# Algorithms for optimized Hybrid Power Plant operation through ME4HP implementation

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## Abstract

This document presents the main algorithms developed in the framework of the ME4HP tool as part of CROSSBOW project. These algorithms are focused on providing different strategies for supporting the Hybrid Power Plant (HPP) operation 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, iii) to demonstrate the capacity of HPP to provide ancillary services, and iv) to demonstrate the functionalites of HPP after a zero voltage event. This document also includes a detailed explanation of the methodology and its implementation in Matlab, considering as main inputs: the weather, energy prices and energy demand forecast, as well as the power system operator constrains. In addition, the results of the tool demonstrate these functionalities and highlights 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 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, iii) to demonstrate the capacity of hybrid power plants to provide ancillary services, and iv) to demonstrate the functionalites of hybrid power plants after a zero voltage event.

Besides to support different use cases, 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.

## 2. Algorithm 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, in comparison with a typical conventional power plant, like the combine cycles, nuclear or carbon power plants, in terms of adapting the power generation to the power demand. Through this use case, it was demonstrated that the HPP concept is an alternative for the

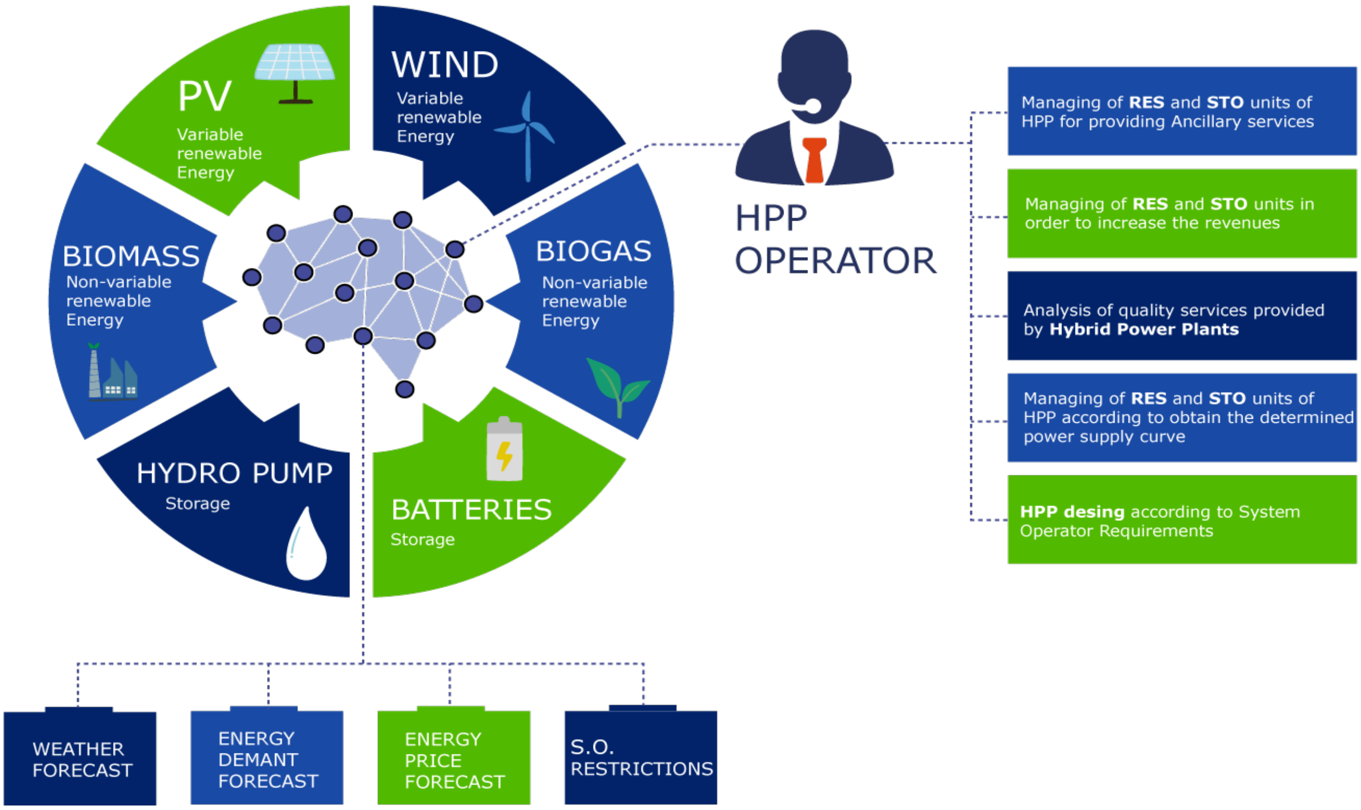

*Figure 1 ME4HP – model structure*

decarbonisation objectives and the maximization of the RES penetration in the European power system.

