Hybrid Power Plant operation through ME4HP implementation in CROSSBOW project

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Abstract

This document presents the main results associated to the final demonstration stage of RES-DU product in the framework of CROSSBOW poject. During this demonstration stage several control strategies have been tested according to the following objectives: i) to supply the power according to different power demand curves, ii) to increment the revenues of the HPP due to energy sale, and iii) to demonstrate the capacity of HPP to provide ancillary services. The demonstration activies have been carried out in the lab of National Technical University of Athens (NTUA) in direct cooperation with its technical and research team. The purpose of this document is to show the results of the tool, demonstrating the main functionalities and highlighting the adaptability of the tool against different plant configurations and operation modes.

Keywords: hybrid power plant, optimization, RES-DU, CROSSBOW, PV, Wind farm, battery, storage, renewable, ancillary services

1. Introduction

ME4HP (Manager Energy for Hybrid Plants) has been developed to provide Power Production Profiles (PPP), thus supporting the operation of a Hybrid Power Plant (HPP) – composed by variable RES (PV and Wind farm), non-variable RES (Biomass and Biogas power plants) and storage units (batteries and hydro pump storage), through different strategies according to the following use cases: i) to supply the power according to different power demand curves, ii) to increment the revenues of the hybrid power plant due to energy sale, and iii) to demonstrate the capacity of hybrid power plants to provide ancillary services.

Besides to support different operation strategies, the main objective of this tool is to maximize the renewable energy penetration in the system energy mix, while the estability and firmness of the grid is guaranteed.

Depending on the use case under consideration the ME4HP inputs are different. These inputs are: i) weather forecast, ii) energy price forecast, iii) power demand forecast, and iv) system operator restrictions.

Figure 1 shows the scheme of the the ME4HP considering its inputs and outputs.

The work described in this document has been conducted by the authors cited above, within the CROSSBOW H2020 project. As main objective, CROSSBOW aims to propose the shared use of resources to foster cross-border management of variable renewable energies (such as photovoltiac and wind) and storage units (such as batteries and hydro pump storage), enabling a higher penetration of clean energies whilst reducing network operational costs and improving economic benefits of RES and storage units.

The demonstration and validation activities have been carryed out in the lab of National Technical University of Athens (NTUA), where PV (1,98 kW nominal power), wind farm (1 kW) and lithium ion battery (2 kW – 2.3h) assets were available. A nominal HPP capacity of 1,2 kW was assumed with the aim of guaranteing certain levels of flexibility, dispatchability and firmness against the power demand and system operator requirements.

2. Use of ME4HP for supplying the required power according to different power demand curves

This use case is focused on demonstrating the flexibility and stability of a HPP when a variable power demand is required. This is a very important point considering that future scenarios are oriented to a 100% renewable power mix without convetional fossil fuel sources, so the required power system flexibility must be provided from this type of power plants or storage assets. Figure 2 shows the results obtained for a specific test considering the power demand curve of the greek power system, rated to the nominal power of the HPP considered in the lab in Athens and the availability of the PV, wind farm and lithium ion battery assets.

The period under demonstration for this test was comprised between 7:30 and 20:00 of 15th April 2021.

