POBOLJŠANJE TRŽIŠNE POZICIJE VLASNIKA ELEKTRANA NA OBNOVLJIVE IZVORE KORIŠTENJEM BATERIJSKIH SUSTAVA

FLEXIBLE SUPPORT, RENEWABLE ELECTRIC ENERGY SOURCES, BATTERY SYSTEMS, PLEXOS, LCOE, ELECTRICITY MARKET

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Obnovljivi izvori energije, posebice vjetrene i sunčane elektrane, postigli su značajnu razinu penetracije u elektroenergetskom sektoru. Razlog tomu je prije svega smanjenje troškova izgradnje tih elektrana čime su postale konkurentne na tržištu električne energije. Sve veći broj elektrana na obnovljive izvore energije izlazi iz sustava poticaja i izlažu se cijenama na tržištu električne energije. Budući da je priroda proizvodnje iz ovih elektrana prilično varijabilna poseban problem predstavlja adekvatno predviđanje buduće razine proizvodnje kako bi se smanjili troškovi za uravnoteženje sustava. U novije vrijeme cijene baterijskih sustava značajno padaju, a istovremeno se tehnologija proizvodnje baterijskih sustava poboljšava. Tako se u novije vrijeme otvara mogućnost kombiniranog rada elektrana na obnovljive izvore energije i baterijskih sustava. Pri tome baterije mogu pomoći uravnoteženju pogrešaka između planirane i ostvarene proizvodnje tih elektrana na tržištu za dan unaprijed. Baterijski sustavi mogu također pružiti i dodatne tržišne mogućnosti vlasnicima elektrana na obnovljive izvore. Tako se na primjer otvara mogućnost za sudjelovanje na tržištu pomoćnih usluga, kao što je sekundarna rezerva. Osim toga, baterije mogu i vršiti cjenovnu arbitražu na tržištu električne energije te tako povećati profit. U radu će se ispitati potencijal korištenja baterijskih spremnika za poboljšanje tržišne pozicije vlasnika elektrana na obnovljive izvore energije.

Ključne reči: *fleksibilna podrška; obnovljivi izvori električne energije; baterijski sustavi; PLEXOS; tržište električne energije*

Renewable energy sources, especially wind and solar power plants, have achieved a significant level of penetration in the electricity sector. The reason for this is primarily the reduction of commission costs of these power plants, which made them competitive in the electricity market. An increasing number of renewable energy power plants are leaving the incentive system and exposed to electricity market prices. Since the nature of production from these power plants is quite variable, a particular problem is to adequately predict the future level of production in order to reduce the cost of balancing the system. In recent times, the prices of battery systems have been falling significantly, and at the same time, the technology of manufacturing battery systems is improving. Thus, in recent times, the possibility of the combined operation of renewable energy power plants and battery systems is opening up. In doing so, batteries can help balance the deviations between the planned and actual production of these power plants on the day-ahead market. Battery systems can also provide additional market opportunities to owners of renewable power plants. Thus, for example, it opens up the possibility of participating in the ancillary services markets, such as the secondary reserve. In addition, batteries can provide price arbitrage in the electricity market, thus increasing profits. The paper will examine the potential of using battery systems to improve the market position of renewable energy plant owners.

Key words: *Flexible support, renewable electric energy sources, battery systems, PLEXOS, LCOE, electricity market*

1 Introduction

Feed-in tariffs and other types of incentives have already encouraged a substantial number of investors in renewable electrical power sources (REPS), which have resulted in a significant increase of REPS installed capacity worldwide, mostly solar and wind power plants. On the other hand, accelerated technology development of REPS power plants, together with recent huge spike in electricity prices, call into question the need for further subsidies of REPS technologies. Due to the aforementioned increase in the price of electricity and the prediction that in the near future prices will remain significantly higher compared to the five-year pre-2021 historic average [1], many owners of wind and solar power plants are leaving the incentive system at their own request and joining the electricity wholesale markets.

