Energy to Digital Asset Conversion as a Business Model for Complex Energy Systems

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***Abstract* – This paper proposes a business model for complex energy systems based on the currently most efficient conversion of electricity into digital value. The need for such approach emerged from increasingly unfavourable and market-competitive environment in which the European power industry has recently found itself. The proposed innovative solution combines several technical domains and results in hybrid, mutually beneficial, system. At the same time, the proposed solution allows rapid relief of the power system in periods of energy shortage or interruptions in power supply. The business model proposed by this paper is observed for single Europe-based power system and for the blockchain-based eco-system of cryptocurrency bitcoin. Proposed methodology is adaptable to any power system that has the same quality of available information.**

***Keywords* – balancing services, blockchain infrastructure, digital asset, energy conversion**

I. Introduction

Changes taking place in the power industry during the last decade culminated significantly in late 2021. The economically justified management of the power system has gained some new approaches and limitations in the environment of multiple price increases in the power market and resource availability. In the second half of 2021, the price of electricity increased multiple times in all national markets, which resulted in an average price twice as high as in the previous year, just over 100 EUR/MWh in every country [1]. Although it has always been important, in such circumstances it became crucial to qualitatively assess the use of each MWh and manage the dynamics of the power system by several conflicting criteria. Electricity is a commodity that with today's technology is impossible to store effectively on a large scale and must be produced when there is a need for its consumption. This production must be economically viable and sustainable in the long run. In times of volatile consumption and uncertain production, and with high market prices and reduced ability to rely on neighbouring countries [2], decisions are not taken lightly in the context of power system management.

One of the economically feasible solutions is the consolidation under the wing of the Aggregator that brings together a multitude of power system users to undergo the Demand Response program [3]. In this way, manageable consumers would behave as a counterbalance to volatile production from some renewable energy sources. Self-management of consumption profile in accordance with requirements of the system operator can generate additional revenue and increase network flexibility and resilience to power system disruptions [4].

The second approach is to logically consolidate the multitude of distributed energy generation (DER) units and offer balancing services on the market in an organized manner [5]. The presented approach achieves high resolution of steps for secondary and tertiary regulation (automatic frequency restoration reserve - aFRR and manual frequency restoration reserve - mFRR), and given the geographical distribution, it is possible to differentiate the supply portfolio over time. DERs generate revenue by making their power available to the operator to participate in the balancing market and participate in reducing congestion in the system.

The third and most recent example is the use of battery storage systems for secondary and tertiary regulation. Although the cost of such systems today is still too high for economic viability, when renewable energy sources become compelled to participate in the open power market it will become acceptable to hedge in energy storage [6,7]. It has been confirmed that some industrial consumers can use battery storage systems to reduce their own energy requirements towards power grid at certain times, while if requested, can in exchange for income provide support to the network by releasing any reserves stored in battery storage system [8].

All these approaches consider financial effects while respecting technical constraints and aim to optimally manage the power system. The optimally controlled power system uses the available MWh most efficiently and effectively. In case of wrong estimates or unforeseen events, the surplus of available energy is released at a lower price, or the deficit is settled in an expensive market. Provided that the technical conditions are met, each operator will want to financially maximize its system management strategy [9].

For the last 12 years, there is a technology that is being industrialized and standardized today, and that uses electricity to turn it into a digital asset of recognized value through the operation of special high-performance computer devices - a cryptocurrency mining (creation) technology in a proof-of-work (PoW) consensus mechanism. The above-mentioned computational work uses electrical power extensively for creation of established, recognized, and regulated cryptocurrencies [10]. It is on these principles that the research presented in this paper is based, focused around proposed Blockchain

Infrastructure (BCI) platform, which consists of hardware and software solutions by industrial standards.

Rest of the paper is organized as follows: Section 2 describes developed methodology that led to new business model proposal. Section 3 gives an insight in the benefits of the proposed business model and provides description of the representative cases. Finally, Section 4 gives an overview and conclusion about the proposition validity.

II. METHODOLOGY AND OBSERVATIONS

It is always a great challenge to propose innovative business models in an industry that is highly established and regulated. In addition, an industry that considers how significant innovations happen only in large research systems and international companies with massive funding, is often sceptical of simple solutions from other domains. But according to the theory in the paper Drews et al. [11] simple systems are such only seemingly. The business model proposed in this paper is based on dynamics of multiple complex systems that are described by most vital variables. In this paper power system with complex engineering background is observed from business aspects with variables as price of electricity, activation of aFRR and activation of BCI considered. Given the digital ecosystem, this paper observes hashrate, exchange rate, current block reward and difficulty for given time. According to that, we have simplified the familiar complex engineering background and focused on the business aspects and opportunities provided by technology.

