Bidding Strategies for Virtual Power Plants in the Iberian Electricity Market

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***Abstract*— In recent years, the energy sector has undergone major changes, particularly in Portugal, where there is complete liberalization of the electricity sector. Like in other European countries, a market agent has been created to facilitate trading relations between producer and trader. The Virtual Power Plant (VPP) agent aims to minimize the costs to the trader and maximizes the profits of producers. In this work, five renewable power plants, which are contractually linked with a VPP, are analyzed to verify the profitability of these contracts for both parties. Using this framework, an analysis is carried out examining the differences between actual renewable production and the planned (forecasted) production. In some instances, there are significant deviations between actual and forecast production and this results in higher costs. Consequently, the greater the deviations, the greater the expenses and, therefore, the lower the profit of each party. Thus, new bidding strategies that result in the reduction of these differences are sought. The bidding strategies proposed in this paper involve markets and various types of contracts to deliver the optimal solution that results in higher profits for both parties. The results show an increase in VPP profit on average of 32%.**

Keywords—Iberian Electricity Market (MIBEL), Renewable Energy, Energy Markets, Bidding Strategies, Forecast, Energy Aggregation.

I. INTRODUCTION

A. Motivation, Aims and Background

The consumption of electric energy has been increasing in recent decades. This increase in demand is also reflected in the evolution of the energy markets, which have grown to incorporate increasing competitiveness in the sector which helps to continuously improve the quality of service and reduce energy prices [1].

In recent decades, renewable energy sources (RES) have emerged to become major players in electricity markets while also contributing to greater economic and environmental sustainability. It is widely expected that the penetration of these RES will increase over the coming years as many countries seek to reduce greenhouse gas emissions.

While large-scale RES projects have been able to participate in wholesale energy markets for a number of years, there has been little progress with the inclusion of smaller scale RES projects into the markets. One way of incorporating these projects is to aggregate them together and then enter the market as a single entity [2]. The aggregation of energy is done through a so-called Virtual Power Plant (VPP), which consists of a virtual representation of a mixture of energy resources.

The VPPs enable the aggregator to get closer to its customers by responding effectively to requests for supply/demand of electrical energy [3]. In Portugal, there is a special regulatory regime for renewable energy production that allows the aggregators to act in the market using previously developed forecasts of expected renewable energy production [4]. However, owing to the variable nature of RES, when these agents interact with the market based on forecasts, differences between actual and forecast production may arise and which result in additional costs.

Within competitive energy markets, market-clearing prices are defined by the point of intersection between the aggregate supply curve and the demand curves for producers and consumers respectively [5]. In a competitive energy market, to maximize profits, agents must bid very close to their marginal cost.

However, the energy market is not perfectly competitive because of buyers with defined prices. Therefore, energy companies bid at a price slightly above the marginal cost of production. When a trading agent makes a bid whose cost differs from the marginal value, to take advantage of market weaknesses, this is called strategic bidding [6]. Within competitive energy markets and considering the bidding behavior of the price taker, strategic bidding models for the competitive energy market can be generally classified into four groups: Optimization Models; Equilibrium Models (Game theory); Agent-Based Models; or Hybrid Models [7].

Regarding optimization strategies, there is a diverse set of papers that consider various types of optimization models for bidding strategies in competitive energy markets. Such a bidding strategy of a VPP is considered in [3]. The VPP bids into both energy and ancillary services markets using a range of Distributed Energy Resources (DERs) and Battery Energy Storage Systems (BESS). The authors use a two-stage robust optimization model to determine the price for buying and selling paid by the VPP in each of the contracts to maximize the profit of the VPP.

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Bidding strategies for an aggregator of small-scale distributed energy resources were addressed in [8]. In the paper, wind turbines, solar PV systems and BESS were utilized to help optimally bid into an electricity market. Robust optimization was used and two types of uncertainties were considered, namely fluctuations in generation output from the renewable energy generators as well as the fluctuations in demand due to real-time price signals.

The objective function was to maximize the aggregator's profit over the bidding window and results show that the approach led to higher profits for the aggregator.

Bidding strategies for a system composed of a combination of Concentrated Solar Plants (CSP) and wind farms were developed in [9] for both day-ahead and following day energy markets. The CSP plants bid into the ancillary services market while providing reserve capacity to balance out the output fluctuations from the wind farm. Chance-constrained programming was used and the results showed significant benefits of this joint approach.