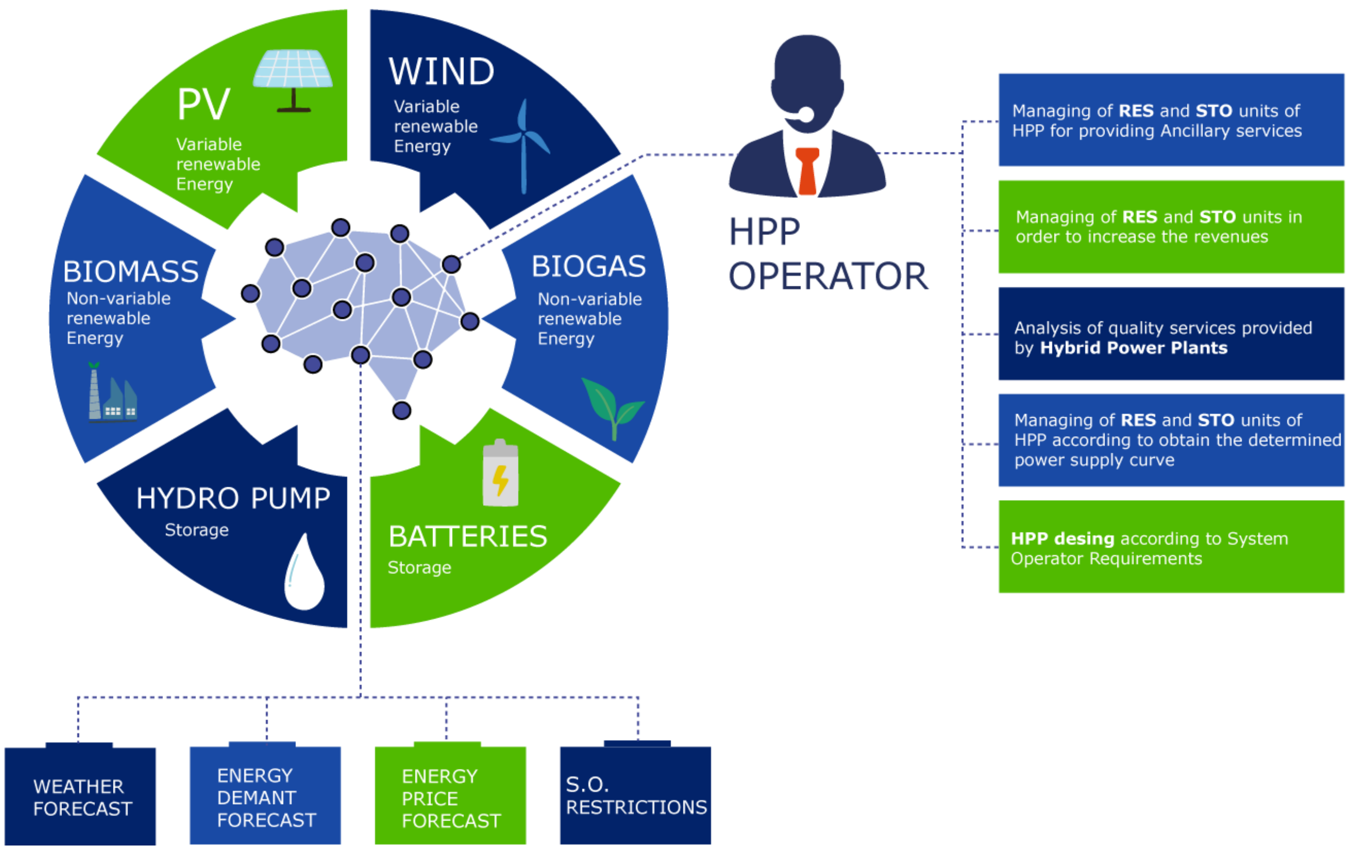

Figure 1 ME4HP – model structure.

Before the test execution the lab operator received the PPP for the whole day, calculated from ME4HP based on the ENTSOe power demand forecast and the weather forecast provided from ICCS (a CROSSBOW partner). This PPP was implemented by the lab operator with the aim of maximizing the correspondence between power generation and power consumption, however, as can be seen in Figure 2 the real power generated from PV (in yellow colour) and wind farm (in blue colour) assets differs from the initial PPP calculated through the ME4HP. The origin of this difference is mainly due to the weather forecast accuracy (estimated 24 hours previously), combined with the characteristic variability and unpredictability behaviour of PV and Wind farm renewable technologies.

This fact shows the limitations of HPP with an only one flexible asset (the lithium ion battery) combined with two different variable RES and remarks the relevancy of carrying out an optimal design of a HPP according to historical data (power demand and weather variables). For this reason, an additional graph combining the real HPP with the incorporation of simulated assets of biomass and biogas power technologies is included in Figure 2. This pseudo simulated configuration demonstrates that if additional flexible and dispatchable (renewable) power is added to the HPP configuration the correspondence between generation and consumption is close to 100%.

Besides the qualitative analysis several KPIs have been calculated with the aim of evaluating the renewable content increment, the accuracy of production forecast (24h in advance), the hybrid power plant flexibility, the hybrid power plant dispatchability, and the hybrid power plant firmness. The corresponding analysis and their associated values have been included in section *KPI calculation associated to previous scenarios*, at the end of the document.