This paper observes two dynamic and complex systems: the frequency reserve activation in one European power system; and the blockchain eco-system behind cryptocurrency bitcoin whose data is publicly available on the Internet. The data of the power system are pseudonymized for security reasons because revealing any details may lead to cyber risks and severe damages to the power system in question. Due to the conditions of use, no more details may be disclosed about the power system data, but for similar research almost identical copies can be found on the ENTSO Transparency Platform [12]. Blockchain data is publicly available at the BIT Mining Group website [13].

Based on many years of experience in the blockchain industry and knowledge of the blockchain infrastructure market, this paper takes the average investment prices from Q4 2021, the period when global supply chains were affected and when prices in all markets were above multiannual averages. After analysing power system in question, BCI proposed by this paper of 83.5 MW would have acquire 25,692 units of Bitman's AntMiner S19 Pro rated at 3250 W of power consumption. BCI of 83.5 MW consists of investment in ASIC hardware just above 220 million EUR with total investment reaching 260 million EUR.

BCI is a hardware that generates revenue by converting energy into digital asset. Since the ASIC units of BCI hardware are highly energy demanding, the BCI needs to be integral part of the power system, providing relief when there is need for reduced consumption in the power system. By observing system operation, interconnection obligations, total production, and consumption in the system, it is possible to maximize expected revenue from a hybrid BCI system. Such income is defined as the Hybrid Expected Profit (HEP) ratio, defined as:

$$\max HEP = \frac{\sum_{i=1}^{n}(P_{n,s}-P_{n,c})\times\beta_{n,D}}{\sum_{i=1}^{n}(P_{n,s}-P_{n,c})\times\lambda_{n,s}} \quad (1)$$

where, λ_s is spot price of the electricity in period n, $P_{n,s}$ implies surplus of energy in period n, $P_{n,c}$ are contractual bilateral obligations of energy exchange in period n, and $\beta_{n,D}$ is expected BCI earnings for period n. Expected earnings in period n - $\beta_{n,D}$ - depend on the totality of the global blockchain infrastructure that results in Total Global Hashrate (TGH). ASIC hardware used in BCI can vary for the most efficient ones to the ones that have borderline financial effectiveness. The proposed methodology enables heterogeneous ASIC hardware implementation by introducing a share coefficient of a particular type of hardware ρ_T in $\beta_{n,D}$ calculation:

$$\beta_{n,D} = \frac{\sum_{i=1}^{n}(\rho_T\times\rho_{HR})}{TGH} \quad (2)$$

where ρ_{HR} implies computational power of single ASIC hardware unit, expressed as hash rate.

The research presented in this paper observes 4 case studies for months of February, May, August, and November built upon available data. Figure 1. presents the complete process of decision making during the analysis of the power system in question.