Game theory approaches have been widely used to model the interactions between various market agents within energy markets. A thorough review of the various papers published considering game theory and bidding strategies is presented in [7].

A model considering bidding strategy within regional electricity markets was presented by [10]. This paper combined a Mixed Complementarity Problem with Stackelberg competition to maximize the social welfare of the agents within a regional electricity market.

Bidding strategies using multi-agent modelling have also been studied extensively. An agent-based model considering the interactions between generators, retailers, residential customers and the Independent System Operator (ISO) is developed in [11] to maximize social welfare and increase the participation of residential customers in the energy market. Results show that there are significant benefits to both suppliers and consumers using this model.

A multi-agent-based model of electricity markets is presented in [12]. The various agents balance the supply and the demand of electricity through two modes, one using the market-clearing price (assuming no congestion) and one considering the local marginal prices due to congestion through an Optimal Power Flow problem. The profit of the generators is significantly improved using this approach.

Combining various techniques results in so-called hybrid bidding frameworks which have gained popularity over the recent years. A novel hybrid deep-learning framework for energy price forecasting was developed by [13]. Various modules work together to decrease the residual error between the expected and actual price of energy within the Pennsylvania-New Jersey-Maryland (PJM) market.

Another hybrid model which uses a combination of an Artificial Neural Network and an Artificial Cooperative Search (ACS) algorithm was proposed by [14]. The model is tested on a year-long data set from the Ontario electricity market and showed significant prediction ability.

The European Commission (EC) has recognized that Local Energy Communities (LECs) can play a significant role in energy management services [8]. As such the EC has recommended that the rules about the market and grid operation be adjusted to incentivize increased flexibility within the electricity system.

A Local Energy Market (LEM) can provide this flexibility and have the following advantages: increase in the amount of self-generated electricity, increased consumption of locally generated electricity, improving the local economy, and development of smart grids. Local markets have been used to lower customer costs and manage DR programs [9].

B. Contributions and Paper Organization

Numerous bidding strategies have been developed, as can be seen from the literature review, however, very few of them consider increasing the flexibility of the energy contracts as well as such a diverse portfolio of renewable energy projects in the Iberian energy market (MIBEL).

Thus, this paper has the following main contributions:

- Development of a new bidding strategy focused on reducing the costs of energy deviations, which result in higher profits for the producer and VPP, focused on making established contracts more flexible.
- Perform an extensive analysis based on a real case study of a Portuguese VPP with renewable energy resources, participating in the Iberian electricity market.

The rest of the paper is organized as follows: Section III contains the strategic framework and mathematical model underpinning the bidding strategy. The results from this model are shown in Section IV while Section V contains the conclusions and recommendations for future work.

II. Strategic Framework

A. Portuguese energy market

This work focuses on the Portuguese wholesale energy market which is a part of MIBEL along with Spain. Specifically, the day-ahead (DA) market is managed by the Iberian Market Operator (Spain) (OMIE) and it is a double-sided market in which the agents can submit hourly energy bids for the next 24 hours [15].

Gate closure for the energy bids is at noon the day before delivery and these bids are then submitted to the EUPHEMIA (Pan-European Hybrid Electricity Market Integration Algorithm) platform. EUPHEMIA clears both the offers and prices to maximize social welfare and ensuring that the power flow limits between the various bidding areas are not surpassed. The market-clearing prices are issues at 13:00 and then the physical bilateral contracts are considered. Before 16:00 the transmission system operators (TSOs) examine the power flows and congestion management issues. If network problems are identified, a combination of market and/or technical mechanisms can be utilized. In the case of MIBEL, market splitting may occur between the Portuguese and Spanish markets if network issues are identified.

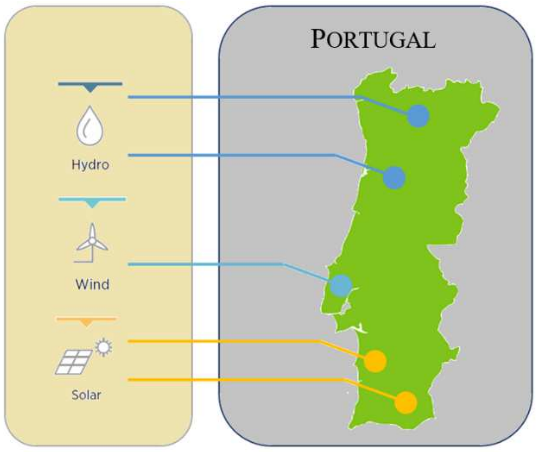

Fig. 1 – Location of the five selected power plants in Portugal.