3. Use of ME4HP for incrementing the revenues of the hybrid power plant due to energy sale

This use case aims to demonstrate the HPP profitability and its potential to increase the revenues when it is properly operated, compared to isolated and non-dispatchable renewable technologies such as PV or Wind. For this purpose, the HPP will demonstrate its capacity to sell energy when the electricity price is high and store it when the price is low, employing the dispatchable RES for supporting both non-dispatchable RES and Storage technologies. Furthermore, this capability of the HPPs will be useful to increase the power stability and security of the system, allowing a reduction in the energy cost by avoiding the employment of old and inefficient technologies during peak

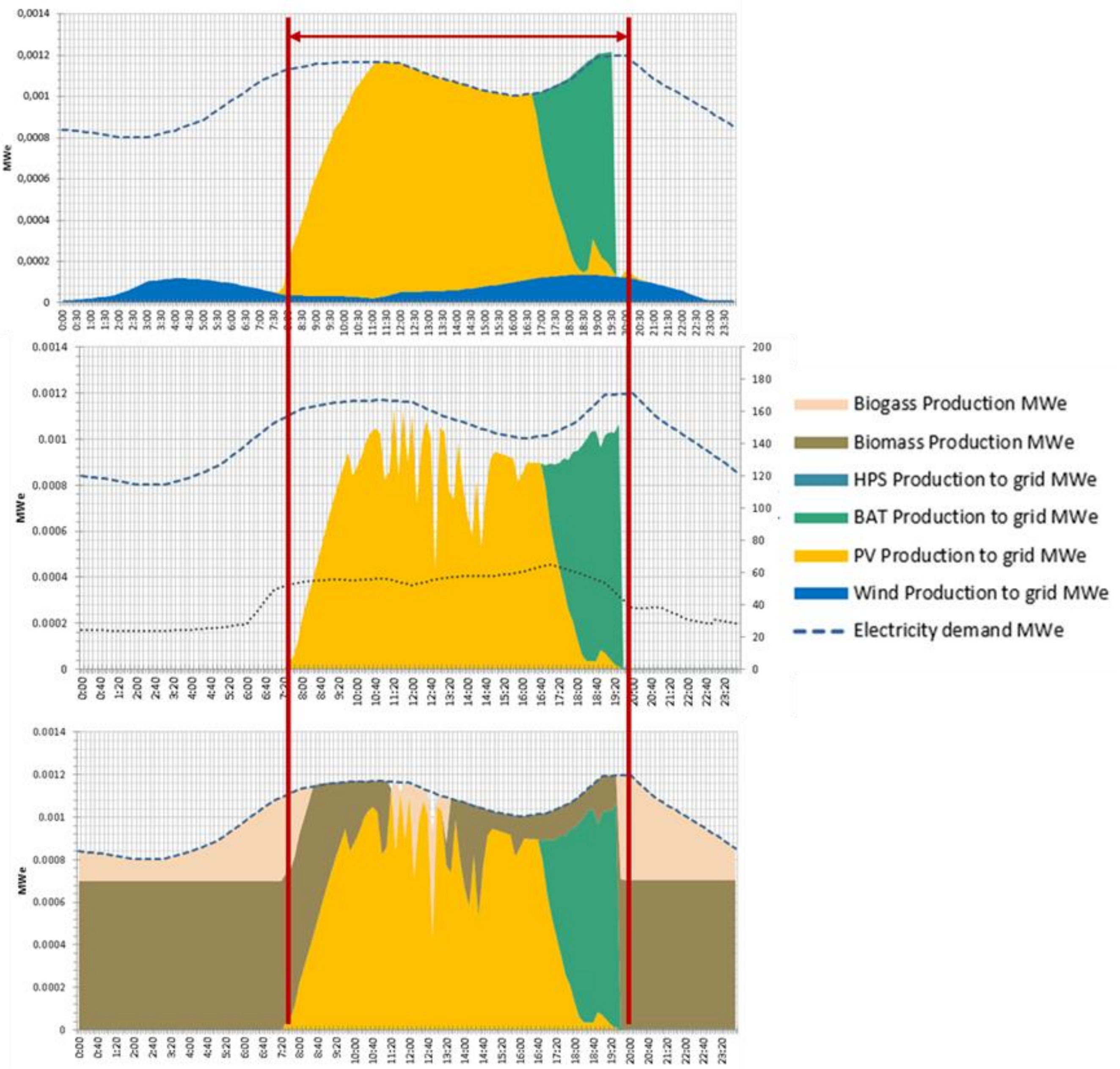

Figure 2. Use of ME4HP for supplying the required power according to different power demand curves. Disaggregated production per technology – 15th April 2021. From top to bottom: theoretical/PPP, real and real + simulated production profiles.

power demand and reducing the costs of increasing generation capacity by reducing peak demand providing power from dispatchable systems. This approach smoothes the generation curve contributing to a more stable generation profile.