One of the best ways to demonstrate that HPPs can be considered as a substitute of the conventional power generators, is to verify their capability for covering the power demand of a region or country. Traditionally, carbon, nuclear and combined cycle power plants have provided the total power of a significant part of the power systems around the World. Currently, the presence of these conventional sources is being reduced in the energy mix of different countries to cover a part of the energy demand, since they are required to act as very flexible energy resources allowing to compensate the deviation introduced by the non-dispatchable RES sources.

## *2.1 Methodology and main algorithms.*

The methodology outlined in this case corresponds to the proper management of storage technologies and dispatchable RES to maximize the part of the power demand that is covered by the power production from an existing HPP. On the other hand, the algorithm associated with this use case is based on the maximization of the non-dispatchable RES penetration, guaranteeing that the storage technologies can reduce the curtailment of these technologies and shift the energy to the time of the day where they are least presence. Besides, the dispatchable RES are managed until the end of the process to cover the gaps where the generation and demand are not coupled yet through non-dispatchable RES and storage technologies.

At a more detailed level, this algorithm calculates the expected power production from PV and Wind technologies, for a specific day, based on weather forecast data. Then, it executes the following simulation steps to evaluate the best use of the storage and dispatchable RES technologies:

a. Comparison of the power demand and the power production profile associated with PV and Wind technologies:

a1. Analysis of curtailment and energy time-shifting for establishing the operation strategy of the storage systems.

a2. Establishment of a specific strategy for the battery operation, and simulation of the PV + Wind + Battery system.

a3. Analysis of curtailment and energy time-shifting for establishing the operation strategy for HPS technology.

b. After the process of curtailment minimization and energy coverage maximization, the following analysis of energy gaps is carried out:

b1. Prioritization of Biomass unit operation for energy gaps with a duration higher than 3 hours. This prioritization is justified by the characteristics of this technology, which usually has appropriate times for the processes of start-up and shut-down and due to the fact that according to O&M issues it is not desirable to perform multiple start-ups in a day.

b2. Analysis of the gaps where the generation and demand are not coupled and calculation of the required strategy for the Biogas turbine. Due to the high flexibility of this technology, it is configured to compensate the limitations of the Biomass steam turbine (mainly associated to the ramp-up/down and start-up/shut-down rates).

### *2.2 Results based on historical data.*

In order to test the functionalities of this use case, a representative day has been selected in which originally the production of PV and Wind exceeds the power demand during some hours of the day. The hybrid power plant considered for the analysis results is composed by the following technologies: PV (265MW), Wind (170MW), Battery (125MW/2h), HPS (50MW/6h), Biomass turbine (65MW), and Biogas turbine (65MW). After running this algorithm, for the previously selected day, the results for a flat and a variable demand have been included in Figure 2 and Figure 3, respectively.

As can be observed in Figure 3, the generation profile proposes: i) when Wind production is lower than the demand profile, all Wind production is injected into the grid, ii) when PV + Wind production exceeds demand (i.e.: from 6 am to 4 pm), the curtailment (striped) is stored in the battery (striped green) or the HPS (striped blue), iii) when PV + Wind production cannot cover the demand, it is asked to discharge the storage units, and iv) finally, when there is no stored energy and PV and Wind productions cannot cover the demand, the dispatchable units (Biomass and Biogas) are required to produce energy.