B. Strategy and formulation

This paper considers a VPP which aggregates five renewable generators spread throughout Portugal. The projects are shown in Fig.1.

They are composed of two solar PV projects in the south of the country, a wind farm in the center and two hydroelectric plants in the north of Portugal. A major obstacle to the ubiquitous adoption of renewable energy is the variability of its generation output and the associated uncertainty that this introduces into the energy system.

This uncertainty means that there will always exist differences between the forecasted or predicted output of a variable renewable energy generator and the actual output and these differences are due to numerous factors, including metrological conditions. These differences or deviations introduce uncertainty and thus extra costs for both the producer and aggregator. For this reason, bidding strategies are needed to minimize these deviations and thus minimize the extra cost burdens placed on the generators and the aggregators. The VPP sits between the producers and the day-ahead MIBEL market.

The VPP has different contracts with the various generators and in this paper, two main contracts are considered. These are fixed-price or power purchase agreements (PPA) or representation contracts (RP) where variable fee (in EUR) is charged on the energy produced depending on certain conditions within the contract.

These two contracts vary in the way they calculate the producer's income which in turn affects the income of the VPP. Mathematically, these two contracts are shown in (1) and (2).

In (1) the producer's profit *(ProdProfit)* is calculated by the product of the contracted price, λ_t^{FPC} and the amount of electricity generated by the producer, $P_t^{ProdGen}$. The RP contracts are shown in (2) where λ_t^{OMIE} and λ_t^{fee} are the following day's market price for that specific hour and the variable rate according to the energy produced, respectively. The total generation for that specific hour is given by $P_t^{TotalGen}$.

$$ProdProfit_t^{FPC} = \sum_{t\in\Omega^t} \lambda_t^{PPA} \cdot P_t^{ProdGen} \quad (1)$$

$$ProdProfit_t^{RC} = \left(\sum_{t\in\Omega^t} \lambda_t^{OMIE} \cdot P_t^{ProdGen}\right) - \left(\lambda_t^{fee} \cdot P_t^{TotalGen}\right) \quad (2)$$

The profit of VPP is calculated using (3)-(6). Equation (3) represents the profit of the VPP and it is the total profit generated from selling electricity minus the profit allocated to the producer. Equation (4) explains how the total profit is derived using the OMIE profit plus the gains from the deviations. The profit obtained from the OMIE in the day-ahead market is presented by (5).

Finally (6) presents the value of deviations, where $|P_{t,a}^{ProgGen}| - |P_{t,a}^{Production}|$ are the deviations, λ_t^{OMIE} is the hourly marginal price of the daily market given by the intersection of the buying and selling offers, SRR_t is the amount of secondary regulation reserve, RR_t is the regulation reserve, and AC_t^{VPP} is the factor of the imputation of the extra costs.

$$VPP_t^{Profit} = Total_t^{Profit} - ProdProfit_t^{RC} \quad (3)$$

$$Total_t^{Profit} = OMIE_t^{Profit} + Deviation_t^{Value} \quad (4)$$

$$OMIE_t^{Profit} = \sum_{t\in\Omega^t} \lambda_t^{OMIE}\, P_t^{ProdGen} \quad (5)$$

$$Deviation_t^{Value} = \left(|P_{t,a}^{ProdGen}| - |P_{t,a}^{Production}|\right) \cdot \lambda_t^{OMIE} \cdot (SRR_t + RR_t) \cdot AC_t^{VPP} \quad (6)$$

To minimize these deviations and maximize profits, a novel bidding strategy is created. This new strategy consists of a better use of the market, to make the established contracts more flexible. Thus, the structure of the strategy consists of, identifying if the cost of deviations is negative or lower than the initial fee then the initial fee will be maintained. If the cost of deviations is higher, it is changed to the cost of the deviations of the previous month. For this, for each production plant, the deviations are calculated and their valuation. This allows the calculation of each participant's earnings as well as the market profit.