Figure 3 shows the results obtained for a specific test considering the energy price forecast curve of the greek power system – published by ENTSOe, and the power demand curve of the greek power system, rated to the nominal power of the HPP considered in the lab in Athens and the availability of the PV, wind farm and lithium ion battery assets.

The period under demonstration for this test was comprised between 7:30 and 20:50 of 26th April 2021. Before the test execution the lab operator received the PPP for the whole day, calculated from ME4HP based on the ENTSOe power demand and energy price forecast, and the weather forecast provided from ICCS.

As can be observed, in this use case as a difference with the previous one, the main input for the PPP optimization is energy price curve instead of the power demand curve. Despite of the power demand curve is covered as far as possible, the major priority is to guarantee that the power production (non-dispatchable originally) is stored during the energy valley prices and injected into the grid when the prices correspond to the daily peak.

The flexibility for applying energy time shifting strategies is mainly due to the integration of a storage unit in the hybrid power plant. Without the support of the storage system the variable renovable power plants (operated in an isolated way) could not offer any optimized PPP.

Figure 3 shows the difficulties for fulfilling the initial PPP, as in the previus use case, due to the lack of accuracy of the 24h weahter forecast services and the unpredictable character of wind and solar resources. However it is important to remark that during the period from 14:30 to 16:00 all the energy produced by the hybrid power plant is stored in the battery due to the energy price correspond with the mimimum value (referenced to the period under demonstration). On this way, the battery can inject a higher quantity of energy after the sunset guaranteing power availability during the peak price of the day. This is the main mechanism for increasing the revenues from the generation side.

Considering the energy price curves in the major part of the european country during the last years, this energy time shifting strategy is not always cost-effective, due to the unefficinecies associated to the charge/discharge process do not compensate the difference between peak and valley prices. However, in the medium term it is expected that in the major part of the south european countries, the named "duck curve" appears as a consequence of the massive PV power penetration in the power systems. In some regions like California, this "duck curve" is a reality.

Besides the qualitative analysis several KPIs have been calculated with the aim of evaluating different aspects of the optimization process. The results can be found in section *KPI calculation associated to previous scenarios*, at the end of the document.