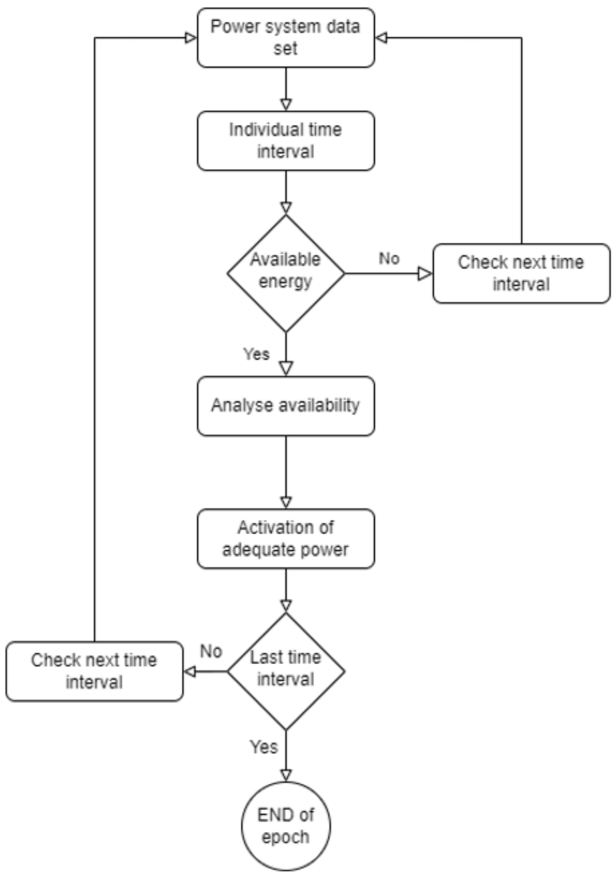

Figure 1. *Flowchart diagram - Analysis of availability of energy*

As seen, available data set of the power system is observed at the start of the process. First step is to identify individual time intervals and in case of this paper this is 1 hour period that corresponds to data available. For that given time interval it is checked if energy for activation of BCI is available. If no, next interval from data set should be checked, if yes, process moves to analysing how much of the energy is available. When determined exact amount of energy available activation of adequate BCI power is performed. When this step is done the process goes to checking if this time interval was also the last one. If not, it checks the next time interval, if yes, it signifies end of an epoch. In the case of this paper, epoch represents one characteristics day in chosen months.

The limited data presented in this paper is considered adequate for presenting hypothesis in clear manner. Although, it should be noted that complete research analysis was based on annul data. BCI activation is proposed in time periods when there is a surplus of energy and the earnings from selling on the spot are lower than the earnings of energy conversion to digital asset but also considering the price of ancillary service activation. Since converting electricity into the leading cryptocurrency is currently the most efficient way to create value and meet financial aspects, despite a significant increase in the price of electricity, BCI is activated every time there is excess power in the power system.

Although it was technically possible to consider all available activations of negative aFRR and make even more financial benefit for operator of the system, for this paper, for simplicity and time constraints it was not studied, but rather it would be considering for the future work. Future work would also include engineering variables like fast response to request to turn BCI off in a case of emergency. That would mean observing presented power system in a more complex and detailed manner which was not necessary with this business model proposal since it can be proven more than adequate with variable presented in this paper.

III. Business Model Evaluation

Observed case studies present analysis of optimal BCI activation needed to timely deploy power consumption in times of need, considering all technical requirements of aFRR in positive direction. BCI power consumption configuration was chosen in accordance with power system in question and data available. Different power system would have different configuration of BCI thus making it suitable for every power system.

Initial investment can be approximated to a little bit more than 300 million EUR is for BCI of 83.5 MW and that includes all costs for electrical equipment needed to make and produce mobile BCI units. Geographical allocation of BCI was not considered but that does not present a constraint since BCI is modular and could be made in modules of 1MW. Moreover, BCI can be used to almost cut off power demand instantly and create additional safety in case of unpredicted events that can rapidly increase instability in the system. Because of broad research spectrum this type of BCI integration was not observed.

Data provided in Figure 2. shows activated aFRR in positive direction, aFRR in negative direction and BCI power activated for the same time interval. Observed time window for the shown data is 24 hours during typical Wednesday of February 2021. For this typical day BCI could have been activated in 11 settlement periods totalling in consumption of 866.44 MWh.

The amount of available power consumption would create 1.22 EX/s of hash rate making it 0.81 % of TGH during that period. Based on globally available information resources, BCI would make a revenue of EUR 265,772.

Energy consumption by BCI would net 306.90 EUR/MWh compared to 62.35 EUR/MWh that would have to be paid for balancing services.

As visible in Figure 2. BCI was activated only when sum of positive and negative direction of aFRR was in favour of negative activation - when it was necessary to reduce production of energy in the system, or if observed another way, to rump up demand in short notice to effectively preserve the stability of the power system. By activating BCI in those settlement periods it is possible to take the burden of the power plants to quickly reduce power output thus preventing unwanted technical barriers when changing power output rapidly.