For each plant, the annual balance is determined by gathering the monthly information. In the base case, the studies are made only based on SPOT market prices. The results of the strategy are presented in the following section.

III. Numerical Results

A. Data

In this paper five renewable power plants are analyzed, two hydro plants, two solar plants and one wind plant, using production data gathered over one year. The power plants are spread throughout Portugal and real data from these plants are used in the strategies. Table I shows the main contractual information for each power plant. For each plant, the calendar year of 2019 is analyzed. The PV2 plant only began operating in February 2019. Therefore, the month of January 2020 was included in this plants analysis to complete the 12 months of production behavior under analysis. The names of the plants have been modified to protect client anonymity.

B. Base Case

This case served as a baseline to evaluate the effect of the proposed bidding strategy. This case examined the deviations between the forecast and actual production, the valuation and cost of production, the benefits due to the organized market and the profit of each participant based on the type of contact.

1) Hydropower Production

In Fig. 2 and 3, it is possible to see the behavior of the HYDRO1 and HYDRO2 plants, relative to the expected and actual production values. Based on these values it is possible to calculate the deviations, which are shown in the respective figures. These plants have different types of contract, one has a fixed price and another has a fixed fee.

TABLE I. CONTRACTUAL INFORMATION FROM THE 5 POWER PLANTS.

Power Plant	Technology	Type of Contract	Fixed Price or Fee	Operating since
HYDRO1	Hydro	PPA	55 €/MW	5 May 2018
HYDRO2	Hydro	RP	2 €/kWh	8 June 2017
PV1	Solar	PPA	40 €/MW	26 October 2017
PV2	Solar	RP	2 €/kWh	30 January 2019
WIND	Wind	RP	1.5 €/kWh	3 August 2017

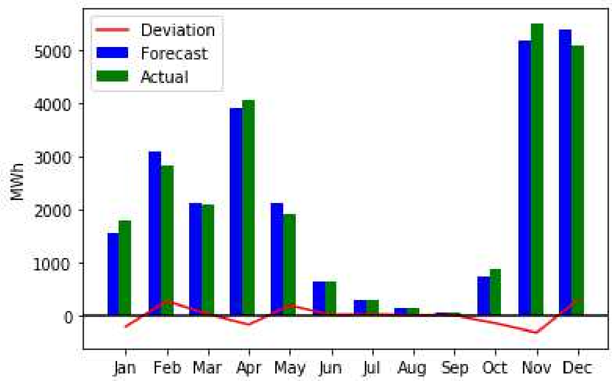

Figure 2 - Analysis of the HYDRO1 plant for 2019.

TABLE II. MONTHLY ANALYSIS OF THE HYDRO1 AND HYDRO2 PLANTS.

