fig. 3. System Imbalance Year 2021 – Histogram

The SI exhibits some basic probabilities which allow the BRP to assume at significant level at least the signum of imbalance for some periods and weekdays. Sample of such cases with signum probability above 0.68 is shown in TABLE *1*. Presence of such values allows presumption, that it seems viable to develop technical based strategies dealing with the SI from the perspective of BRP.

BRP should aim to minimize its difference between allocated and distributed electricity to minimize the imbalance payments, which can be considered a form of fine for not keeping these two equals for each ISP. Even more, the BRP might want to profit from system imbalance by supplementing the system against the actual SI, this way providing hidden regulation benefited by the negative system imbalance fine.

However, it must be admitted that 2020 market and consumer behavior was strongly influenced by COVID-19 lockdowns and restrictions, while 2021 introduced a lot of market perturbations in both electricity prices and consumers behavior. The abovementioned data should be subject of further studies. The actual analysis and prediction of SI is discussed in other studies, e.g. [3], [5].

TABLE 1: System imbalance signum and price prediction based on SK data from 2019 to 2021

Period	**Weekday**	**2019**		**2020**		**2021**	
		Signum probability	***Average price [€/MWh]***	***Signum probability***	***Average price [€/MWh]***	***Signum probability***	***Average price [€/MWh]***
00:45 - 00:59	Monday	0.923	14.73	0.923	11.52	0.731	6.72
05:00 - 05:14	Monday	0.962	15.70	0.923	17.20	0.885	9.32
05:45 - 05:59	Monday	-0.692	-6.98	-0.692	-5.14	-0.885	-12.78
06:00 - 06:14	Monday	0.962	19.01	0.962	23.02	0.846	10.97
	Thursday	0.923	16.90	0.925	18.55	0.692	8.28
06:45 - 06:59	Monday	-0.846	-9.48	-0.692	-6.94	-0.885	-17.51
	Wednesday	-0.923	-9.90	-0.660	-8.22	-0.885	-18.74
08:00 - 08:14	Sunday	0.923	16.20	1.000	18.52	0.692	10.38
21:45 - 21:59	Thursday	0.885	15.31	1.000	14.16	0.692	6.85
	Friday	0.885	15.73	0.846	13.97	0.736	6.95

III. LOAD SHAPING SIMULATION USING BATTERY

We carry out feasibility and profitability studies of a solution using a battery system at the level of the Electricity Market Participant which is responsible for its imbalance. Solution focuses to manipulate the expected BRP imbalance using a battery system. The battery together with the optimization algorithm could help to balance the expected consumption and the real consumption of the market participant. In other words, BRP imbalance could be mitigated or even eliminated. Based on the assumption that BRP usually pays a fine for non-compliance with the imbalance, this procedure should create economic resources that can be used to purchase and operate such a system.

For all the following simulations, we used real data from the Local Distribution Network (LDN), which are from 2021. The data are originated from the border meter of LDN, which has over 10 end consumption points of an industrial nature.

In the following section, we analyze the economic feasibility of the solution, in which we use a battery to compensate for the imbalance of the subject in details.

The subject of the settlement must report the expected consumption profile for the following day by 12:00 each day. Therefore, the entity must use some model of prediction of its consumption in its daily operation. Still, it cannot manipulate in any way the consumption of its customers. Since the consumption profile changes during the week, month but also year, we used a very basic prediction algorithm in this simulation: the consumption estimate for the current day is the actual consumption seven days ago. In other words, it is a consumption at the same time and week before.

Based on this prediction algorithm, we created a BRP imbalance at a given sampling point, which is illustrated in Fig. 4.

In each settlement period, the battery decides whether to charge if the actual consumption is lower than expected or discharged otherwise.

The simulation uses a battery that has a limited amount of charge and discharge step in order to simulate the charging and discharging of a real battery. The subject's imbalance has either been zeroed in absolute value or at least reduced by a charge/discharge step.

In this case, we set the charging step to 30 kWh/15 min and the discharging step to 40 kWh/15 min.

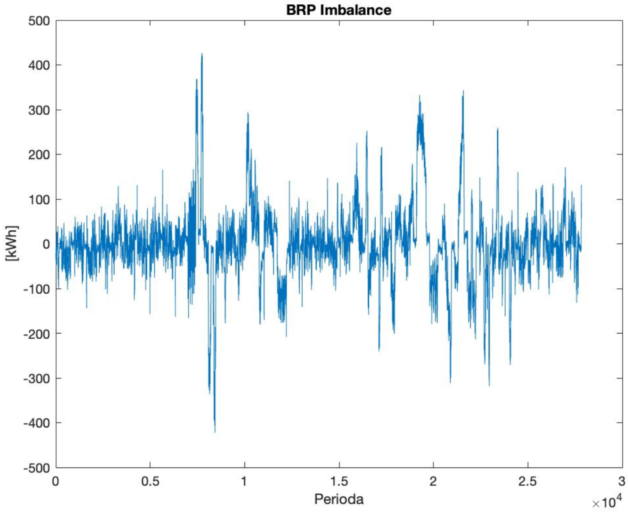

Fig. 4 Example of BRP Imbalance based on LDN data

TABLE 2: ECONOMICAL SUMMARY

Volume of purchased electricity without battery	10 275,32 MWh
Price of purchased electricity*	-€1 438 544,73
Original Imbalance	14 856,00 kWh
Imbalance settlement*	**-€9 060,14**
Volume of purchased electricity with battery	10 190,34 MWh
Price of purchased electricity*	-€1 426 648,16
Imbalance after battery load shaping	99 831,50 kWh
Imbalance settlement	**€1 143,91**

*) Negative sign represents money paid by market participant.