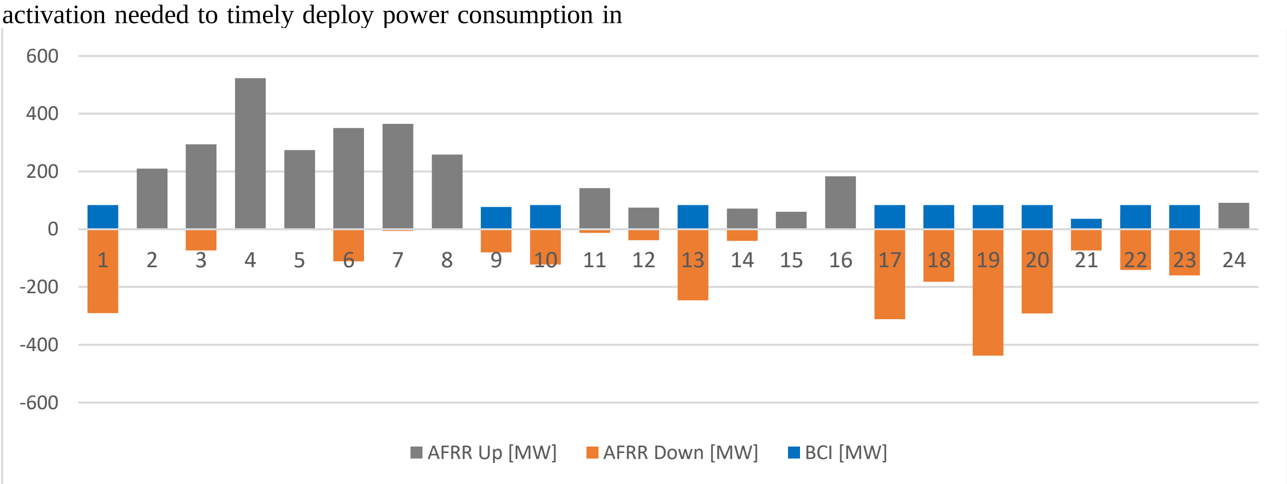

***Figure 2**. aFRR Up, aFRR Down and BCI Activation Data for Typical Wednesday in February of 2021.*

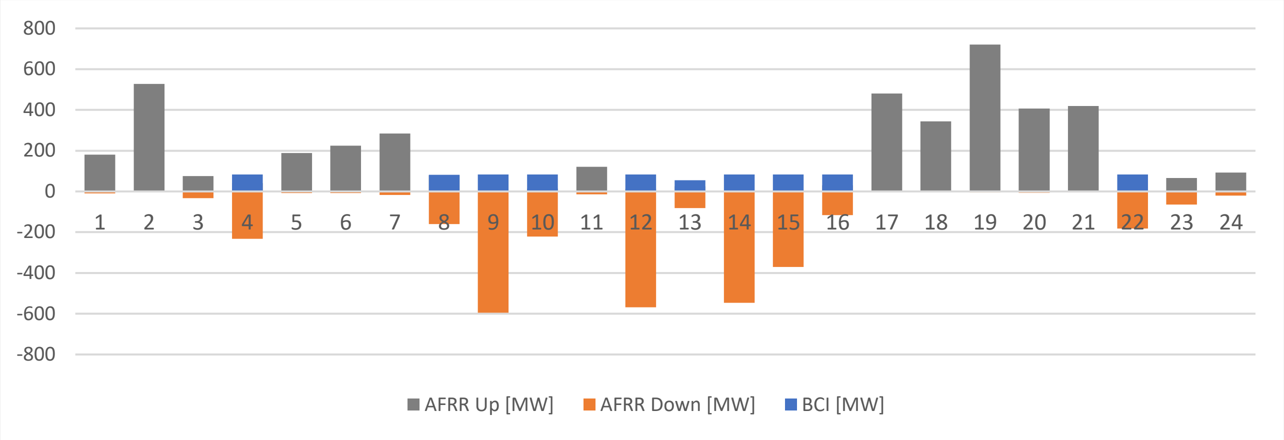

Figure 3. *aFRR Up, aFRR Down and BCI Activation Data for Typical Wednesday in May of 2021.*

Figure 3. gives data for typical Wednesday of May 2021. Activation of aFRR in positive and negative direction was shown together with BCI activation in suitable periods during the day. The model observes 24 settlement periods, of which, 10 periods would have been suitable for BCI activation with power as presented in Figure 3. BCI with power consumption of 83.50 MW consumes a total of 805.10 MWh in those periods.

Amount of power available in settlement periods would result in average available hash rate of 1.14 EH/s. Available hash rate in that moment would have made a 0.75 % of the TGH. Possible revenue for those 24 settlement periods would have been EUR 246,957. It is important to take into observation also the amount that would otherwise have been paid to providers of balancing services totalling in EUR 22,971.

BCI would net 306.78 EUR/MWh compared to 61.01 EUR/MWh that would have to be paid for providers of balancing services.