The REPS integration into the worldwide power systems is a key prerequisite for the successful accomplishment of long-term sustainable goals set by world-leading economies, countries and associations. According to the IEA [2], solar and wind power plants should, depending on the considered scenario, produce a total of between 8,000 and 12,000 TWh of electricity annually by the year 2030. On the local scale, based on the Energy Strategy of the Republic of Croatia [3], [4], the Strategy of Low Carbon Development of the Republic of Croatia [5], [6] and Climate neutral scenario of the Republic of Croatia [7] it is expected that installed capacity of wind and solar power plants in Croatian power system by the year 2030 will be over 1.5 GW and 1.0 GW respectively.

The EU is constantly updating its climate, energy, and transport legislation. One of the latest set of ambitious goals is introduced by the so-called “Fit for 55 package” [8]. Its main goal is to adjust the existing legislation and regulative according to goals for the 2050.

Besides obvious and well-known advantages of REPS, there are of course also certain drawbacks in comparison to traditional power plants. The major disadvantage is high volatility of REPS power plants power output, especially regarding wind power plants. For that reason, there is a need for additional flexibility (mostly in the form of energy storage systems at the moment) in power systems in order to transfer electricity surpluses from high to low REPS power output periods. Power system’s flexibility determines its ability to reliably balance power supply and demand in each time period. The IEA has made Techno-Economic Definition [9] of power system flexibility as: “Power system flexibility is the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales”. One of the most promising power system flexibility providing technologies are battery storage systems or electric batteries.

Although their investment costs are still rather high, electric batteries are becoming more market competitive in recent years. Besides its role in providing power system flexibility, there is also emerging possibility of the combined operation of REPS power plants and battery systems. In this cooperation electric batteries provide opportunity to mitigate the imbalances between the planned and actual production of associated REPS power plants. Battery systems can also provide additional market opportunities to owners of renewable power plants. Thus, for example, it opens up the possibility to sell electricity from REPS power plants in hours with more favorable prices (postpone output using battery storage capacity). In addition, electric batteries can be used for price arbitrage in the electricity market in case they are not needed for delayed REPS power plant output.

This paper examines the potential of using battery storage systems in cooperation with REPS power plant in order to increase e the profit of REPS power plant owner.

2 A need for additional flexibility and electric batteries

The increasing competitiveness of REPS technologies can be confirmed by literature review in the associated field of scientific research, as well as numerous reports made by leading energy associations. The installed capacity of REPS power plants (especially wind and solar power plants) has recorded constant growth in recent decades [10]. Besides decreasing overall production costs related to REPS power plants there are certain other REPS related costs. Some of them are the costs of up-grading of transmission/distribution networks and costs related to increased balancing issues and need for additional flexibility in power systems.

Due to fact that large capacity electrical energy storage technologies are still unavailable (not commercially ready) the imbalances in power systems due to REPS volatility are still mainly handled by traditional, coal or gas power plants. Those units have high ramp-up and ramp-down rates, meaning that they can adjust output power very fast. Other sources of flexibility are well elaborated and presented in [11]. Same source claims that increase in REPS penetration requires also increase in power system flexibility (both in short and long-term). According to [11] power system flexibility sources can be classified in following groups:

- Demand side management and demand response,
- Reinforcement of distribution and transmission facilities,
- Energy storage systems, electric vehicles and
- Flexible generation.

This paper focuses on electric batteries as the main source of flexibility in power system and they are representatives of energy storage technologies. At the first main role of energy storages was electrical energy time-shifting from high to low-load periods. In this energy storages were actually served as replacement for expensive gas-fired peak power plants. This logic led to introduction of large capacity in pumped storage hydropower plants [12]. Further increase in this energy storage technology was constrained by the lack of new attractive locations, the increased focus and concern regarding clean environment and the restructuring process of power sector. As a result, investment in electric battery R&D increased significantly. The main advantage of electric batteries is ability to react very fast and provide vital power system ancillary services. However, as stated in our previous work [13], electric battery investment cost is still a main issue regarding making decision to build battery storage system. As a consequence of most recent rapid development of the electric vehicles industry most attractive electric battery technology today is lithium-ion. The increased demand for electric batteries together with increase in production and utilization efficiency brought down price of lithium-ion technology. In contrast to pumped storage hydropower plants, electric batteries can be placed as stationary devices in was majority of existing assets within power system, such as substations. However, the price of lithium-ion batteries depends on the chosen specific lithium-ion technology. For the purpose of calculus in this paper same costs as in [13] are used. The logic behind is following. In the last two years price of electric batteries has decreased somewhat due to technology development and increase in production efficiency. On the other hand, electricity price has increased almost tenfold during same time period. Namely, electricity price plays important role in electric battery price due to fact that production process requires significant amounts of energy, around 50–65 kWh of electricity is spent foe each kWh of battery capacity according to [14]. Therefore, it is assumed that these two effects have net zero cumulative effect on electric battery price since [13] was published.