Only a small amount of the energy is curtailed at 2:30 pm (in striped red) because the battery is full and the curtailment at that moment is lower than the pump minimal power: 10% of its nominal power (250MW ·10% = 25MW). The total energy lost due to curtailment is the 0.19% of the total energy produced. It should be noted that the initial SOC of the battery considered in this first scenario is 0%. Thus, the plant does not satisfy the power demand at the beginning of the day. In addition, the solution also can not match generation and demand at the end of the day, because the stored reserves have been consumed. For the examined day, 55% of the daily demand is covered by PV and Wind. This percentage increases by 71% when the energy stored in the batteries and HPS is considered. 25% of the generation is produced with dispatchable units (Biomass and Biogas) and only 4% of demand cannot be satisfied.

The generation profile changes when a flat demand is considered. Figure 2, indicates how the ME4HP operates when the Hybrid Plant is required to operate like a nuclear plant (flat demand). The points where the plant cannot cover the requested demand correspond to the starting times of the gas and steam turbines. As a result, there is a 2% unsatisfied demand.

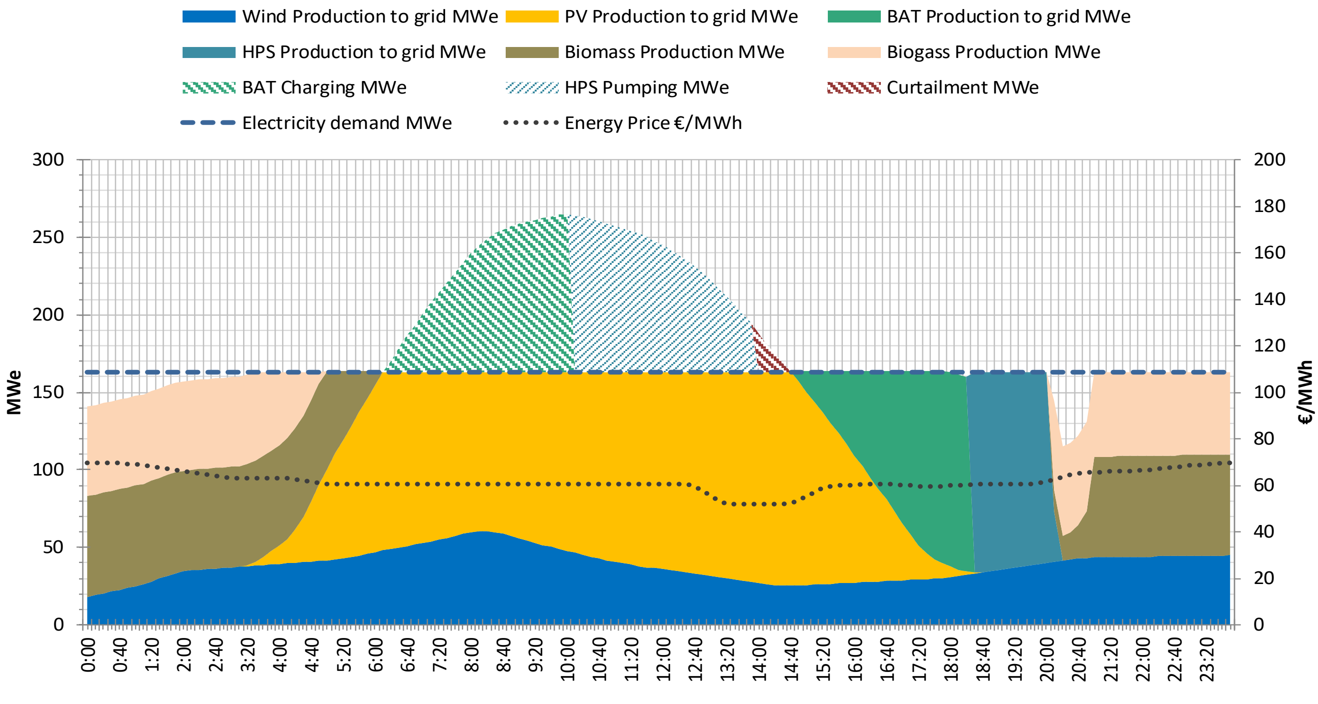

*Figure 2. Daily generation profile with variable demand*

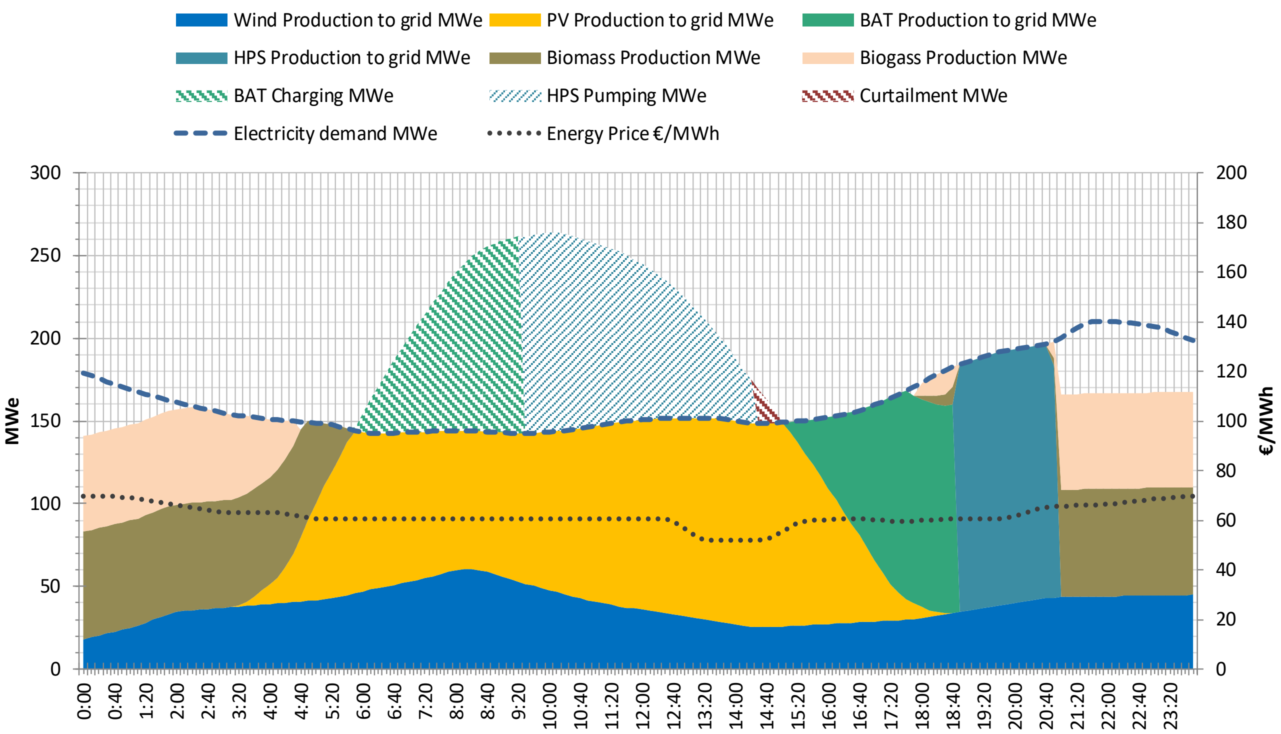

*Figure 3. Daily generation profile with variable demand.*

## 3. Algorithm 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 power demand.

### *3.1 Methodology and main algorithms.*

The methodology applied to carry out this revenue optimization is based on the time-shifting concept. It is focused on identifying the expected time windows when the electricity price is higher and guarantees that the maximum energy production from non-dispatchable RES is generated (by the storage systems) during the expected higher energy prices.

Furthermore, one of the main causes of profit losses associated with the non-dispatchable RES (injecting electricity into the grid when the prices are lower) is strongly reduced. Thanks to the energy scheduling associated with the different technologies, the excess of renewable energy is properly stored and injected into the grid when the energy prices are higher.

Additionally, the algorithm incorporates the ability to calculate the benefit of shifting the energy produced at each instant to periods with higher energy prices. In particular, if the increase in revenue is greater than the losses (due to the charge/discharge efficiencies) during loading/unloading, the algorithm will propose to shift that amount of energy.

Moreover, the dispatchable RES units (Biomass and Biogas) can support generation during preference gaps (the ones with higher prices) of energy generation, covering these days where non-dispatchable RES units are not able to produce the required energy due to unfavourable weather conditions.