For observed May total available energy was slightly less than February due to only 10 suitable settlement periods and difference of 2.55 MWh/h of available power thus making difference of 7.3 % in realized income compared to February. As in the previous case, only settlement periods where sum of positive and negative aFRR activation was in favour of negative activation were considered for analysis.

Figure 4. gives data for typical Wednesday of August 2021. Same block of 24 settlement periods was observed as in previous study cases. BCI with power consumption of 83.50 MW would have consumed 497.81 MWh.

Capacity of installed BCI would account for 0.70 EH/s thus making 0.46 % of TGH. Represented value of produced hash power would have generated EUR 152,701 of revenue for observed day in a week. Also, for the same observed day amount of EUR 35,969 would be saved as aFRR from providers of balancing services would not be activated.

Compared to results from February and May, available average power was 40% less with only 7 settlement periods available for activation, but with the average price of 88.55 EUR/MWh for aFRR ‘Down’ activation. Higher price of aFRR activation provided *HEP* of EUR 188,670 thus confirming BCI’s ability to avoid major financial impact in the power system operator’s day-to-day operations.

BCI power consumption would net 306.75 EUR/MWh compared to mentioned above price of 88.55 EUR/MWh of aFRR activation.

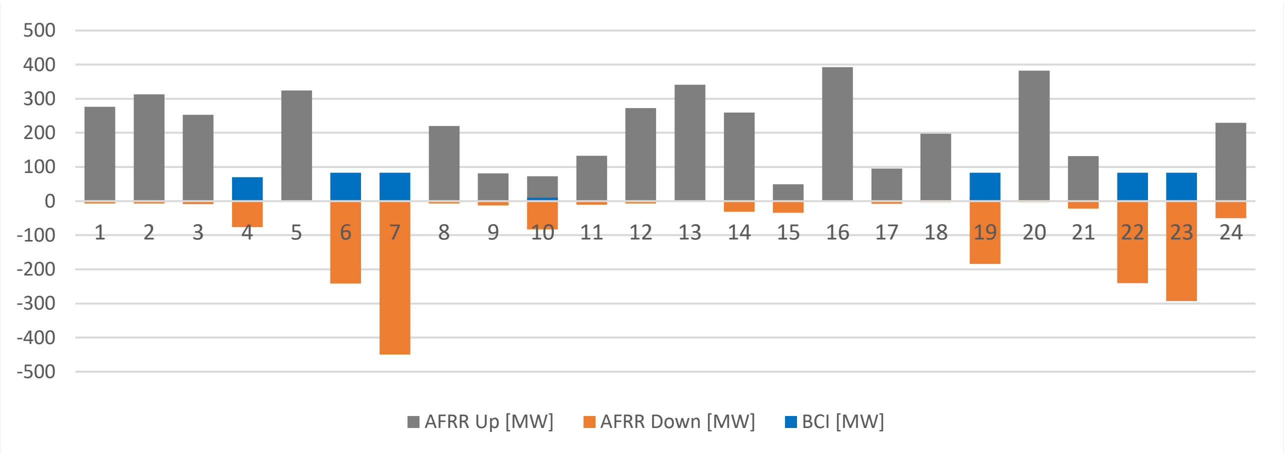

Figure 4. *aFRR Up, aFRR Down and BCI Activation Data for Typical Wednesday in August of 2021.*