		OMIE Profit	Value of Deviations	Total Profit	Cost of Deviations	Dev. from the Forecast (%)	Producer Profit	VPP Profit
HYDRO1	January	100 567.71 €	-2 226.89 €	98 340.82 €	-1.42 €	-13.6 %	97 804.71 €	536.11 €
	February	170 256.63 €	32 017.98 €	202 274.60 €	10.35 €	8.7 %	155 284.94 €	46 989.67 €
	March	107 869.34 €	13 601.56 €	121 470.91 €	6.42 €	1.2 %	115 139.20 €	6 311.71 €
	April	197 647.73 €	11 425.95 €	209 073.68 €	2.93 €	-4.5 %	223 843.54 €	**-14 769.86 €**
	May	101 397.06 €	14 799.22 €	116 196.28 €	7.02 €	9.0 %	105 502.10 €	10 694.18 €
	June	31 843.05 €	4 178.92 €	36 021.97 €	6.42 €	1.8 %	35 165.90 €	856.07 €
	July	16 353.74 €	2 456.43 €	18 810.17 €	8.08 €	6.3 %	15 661.66 €	3 148.50 €
	August	6 442.92 €	987.84 €	7 430.76 €	7.10 €	4.9 %	7 278.15 €	152.61 €
	September	2 554.50 €	706.61 €	3 261.11 €	11.97 €	4.7 %	3 092.51 €	168.60 €
	October	35 895.65 €	766.05 €	36 661.70 €	1.04 €	-20.1 %	48 596.49 €	**-11 934.79 €**
	November	216 375.78 €	1 726.59 €	218 102.36 €	0.33 €	-6.4 %	302 067.43 €	**-83 965.06 €**
	December	174 251.84 €	28 699.99 €	202 951.83 €	5.34 €	5.5 %	279 317.09 €	**-76 365.26 €**
HYDRO2	January	103 292.86 €	4 051.05 €	107 343.91 €	2.12 €	-2.5 %	118 449.28 €	**-11 105.37 €**
	February	157 448.94 €	7 375.72 €	164 824.66 €	2.57 €	1.9 %	149 270.29 €	15 554.37 €
	March	117 925.88 €	17 184.36 €	135 110.24 €	7.20 €	11.1 %	100 553.31 €	34 556.93 €
	April	148 179,73 €	11 364.37 €	159 526.10 €	3.81 €	5.5 %	135 645.52€	23 880.58 €
	May	112 666.12 €	4 536.36 €	117 202.48 €	1.96 €	0.6 %	106 457.63 €	10 744.86 €
	June	36 068.39 €	661.05 €	36 729.44 €	0.86 €	-6.4 %	36 576.02 €	153.43 €
	July	18 386.45 €	3 180,63 €	21 567.07 €	8.95 €	9.3 %	15 950.87 €	5 616.20 €
	August	9 777.57 €	2 535.23 €	12 312.80 €	11.63 €	2.9 %	9 096.27 €	3 216.53 €
	September	3 907.17 €	**-616.76 €**	3 290.41 €	**-6.65 €**	-39.0 %	5 183.74 €	**-1 893.33 €**
	October	16 015.83 €	**-1 348.75 €**	14 667.08 €	**-3.92 €**	27.0 %	19 982.06 €	**-5 314.98 €**
	November	141 331.16 €	834.06 €	142 165.22 €	0.25 €	-4.0 %	137 385.23 €	4 779.99 €
	December	119 800.95 €	3 535.50 €	123 336.45 €	1.01 €	0.3 %	111 996.57 €	11 399.88 €

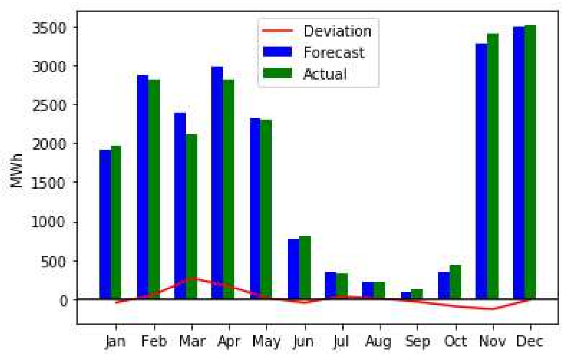

Figure 3 - Analysis of the HYDRO2 plant for 2019.

Table II shows the value of the deviations, the costs that the trader has with the deviations, as well as the producer and VPP profit for both plants. The value of the deviations for both plants are shown in Table II and that these values are either positive or negative. In the case of HYDRO1, the profit in January is lower than initially foreseen (due to the negative value of the deviations). In HYDRO2 the profit is lower than that initially foreseen in September and October. In the remaining months, the expected profit is positive.

Regarding the costs borne by the trader, due to the difference between the forecast and the actual production, these will be included later in the calculation of the gains of the producer. The monthly balance of earnings for the renewable producers and VPP, with a fixed price of 55 euros/MW in the case of HYDRO1 and the fixed fee of 2 euros is presented in the table. It can be seen that the profit of VPP in April, October, November and December is negative for the HYDRO1 plant, which shows that the producer has incurred losses based on the current contract. Based on Table III, it is possible to verify the annual profit of the VPP including the losses of the HYDRO1 hydroelectric power plant. This information points to the conclusion that the price contracted by both parties, namely €55/MW, should have been lower. The HYDRO2 plant, on the other hand, using a fixed fee results in profit for both parties.

TABLE III. ANNUAL SUMMARY OF HYDROPOWER PLANTS (€).