Table 2 summarizes the economic indicators of the simulation example. In the first part, there is a state without a battery. The total volume of purchased energy in the given period can be seen here for a total price of 1,438,000 EUR. The payment for the imbalance that the subject must pay to the Market Organizer is 9,060.14 EUR. Second part of the table shows situation after battery implementation. It states that after implementation, subject earn 1 143 EUR. Nevertheless, amount of imbalance energy is significantly higher than originally. This paradox is caused by positive mix of imbalance energy.

Battery capacity required for this type of load shaping would be extremely high at 88,893 MWh. According the current price level of battery systems, which is 539 EUR/kWh [6] this would make whole battery system extremely costly at 45 Million EUR.

Such a costly solution is, of course, beyond the scope of economic viability. Possibilities to reduce this economic complexity lie in adjusting the size of the battery. Battery size could be reduced significantly when we will decide to load shape only a part of the original imbalance. Such simulation has been performed and its results are shown in Table 3. As we can see, also with these corrections is this standalone load shaping strategy non-viable and does not produce any sustainable RoI. So, it makes sense only as side-scenario, while the primary purpose of the battery is different.

TABLE 3 EXTENDED ECONOMICAL SUMMARY

Percentage of shaped imbalance	**10**	**25**	**50**	**75**	**100**
Volume of purchased electricity without battery	10 275,32 MWh	10 275,32 MWh	10 275,32 MWh	10 275,32 MWh	10 275,32 MWh
Price of purchased electricity	-€1 438 544,73	-€1 438 544,73	-€1 438 544,73	-€1 438 544,73	-€1 438 544,73
Original Imbalance	14 856,00 kWh	14 856,00 kWh	14 856,00 kWh	14 856,00 kWh	14 856,00 kWh
Imbalance settlement	-€9 060,14	-€9 060,14	-€9 060,14	-€9 060,14	-€9 060,14
Volume of purchased electricity with battery	10 266,82 MWh	10 254,08 MWh	10 232,83 MWh	10 211,59 MWh	10 190,34 MWh
Price of purchased electricity	-€1 437 355,07	-€1 435 570,59	-€1 432 596,45	-€1 429 622,30	-€1 426 648,16
Imbalance after battery load shaping	23 353,55 kWh	36 099,88 kWh	57 343,75 kWh	78 587,63 kWh	99 831,50 kWh
Imbalance settlement	-€8 039,74	-€6 509,13	-€3 958,12	-€1 407,10	€1 143,91
Imbalance settlement savings/year	**1 020,40 €**	**2 551,01 €**	**5 102,02 €**	**7 653,04 €**	**10 204,05 €**
Required battery size	**8,71 MWh**	**22,07 MWh**	**44,35 MWh**	**66,62 MWh**	**88,893 MWh**
Price of required battery	4 694 326,17 €	11 897 515,44 €	23 902 830,88 €	35 908 146,31 €	47 913 461,75 €
RoI/years	4600,454117	4663,840716	4684,969583	4692,012538	4695,534016

Other purposes of storage may include the strategies where we do not want to store energy for long term but only for short-term storage. It would be convenient to charge the battery at low energy prices (typically at night) and to discharge and sell at high prices (during peak load hours). With this adjustment, the prediction algorithm must be fundamentally reworked and is currently out of scope of this paper.

IV. CONCLUSION

In the article, we performed a statistical analysis of the system imbalance based on SK data. To evaluate the system imbalance predictability, we made basic signum and price predictions. These features can further be used when creating a load shaping strategy through a battery system. In the simulation part, we performed a simulation of the economic profitability of the solution of compensating the deviation of the participant by means of batteries. At present, such a solution has proved to be unsuitable due to the still high price of battery solutions. To further streamline this solution, it is possible to use other modifications of the strategy and the use of stored energy.

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Advanced techniques for landmine detection using UAV
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Truncated SVD Based Microwave Tomography Imaging for Stepped Frequency Ground Penetrating Radar
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Different Antennas Consideration for Advanced GPR Applications
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Special Session on Smart Energy

Design of Photovoltaic Systems for Residential Houses
Ivan Katrencik, Julius Golej, Monika Zatrochova, Miroslav Panik, Branislav Misota

Identification of Generator Active Power Oscillations Stability Measure
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Advanced load shaping using battery
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Multiple-camera System for 3D Object Detection in Virtual Environment using Intelligent Approach
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UBT 5S (Small Scale Smart Sustainable System) – Invited lecture
Edmond Hajrizi

Data augmentation techniques for expanding the dataset in the task of image processing
Blerina Rrmoku, Edmond Hajrizi, Besnik Qehaja

Image Analysis of Water Level using Remote Sensing
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5G Network Deployment at UBT: Features, Capabilities and Challenges
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