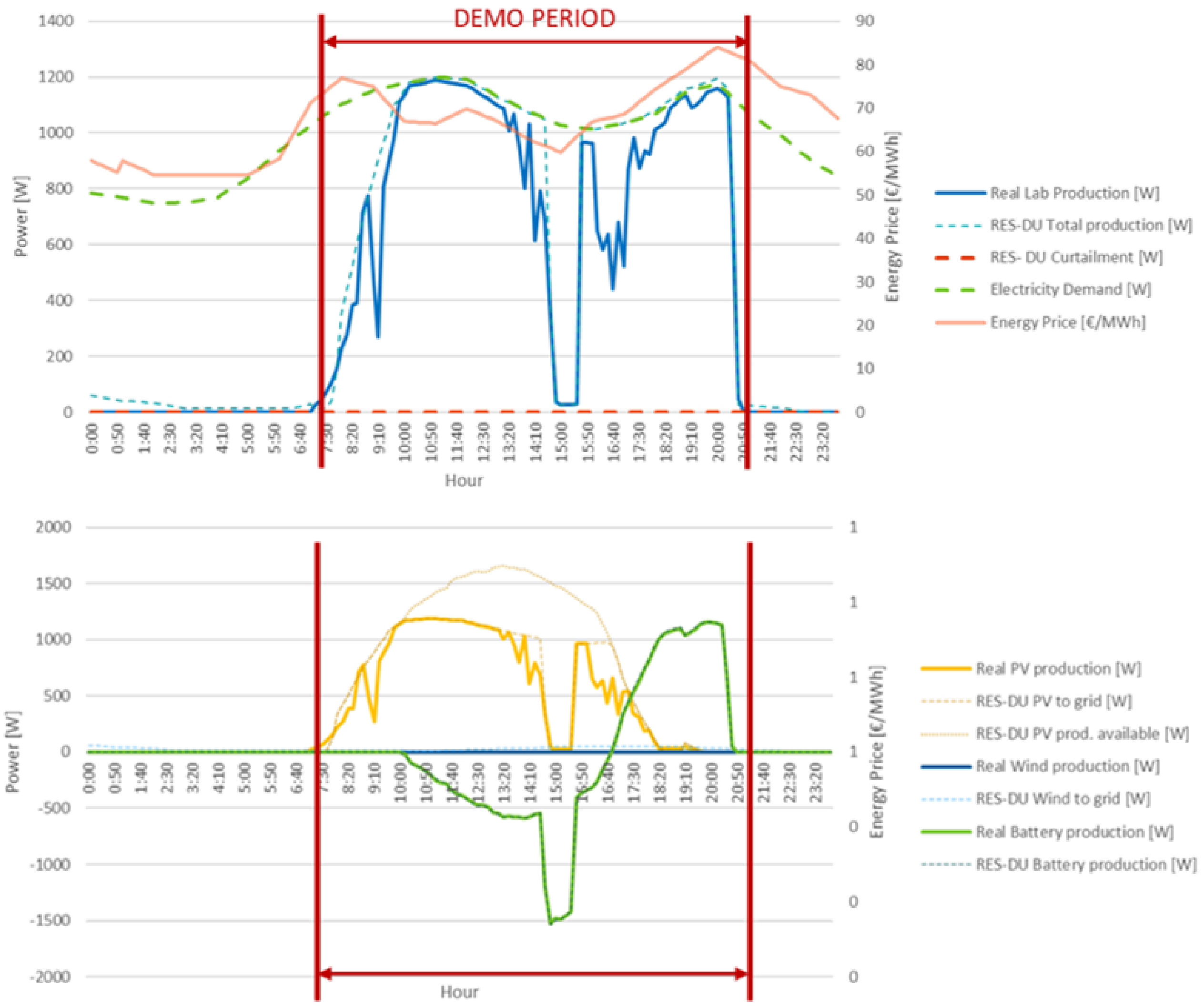

Figure 3. (Top) Total product comparison: PPP vs real; (Bottom) Disaggregated production per technology. 26th April 2021.

4. Use of ME4HP for demonstrating the capacity of hybrid power plants to provide ancillary services

The high penetration of non-dispatchable renewable plants, increases the need to balance the generation and the demand and thus, the need for AS. In this respect, this use case aims to demonstrate the ability of HPPs to combine renewable technologies in order to provide frequency regulation, increasing or reducing the active power generation, when it is requested. In addition, it is demonstrated the capabilities for reducing curtailment, through the use of storage units, once it is requested from the system operator.

Current markets are designed according to conventional generation plants, not considering the participation of renewable technologies or storage systems (i.e. batteries) in the procurement of these services.

Despite the lack of actual regulation to provide AS with RES plants, the ME4HP tool includes a flexible algorithm to modify and re-adapt the PPP of each plant's technologies, in order for them to meet with the power up and down commands that may come from the system operator. At this point, it is important to highlight that the PPPs are re-calculated without interfering with the production scheduled, which was agreed the day before (obviously it is not applicable in case of curtailment management).

Figure 4 shows the results obtained for a specific test considering the energy price forecast curve of the greek power system – published by ENTSOe, the power demand curve

of the greek power system, rated to the nominal power of the HPP considered in the lab in Athens and the availability of the PV, wind farm and lithium ion battery assets. In addition, in this case it is also considered the ancillary services/curtailment requested from the system operator.

The period under demonstration for this test was comprised between 10:00 and 18:30 of 9th July 2021. Before the test execution the lab operator received the PPP for the whole day, calculated from ME4HP based on the ENTSOe