	HYDRO1	HYDRO2
Total from the program	25 207. 59	21 028.45
Total production	25 250.07	20 857.49
Total deviations	- 42.48	170.96
Deviations Valorization	109 140.24	53 274.81
Cost of program deviations	4.33	2.53
OMIE Total profit	1 270 596.18	1 038 075.86
Producer's profit	1 388 753.71	946 546.78
VPP Profit	**-118 157.53**	91 529.08

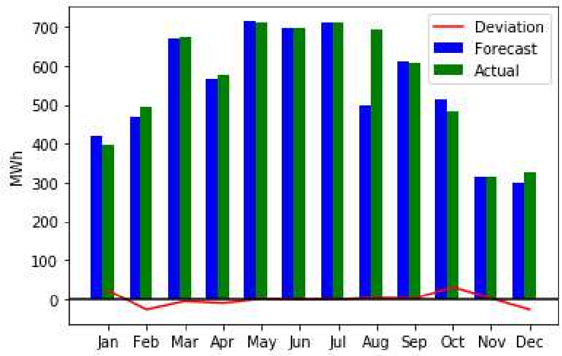

Figure 4 - Analysis of the PV1 plant in the year 2019.

2) Solar Power Production

The PV1 and PV2 plants use photovoltaic technology. In Fig. 4 and 5, the actual production of both plants compared to the expected production are shown. These plants use different types of contracts as was presented in Table I.

In Table IV the deviations are presented as well as the OMIE profit, the producer and VPP profit. From the analysis of the table it can be seen that for both plants, the monthly profit is positive as the actual production exceeds the expected production. Except for February in the PV2 plant, due to the type of contract, the plant suffers a loss in February.

Table V compares the plants annually and shows that there are profits for both PV plants even though they utilize different types of contracts. This is not the case for the hydroelectric plants.

TABLE IV. MONTHLY ANALYSIS OF THE PV1 AND PV2 SOLAR POWER PLANTS.

		OMIE Profit	Value of Deviations	Total Profit	Cost of Deviations	Dev. from the Forecast (%)	Producer's Profit	VPP Profit
PV1	January	27 159.99 €	3 402.53 €	30 562.52 €	8.07 €	5.3 %	15 968.02 €	14 594.50 €
	February	26 046.48 €	1 064.16 €	27 110.64 €	2.27 €	-5.8 %	19 794.19 €	7 316.45 €
	March	33 107.41 €	961.35 €	34 068.76 €	1.43 €	-0.8 %	27 029.14 €	7 039.62 €
	April	29 679.20 €	3 606.70 €	33 285.90 €	6.36 €	-1.9 %	23 124.39 €	10 161.51 €
	May	28 592.94 €	1 654.11 €	30 247.05 €	2.31 €	0.1 %	28 592.94 €	8 359.48 €
	June	32 655.94 €	1 616.23 €	34 272.17 €	2.32 €	-0.1 %	27 878.89 €	6 393.28 €
	July	37 847.17 €	1 134.23 €	38 981.40 €	1.59 €	0.0 %	28 463.29 €	10 518.11 €
	August	32 058.34 €	1 579.17 €	33 637.51 €	2.26 €	0.6 %	27 725.58 €	5 911.93 €
	September	25 853.85 €	1 308.89 €	27 162.74 €	2.14 €	0.4 %	24 391.97 €	2 770.77 €
	October	23 993.16 €	3 478.36 €	27 471.52 €	6.77 €	6.1 %	19 295.35 €	8 176.17 €
	November	13 961.87 €	2 642.28 €	16 603.16 €	8.38 €	0.7 %	12 526.82 €	4 076.34 €
	December	11 249.82 €	1 263.84 €	12 513.67 €	4.22 €	-8.9 %	13 058.62 €	-544.95 €
PV2	February	63 321.44 €	1 901.66 €	65 223,10 €	1.67 €	-8.5 %	66 225.13 €	**-1 001.03 €**
	March	102 836.41 €	4 742.02 €	107 578.43 €	2.29 €	-0.4 %	99 131.02 €	8 447.41 €
	April	100 994.78 €	11 996.91 €	112 911.69 €	6.12 €	1.2 %	95 498.55 €	17 493.14 €
	May	135 136.00 €	9 148.37 €	144 284.37 €	3.34 €	3.1 %	125 247.75 €	19 036.63 €
	June	132 738.91 €	9 031.62 €	141 770.53 €	3.20 €	2.5 %	123 382.95 €	18 387.58 €
	July	140 727.40 €	13 766.61 €	154 494.01 €	5.21 €	7.3 %	125 510.96 €	28 983.05 €
	August	121 794.55 €	10 546.25 €	132 340.79 €	3.97 €	4.6 %	111 050.69 €	21 290.10 €
	September	93 288.40 €	9 566.43 €	102 854.84 €	4.38 €	4.8 %	84 024.94 €	18 829.89 €
	October	71 380.37 €	2 124.09 €	73 504.46 €	1.39 €	-3.4 %	69 974.19 €	3 530.27 €
	November	38 756.35 €	2 675.44 €	41 431.80 €	2.96 €	-1.2 %	37 167.59 €	4 264.21 €
	December	33 800.65 €	7 520.71 €	41 321.36 €	8.38 €	12.3 %	28 187.08 €	13 134.28 €
	January (2020)	39 984.15 €	8 279.61 €	48 263.76 €	7.87 €	-11.8 %	36 200.36 €	12 063.40 €