3 Cooperation of REPS power plants and electric batteries

The issue of coupled operation of REPS power plants and battery systems is fairly well represented in the scientific literature. There are two basic approaches to analyzing the combined operation of REPS power plants and battery systems. The first approach is an aggregated approach that does not take into account constraints regarding the transmission network. In other words, it does not distinguish the case of cooperation when both the REPS power plant and the battery system are built in the same physical location from the case when they are located in different physical locations. For example, papers [15], [16] and [17] do not take into account the mentioned constraints regarding the transmission network. A well-explained difference between these two approaches can be found in the paper [18], and Figure 1 shows the difference graphically.

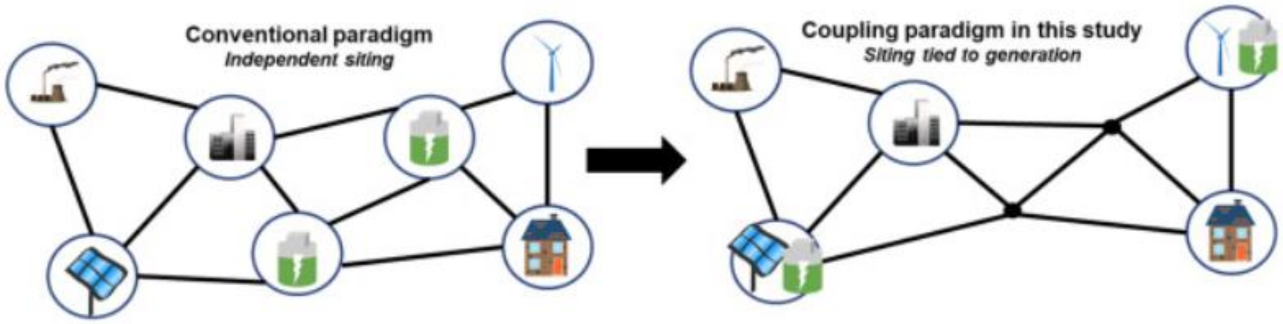

Figure 1: Depiction of two different approaches regarding coupled renewable-battery power plants [18]

The same paper lists both the advantages and disadvantages of the coupled operation approaches of REPS power plants and batteries shown in Figure 1. According to [18] coupling REPS power plants and batteries has the potential to increase the average value of energy sold, to reduce curtailment losses and to decrease permitting, planning, and construction costs compared to physically separated projects. There are also some benefits in the case of a physically separated REPS power plant and battery projects, but this paper assumes physically coupled projects and therefore these benefits are out of the scope of this paper. According to [19] locating the REPS power plants and batteries at the same physical location can make them more attractive for grid operations due to fact that batteries have significant operational flexibility.

4 Methodology and model

The methodology has goal to provide insight into potential for increasing REPS power plant owner profit by introducing new battery system to existing REPS power plant. In the first stage, or 'base case', it is assumed that there is only REPS power plant available that can sell produced electricity only when primary source of energy (wind or sunshine) is available. In the second stage a battery system is introduced on the same physical location as REPS power plant. In this stage battery is allowed only to take produced electricity from REPS power plant in periods with low electricity prices and to discharge it later, when prices are higher. Therefore, this stage is referred as 'energy arbitrage case'. In the last stage battery is allowed, besides energy arbitrage, to perform price arbitrage on the market. In other words, charge from network during low electricity price periods and discharge during high electricity price periods. Therefore, this stage is referred as 'price arbitrage case'. It is expected that net revenue will increase in every stage compared to the previous one, but in order to assess real effect on net profit it is also necessary to take into account battery system investment costs.