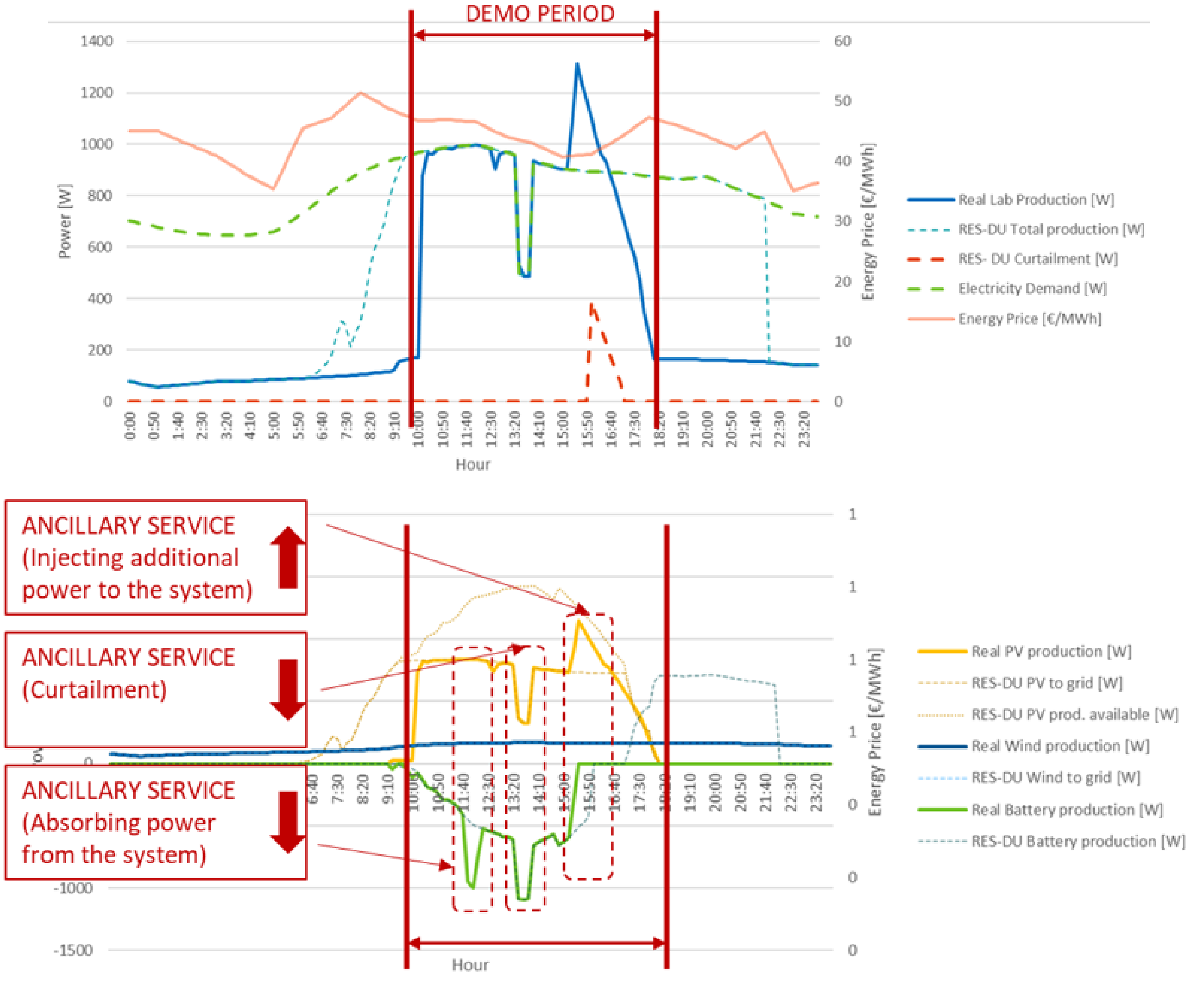

Figure 4. (Top) Total product comparison: PPP vs real; (Bottom) Disaggregated production per technology. 9th July 2021.

power demand and energy price forecast, and the weather forecast provided from ICCS, in a similar way than in the first use case considerd in this document. However, along the day different events appear, and some udpates/recalculations are needed for fulfilling the system operator requirements and guaranteeing the power generation commited day-ahead.

As can be seen in Figure 4, the first ancillary service requested is absorbing power from the power system. This service maintains the whole production of the HPP, but increases the energy stored in the battery because of absorbing the additional power from the power grid. The second event in the day is the application of a curtailment request from system operator. As showed in the previous figure, the PV production is limited for fulfilling the curtailment limitations and the excess of PV production is stored in the battery unit. Finally, the last ancillary service consists of injecting additional power to the system. In this case, the PV production is used to inject the additional power required due to its availability at the required period. This also causes the energy that is being stored in the battery is reduced during that period as it is used to provide the ancillary service.

Besides the qualitative analysis several KPIs have been calculated with the aim of evaluating different aspects of the optimization process. The results can be found in section *KPI calculation associated to previous scenarios*, at the end of the document.