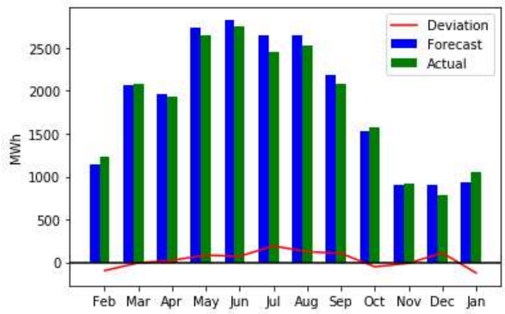

Figure 5 - PV2 plant analysis from February 2019 to January 2020.

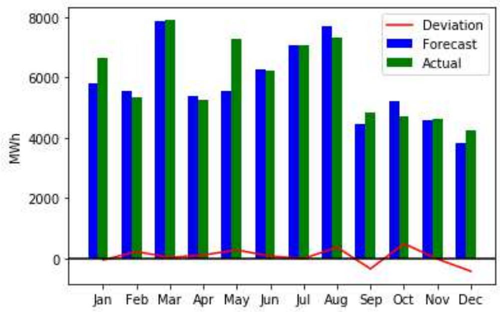

Figure 6 - Analysis of WIND in 2019.

3) Wind power production

Regarding the sole wind farm included in this study, Fig. 6 shows the expected and actual production figures for the WIND power station. From this figure and Table VI, it can be seen that the plant has monthly profit due to the positive deviations throughout the year, except for January September and December. Further detail of the behavior of the WIND plant is shown in Table VI.

However, when looking at the annual profit, shown in Table VII, it can be seen that the contract is overall beneficial to the plant and the VPP as it records a profit.

TABLE V. ANNUAL SUMMARY OF SOLAR POWER PLANTS(€).

	PV1	PV2
Total from the program	6689.45	22 467.14
Total production	6696.23	22 051.32
Total deviations	-6.78	415.82
Deviations Valorization	23 710,83	91 299.72
Cost of program deviations	3.54	4.06
OMIE Total profit	345 917.02	1 166 059.14
Producer's profit	267 849.20	1 001 601.21
VPP Profit	84 773.19	164 457.93

TABLE VI. MONTHLY ANALYSIS OF THE WIND PLANT.

	OMIE Profit	Value of Deviations	Total Profit	Cost of Deviations	Dev. from the Forecast (%)	Producer's Profit	VPP Profit
January	360 025.72 €	**-29 843.93 €**	330 181.79 €	-5.15 €	-14.7 %	402 575.69 €	**-72 393.90 €**
February	300 120.27 €	36 336.35 €	336 456.61 €	6.53 €	4.1 %	278 258.81 €	58 197.80 €
March	389 261.59 €	18 142.09 €	407 403.68 €	2.30 €	-0.4 %	380 161.60 €	27 242.08 €
April	265 565.57 €	20 095.57 €	285 661.13 €	3.74 €	2.1 %	250 491.00 €	35 170.13 €
May	265 179.74 €	26 967.93 €	292 147.67 €	4.86 €	5.1 %	244 172.65 €	47 975.01 €
June	299 437.83 €	17 247.47 €	316 685.26 €	2.74 €	1.2 %	286 475.45 €	30 209.81 €
July	363 329.78 €	12 634.95 €	375 964.74 €	1.79 €	0.0 %	352 765.63 €	23 199.11 €
August	348 513.56 €	29 209.35 €	377 722.91 €	3.80 €	4.8 %	321 673.28 €	56 049.63 €
September	191 560.93 €	1 035.56 €	192 596.48 €	0.23 €	-7.7 %	200 148.17 €	**-7 551.69 €**
October	249 168.97 €	38 246.17 €	287 415.14 €	7.33 €	9.5 %	220 596.82 €	66 818.32 €
November	187 603.79 €	16 629.71 €	204 233.50 €	3.61 €	-0.4 %	178 893.24 €	25 340.27 €
December	127 043.99 €	3 642.06 €	130 686.05 €	0.95 €	-11.1 %	133 627.14 €	**- 2 941.09 €**