The model created in scope of presented methodology is made in software PLEXOS. Model includes REPS power plant, associated battery system and model of power system to which REPS power plant is connected. This power system is modeled actually as external market represented by hourly electricity prices. Even though coupled REPS power plant and battery system have potential to participate in other markets, such as balancing or reserve market, for the sake of simplicity it is assumed that only day ahead market is available.

It is assumed that potential for increasing REPS power plant owner profit is largely affected by electricity prices on day ahead market. Therefore, sensitivity analysis regarding electricity price will be made.

5 Case study

REPS power plant in this paper is assumed to be wind power plant, due to higher volatility compared to solar power plant. In addition, coupled wind power plant and battery system operation is less represented in available literature in comparison to coupled solar power plant and battery system operation. Installed capacity of wind power plant is set to 10 MW and production pattern is modeled by historically observed real life data, as presented in Figure 2.

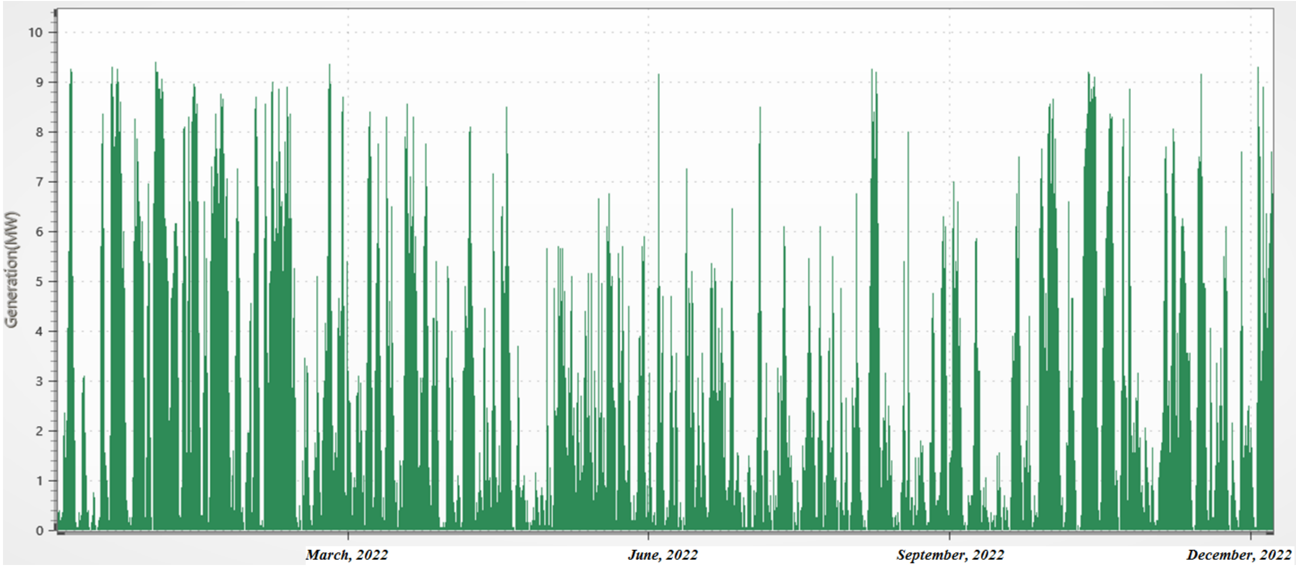

Figure 2: Hourly wind power plant power output [MW]

Other data regarding wind power plant, such as its real location and year for which production data are taken are confidential (authors do not have rights to share that kind of data).

External day ahead market is in referent case modeled using real hourly prices from Croatia Power Exchange (CROPEX) for year 2020 (last 'normal price' year), and in higher price scenario using real hourly prices from Croatia Power Exchange (CROPEX) for period from September 1st 2021 to August 31st 2022 (last 12 months with complete hourly data at time of preparing this paper, therefore called 'high price').

Battery is modeled with following input data: Power: 10 MW; Capacity: 20 MWh; Minimum SoC: 20%; Battery cycle efficiency: 90%; Battery build cost: 125,000 EUR/MW + 375,000 EUR/MWh; WACC (Weighted Average Cost of Capital): 7%; Battery lifetime: 10 years.