At a more detailed level, the algorithm associated with this use case comprises the following steps:

a. Pre-processing: Calculation of four ranges of dayly prices according to the energy price curve of the day, and classification of each time step in previous ranges.

a1. Calculation of the energy generated by the PV and Wind units for each time steps, using individual simulation models developed in the CROSSBOW project [1].

a2. Curtailment calculation for PV and Wind units considering the expected power generation from these RES and the expected power demand for the same periods.

b. Curtailment reduction: Considering previous calculations on the curtailment and the characteristics of the Battery included in the HPP (power and capacity) the algorithm considers in the relevant simulations that the Battery system is charged when curtailment occurs and is discharged (if possible) during the time steps where the energy price is higher. In this respect, an initial strategy for managing the Battery system is established.

c. Revenues Maximization: Taking into account the previous steps, the algorithm indicates the charge mode for the battery during the time steps where the energy prices correspond to the Range with the lowest values, and the discharge mode when the energy prices correspond to the highest energy prices. During the charge mode, the charging power of the battery will be equal to its nominal power, however, during the discharge mode, the selected power for the battery will be the minimum among the nominal discharge power and the nominal power minus the injected power from PV and Wind units.

c1. This same algorithm is applied to HPS technology with similar criteria adapted to the nominal characteristics of this unit. Finally, the last step is oriented to introduce the Biomass and Biogas technologies, which will be focused on covering the power demand, guaranteeing as far as possible the maximum power demand coverage.

### *3.2 Results based on historical data.*

To test the functionality of this use case, a representative day has been selected with a potential difference among the energy prices during the day (it has been assumed an electricity price of 15€/MWh during the central hours of the day). Using this algorithm, it is expected a solution in which the production profile optimizes the reserves stored in the battery and in the HPS, which will be discharged only during peak hours.

The HPP configuration selected for this demonstration is the same than in previous use case, but without biomas/biogas assets (in order to see how the optimized operation of the storage systems can improve the incomes of the plant).

The following two figures, Figure 4 and Figure 5 indicate the results of with the application of this algorithm compared to the default strategy of injecting the stored energy as soon as possible after storing the potential curtailment.

After applying this algorithm, the Battery and HPS units have stored the energy during the curtailment period. However, in contrast with Figure 4, the stored energy is not injected to cover the energy demand as soon as possible, but it is injected when the energy price is higher at the end of the day – in this case.

This energy time-shifting has been carried out through the proper management of the PV generation and the Battery and HPS units because Wind production for this day is considerably low. On the other hand, the Biomass and Biogas energy may provide the required support for generating