C. New Bidding Strategy

In this section, the novel bidding strategy is assessed. The strategy consists of altering the fee charged in the representative contracts, specifically changing the value of the fee according to the cost of the deviations.

This strategy is applied to the power plants with RP contracts. Table VIII displays the plants with RP contracts and their fees. It should also be noted that this strategy only alters the profits for each party. This means that if the cost of deviations is negative or lower than the initial fee, the original bidding strategy is maintained. If the cost is higher, the strategy is changed to reflect the cost of the deviations of the previous month.

Taking this strategy into account, the new fees for each month are calculated by taking the base case as a starting point. The new values of the fees for each month for the different plants are presented in Table IX.

As can be seen, there are months in which the fee is maintained at € 2. In the other months, the fee is altered and therefore the profits will be different. In the HYDRO2 example, the fee was only kept at €2 in two months, having changed in all the others especially in September where the fee reached 11.63 euros. In WIND there are no changes in the fee, €1.5, in January, February and October, with changes in the remaining months. Finally, in Table X the results of the bidding strategy at HYDRO2, PV2 and WIND are presented.

TABLE VII ANNUAL SUMMARY OF THE WIND PLANT (€).

	Annual
Total from the program	69 305.34
Total production	69 413.80
Total deviations	-108.46
Value of deviations	190 343.22
Cost of program deviations	2.75
OMIE Total profit	3 537 154.96
Producer's profit	3 249 839.47
VPP Profit	287 315.49

TABLE VIII. CENTRAL UNITS WITH THE REPRESENTATION CONTRACT

Power Plants	Fee defined in the contract (€/kWh)
HYDRO2	2.00
CNVA 1V	2.00
WIND	1.50

TABLE IX. NEW MONTHLY FEES (€/KWH) FOR HYDRO2, PV2 AND WIND.

	HYDRO2	PV2	WIND
January	**2.00**	**2.00**	**1.50**
February	2.12	**2.00**	**1.50**
March	2.57	2.29	6.53
April	7.20	6.12	2.30
May	3.81	3.34	3.74
June	**2.00**	3.20	4.86
July	2.00	5.21	2.74
August	8.95	3.97	1.79
September	11.63	4.38	3.80
October	2.00	**2.00**	**1.50**
November	2.00	2.96	7.33
December	2.00	8.38	3.61

TABLE X. RESULTS OF THE BIDDING STRATEGY AT HYDRO2, PV2 AND WIND.

	Base Case	New Strategy
HYDRO2	91 529.08 €	114 575.73 €
PV2	164 457.93 €	205 230.48 €
WIND	287 315.49 €	421 833.08 €

IV. CONCLUSIONS

In this paper, five renewable generation plants contracted to a VPP were analyzed to develop a bidding strategy that improves the flexibility of the established contracts. The objective was to find a bidding strategy within the MIBEL day-ahead market so that both the producer and the VPP obtain greater profits, by changing the fee in the representation contracts throughout the year, depending on the cost of deviations. The results showed, relative to the Base Case, that the PPA contacts with a high fixed price, which may result in losses to the VPP. The new strategy developed in this paper has proved to be beneficial for the plants with representation contracts. With the new strategy, for the three renewable energy plants with this type of contracts, the profit of the VPP increased on average 32% compared to the base case. In general, the new strategy provided a better profit distribution for both parties. It should be noted that increasing the flexibility of energy contracts is extremely important, especially in times of great uncertainty surrounding energy demand. If these contracts are not flexible enough, significant financial losses may be seen for all parties due to an abrupt fall in energy prices or demand.

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