6 Results and discussion

The investment cost for the battery system is around 12.46 million EUR (taking into account input data from previous chapter. Therefore, if battery lifetime is 10 years, annualized build cost for battery is equal to around 1.246 million EUR. This value will be important when calculating battery effect on coupled operation net profit.

Table 1 shows expected yearly profit levels for only wind power in place (base case) for two electricity price scenarios. Profit for wind power plant owner was 0.915 million EUR and 5.279 million EUR in 'normal price' and 'high price' scenarios respectively. In this case there were no additional costs (battery is not built) but also there was no additional profit.

Table 1: Base case expected yearly profit for 'normal price' and 'high price' scenarios

Base case	*'normal price' scenario*	*'high price' scenario*
Profit [mil €]	0.915	5.279
Added cost [mil €]	NA	NA
Net Profit [mil €]	0.915	5.279
Net change to Base case [mil€]	NA	NA

Table 2 shows expected yearly profit levels for coupled wind power plant and battery system (energy arbitrage case) for two electricity price scenarios. Profit for wind power plant and battery system owner was 1.039 million EUR and 5.872 million EUR in 'normal price' and 'high price' scenarios respectively. In this case there were additional costs (battery is built) but also there was additional profit. But as it can be seen, even in ‘high price’ scenario net effect on profit is negative, therefore this mode of coupled operation is strongly economically infeasible.

Table 2: Energy arbitrage case expected yearly profit for ‘normal price’ and ‘high price’ scenarios

Energy arbitrage case	*‘normal price’ scenario*	*‘high price’ scenario*
Profit [mil €]	1.039	5.872
Added cost [mil €]	1.246	1.246
Net Profit [mil €]	-0.207	4.626
Net change to Base case [mil€]	-1.122	-0.653

Table 3 shows expected yearly profit levels for coupled wind power plant and battery system that in addition to energy arbitrage can be engaged in price arbitrage (price arbitrage case) for two electricity price scenarios. Profit for wind power plant and battery system owner was 1.099 million EUR and 6.207 million EUR in ‘normal price’ and ‘high price’ scenarios respectively. In this case there were additional costs (battery is built) but also there was additional profit. But as it can be seen, even in ‘high price’ scenario net effect on profit is negative, therefore this mode of coupled operation is still economically infeasible.

Table 3: Price arbitrage case expected yearly profit for ‘normal price’ and ‘high price’ scenarios

Price arbitrage case	*‘normal price’ scenario*	*‘high price’ scenario*
Profit [mil €]	1.099	6.207
Added cost [mil €]	1.246	1.246
Net Profit [mil €]	-0.147	4.961
Net change to Base case [mil€]	-1.062	-0.318

It is obvious from results that coupling wind power plant with battery system brings some additional revenues. But still, even in ‘high price’ scenarios, large investment costs in battery systems make this coupled construct economically infeasible. This cooperation therefore seeks for some additional stimulus, such as investment tax credit [18]. In other words, results from analysis in this paper confirm need for such subsidies, especially due to their beneficial effects on boosting power system flexibility.

7 Conclusion and the future work

High penetration renewable electrical power sources (REPS) levels in power systems issues need for additional power system flexibility. This paper focuses on battery systems as means of boosting power system flexibility. Namely, focus of the paper is assessing potential for increasing REPS power plant, in this case wind power plant, owner profit by coupling REPS power plant with battery system.

Analysis has been executed for two electricity price scenarios – one with ‘normal’ electricity prices (pre-2021 levels) and the other one with current rather ‘high’ electricity prices. Results show that this coupling can increase revenues, but battery system large investment costs, even in ‘high’ price scenario, drag this kind of project into the area of unprofitability. In order for this coupling to be economically feasible certain financial stimulus is required, such as investment tax credit are necessary. In short, results from analysis in this paper confirm need for such subsidies.

It also seems that coupling solar power plants with battery systems makes better synergies than coupling wind power plants with battery systems as proposed in this paper. Therefore, future work will examine coupling solar power plant and battery systems using the same methodology.

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