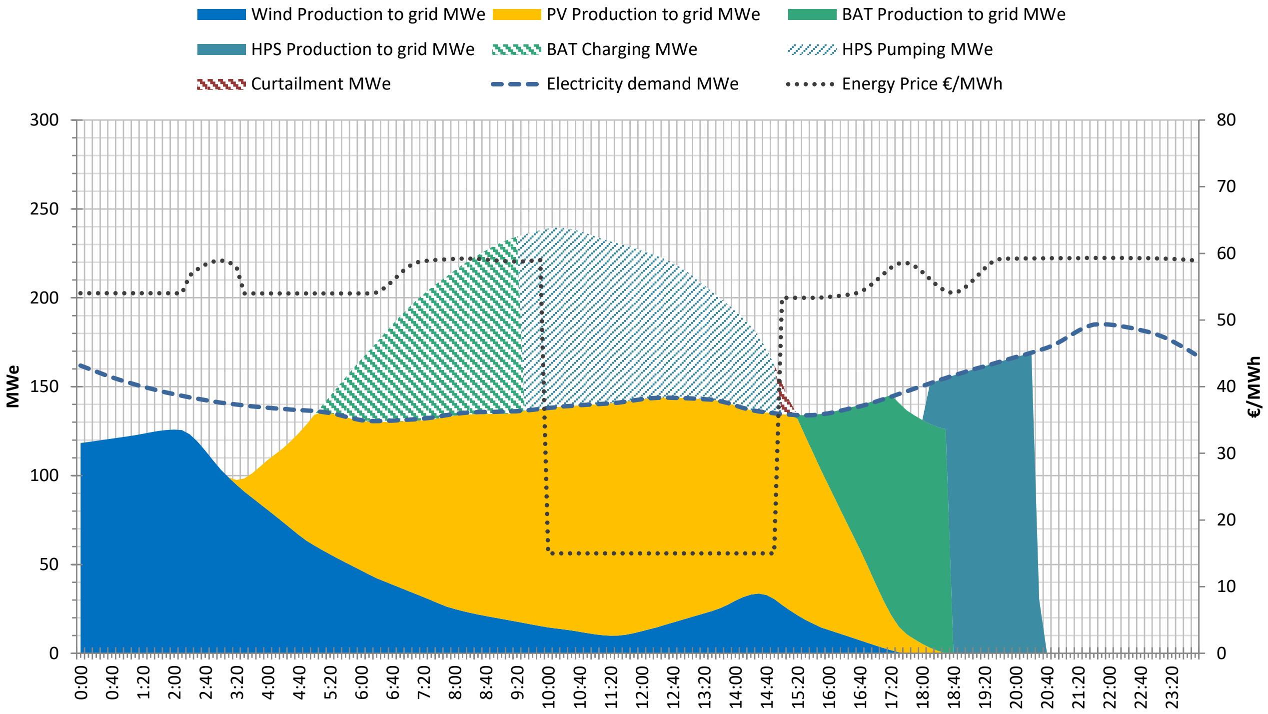

*Figure 4. Default strategy for storage units*

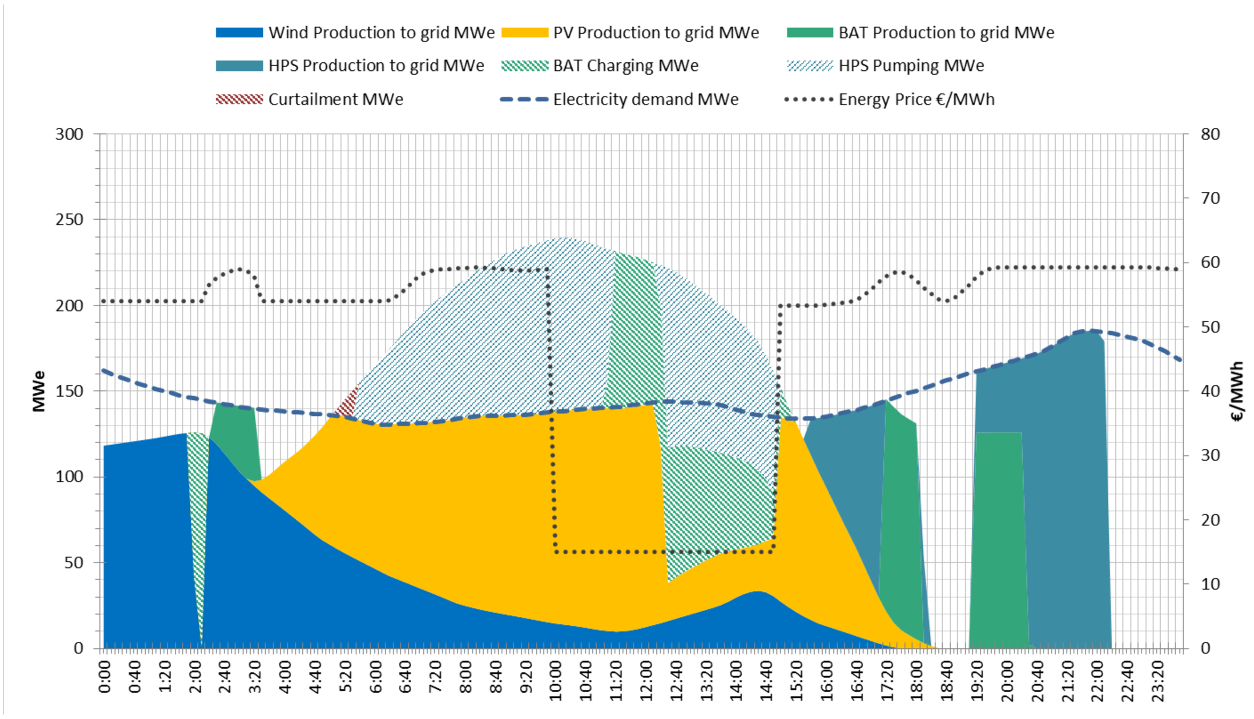

*Figure 5. Application of specific strategy for storage units*

energy during the rest of the day, trying to cover the power demand as much as possible. It can be noted that the curtailment has not disappeared completely due to the technical minimum of the storage technologies, Battery and HPS.