5. KPI calculation associated to previous scenarios

As mentioned in previous sections, besides the quantitaive analysis, a detailed study based on KPI definition considered in “Deliverable 2.2: CROSSBOW Use cases, scenarios and KPIs identification” is contemplated in Table 1.

<table>
<tr><th></th><th>Supply of power according to different curves</th><th>Increment of revenues due to energy sale</th><th>Capacity to provide ancillary services</th></tr>
<tr><td>Renewable content increment</td><td>8-22%</td><td></td><td></td></tr>
<tr><td colspan="4">The percentage of renewable content increment corresponds with the renewable energy (from PV or wind assets) stored in the battery unit. In case of considering HPP with higher storage capacity and higher power of PV and Wind plants, the renewable content increment could be higher than the ratios obtained in this demonstration period.
In case of the concept of HPP managed by ME4HP was not implemented, these ratios of renewable content increment will be traduced in direct renewable curtailment, and generation with the conventional power mix (renewable and non-renewable) in substitution of the storage power discharge period.</td></tr>
<tr><td>Accuracy production forecast</td><td>0-46%</td><td>10-32%</td><td></td></tr>
<tr><td colspan="4">As can be observed this KPI is notably variable, this considerable range is due to the weather forecast accuracy. In those cases where there is a high weather forecast accuracy, the production forecast accuracy is very high; however, in those cases where the weather forecast accuracy is low, the production forecast accuracy is also limited.
During the demonstration stage, there were clear days with good and non- variable solar radiation periods and constant wind velocities, however there were also several days very cloudy, and in this case the weather forecast models reduce their accuracy. The associated weather forecast errors are directly transferred to the power production forecast.</td></tr>
<tr><td>HPP flexibility</td><td>8-25%</td><td>18-57%</td><td>0-30%</td></tr>
<tr><td colspan="4">The flexibility character of the HPP managed according to the ME4HP product is very high, reaching values over 50%.
This KPI is conditioned by the HPP configuration. If the storage capacity and the non-variable RES technologies capacity is high in comparison with the rest of the plant, the power plant flexibility is also elevated.</td></tr>
<tr><td>HPP dispatchability</td><td>67%</td><td>67%</td><td>67%</td></tr>
<tr><td colspan="4">This KPI is a characteristic of the hybrid power plant configuration. According to the assets available in the NTUA Lab the hybrid power plant dispatchability is 67%.</td></tr>
<tr><td>HPP firmness</td><td>0-24%</td><td>3-22%</td><td></td></tr>
<tr><td colspan="4">This KPI shows one of the most important limitation of Hybrid power plants with a high presence of variable renewables sources. As happened during the different demonstration stages in the NTUA lab, the difficulties for having a high accuracy of the weather forecast impact directly in the expected accuracy power production forecast, and consequently the set points suggested to the hybrid power plant operator do not allow to fulfil exactly the power demand target.
In addition, and as demonstrated theoretically, the introduction of biomass and biogas technologies will increase radically this parameter, allowing to reach ratios close to 100%.</td></tr>
<tr><td>Profit increase - optimization</td><td></td><td>0-14%</td><td></td></tr>
</table>

Based on the results obtained there is a high potential for increasing the profit (up to 14%) in comparison with variable and isolated renewable plants, which only can inject the energy in the grid when it is generated (0%). However, the HPP requires higher investment ratios than isolated PV or Wind power plants. This is the real point that will determine the profitability of implementing HPP instead of isolated variable renewable power plants. The capacity of this algorithm is currently limited to the daily price variability among the peak and valley periods, being reduced in power system with low renewable penetration. Despite of in the south-east European countries the renewable penetration is low, it is expected an increment in the following years, contributing to the use of this type of algorithms for maximizing the power plant incomes.

Table 1. KPI summary

Conclusions

ME4HP has demonstrated its functionalities related to i) the supply of power according to different power demand curves, ii) the increment of revenues due to energy sale, and iii) the capability to provide ancillary services. In addition the impact of its implementation has been measured considering the following aspects: renewable content increment, accuracy production forecast, flexibility, dispatchability, firmness and profit increase/optimization.

In general terms, it can be concluded that the HPP implementation, managed through ME4HP, maximizes the renewable penetration in the power system, guaranteeing an increment on terms of flexibility, dispatchability and firmness in comparison with variable renewable plants.

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