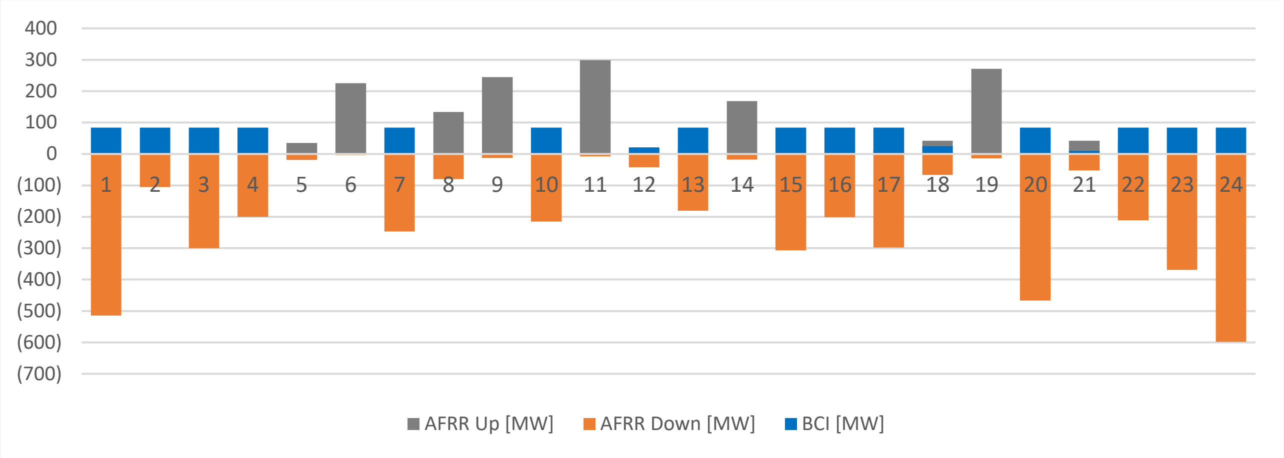

Figure 5. *aFRR Up, aFRR Down and BCI Activation Data for Typical Wednesday in November of 2021.*

Figure 5. provides data for typical Wednesday in November of 2021 for aFRR 'Up', aFRR 'Down' and BCI activation during 24 settlement periods. As shown BCI activation is provided only in periods where substantial amount of negative aFRR activation was needed. For shown typical Wednesday BCI would have been activated in 17 settlement periods thus consuming 1225.61 MWh. For available periods average power would have produce hash rate of 1.73 EX/s and making BCI 1.14 % of TGH.

BCI would make revenue with 306.90 EUR/MWh compared to 152.65 EUR/MWh for activating balancing reserve.

Presented typical Wednesday in November shows amounts which are evidently record amounts compared to other typical Wednesdays. Reason behind this is price on the energy market at the end of 2021. For this period BCI would make *HEP* of EUR 561,808 when considered savings from not activating balancing services from external providers.

By conducting complex analysis before economic calculations, it has been concluded that optimal power of CBI would have been 83.5 MW. Shown study cases provide optimal distribution of controllable load through BCI for presented power system. For available data sets of 4 typical Wednesdays, analysis for presented power system was conducted as research to prove the utility of the presented solution in the form of BCI for power system stability, primarily through the activation of aFRR, which is an essential component of maintaining power system stability. Obtained results for observed period were scaled for complete year of 2021.

In total, with available data sets, presented solution would provide annual revenue of EUR 95,025,728 just with the value of digital asset obtained. Considering that for presented settlement periods aFRR would not have to be activated in needed amounts thus providing additional annual revenue of EUR 24,750,092.

For the final economic calculus, it must be considered that manufacturer provides information about 10 % possible deviations from factory maximum hash rate available. Another economic variable that must be considered is pool fee for mining on most popular pools that is around 2 %. With those variables final calculation for worse case comes as follows.

Revenue from converting energy into digital asset and saved amount from not activating aFRR from providers of balancing services nets EUR 108,562,787 for the presented annual period. To conclude, final calculation brings ROI in just below two and a half years, thus making it economically more than a viable novel solution for aFRR activations in eyes of power system operators.

IV. Conclusion

Objective function of this paper was to propose a business case for providing balancing services with a cross-domain hybrid solution integrated in power system considering all constraints of available data. Technical requirements for providing aFRR activation in negative direction were respected by the proposed business model.

Solution proposed by this paper is based on ASIC-type Blockchain Infrastructure that consumes excess of energy in time of high-power generation from non-controllable sources. Application of such Blockchain Infrastructure is observed and confirmed as a valid business model for complex energy systems of the future. The main advantage of the proposed system is in the current most efficient conversion of energy into digital asset with financial representation - in the cryptocurrency eco-system. The digital eco-system observed in this paper is the one of the cryptocurrency bitcoin since it is the one that is high in energy demand.

The observed electric power system has a large share of large-scale renewable energy sources of unpredictable and unmanageable production, and often has surplus electricity that needs to be consumed quickly. This paper proves that the activation of Blockchain Infrastructure in such periods brings revenues multiple times higher than the ones that come from placement surplus of energy on an uncertain market in terms of aFRR activation.

This paper shows the benefit of integrating the proposed solution in the power system that has ancillary services available particularly evident by providing ROI of a bit over 2 years. Finally, it is the modularity of the proposed solution that makes it a unique and a completely adaptable solution for aFRR activation services since it can be defined in a smallest unit of 1 MW thus making it geographically dispatchable in accordance with technical requirements of the power system.

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