Thanks to the optimisation in the management of the storage systems, the plant's incomes increases by just over 5%/per day. This value will be higher if the difference between peak and valley periods increases, which is expected once the PV technology maximizes its presence in the energy mix of each power system.

## 4. Algorithm for demonstrating the capacity of hybrid power plants to provide ancillary services

The high penetration of non-dispatchable renewable plants, with an availability which is difficult to be predicted, increases the need to balance the generation 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 when it is requested.

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.

### *4.1 Methodology and main algorithms.*

The methodology and instructions followed to adapt the plant operation, in order to provide AS is as follows:

a. In case of increased output power:

a1. If curtailment exits, the surplus production (from the PV or Wind plant) will be used to increase the power.

a2. If there is no curtailment (or in case it is not enough), the battery will be discharged (if the battery is available for such an operation).

a3. In the last case, the Gas Turbine shall operate. The start-up time may vary according to its current status (cold or warm).

b. In case of a decrease in the power output:

b1. Only the battery will be able to absorb energy. Compliance with the agreed production schedule is possible if the battery is not fully charged and if it is not being discharged (at that moment)

It is significant to mention that the most important point is to verify if the HPP can (or cannot) provide the required AS considering the power production, which was agreed the day before (day D-1).

Furthermore, as there is not a standard AS market (variations are noted according to each country) some variables, such as response time or the duration of each service, can be modified by the user to properly adjust the parameters to the market to be simulated.

### *4.2 Results based on historical data.*

Battery Management to provide as: The battery installed in the HPP is used to provide two different services: i) Load-shifting: Moving energy from periods with curtailment to others when the demand is not satisfied. These charge/discharge commands, for the day D, are agreed/calculated during the day before (D-1), and ii) Back-up for provision of AS. Charging and discharging energy according to the AS orders from the grid operator. These profiles must be calculated in real time during the day D.

Since these two services may occur at the same time, the user must decide on the day D-1, what percentage of the battery is used for load shifting and what percentage will be allocated or reserved for AS supply during day D. In any case, the three following operational restrictions must be ensured:

1. The sum of the power used to charge/discharge, at a certain time “T”, cannot exceed the nominal power of the battery. For instance, if a 125 MW battery is charging at “T” time with a power of 100 MW during the normal operation, the maximum power available to provide AS at that moment will be 25 MW. The same rule applies for discharge.

2. The energy stored in the battery (as a sum of the normal operation and the AS provision) cannot exceed the total capacity of the battery (MWh).

3. The battery cannot charge and discharge at the same moment. It means that if the battery is in charge mode at a certain time “T” (to comply with the agreed production schedule, agreed the day D-1), that battery will not be available for discharging during this period “T”.

Considering these limitations, the algorithm divides the existing battery into two sub-systems: a battery model for load shifting operation and another one which is used as a backup to provide AS. This partition is realised by distributing the capacity of the battery in two parts.

Finally, the battery’s initial state of charge shall be considered. More specifically, the algorithm has been programmed to allocate as much energy as possible into the partition of the battery aimed to provide AS.

Figure 6 shows an example where the algorithm does employ all the stored energy at the beginning of the day, although this energy could have been used in that moment to cover the demand, instead of using the GT. Nevertheless, this energy is stored to provide AS during the day ahead.

Thanks to these reserves, the plant can realise, for example, a power rise of 50 MW at 2 am. The graph in Figure 6 also indicates how the battery is affected. Nevertheless, it can be observed that the normal generation has not changed and that the only effect that can be noticed is the decrease in the battery’s SOC at 2 am (dotted black trend). As explained earlier, this drop is linked with the capacity reserved for AS and therefore it does not compromise the capacity for load-shifting.

Moreover, another noteworthy event takes place at 11:40 am. Since the level of reserves is less than 50% at this particular time, the algorithm advises the operator to charge

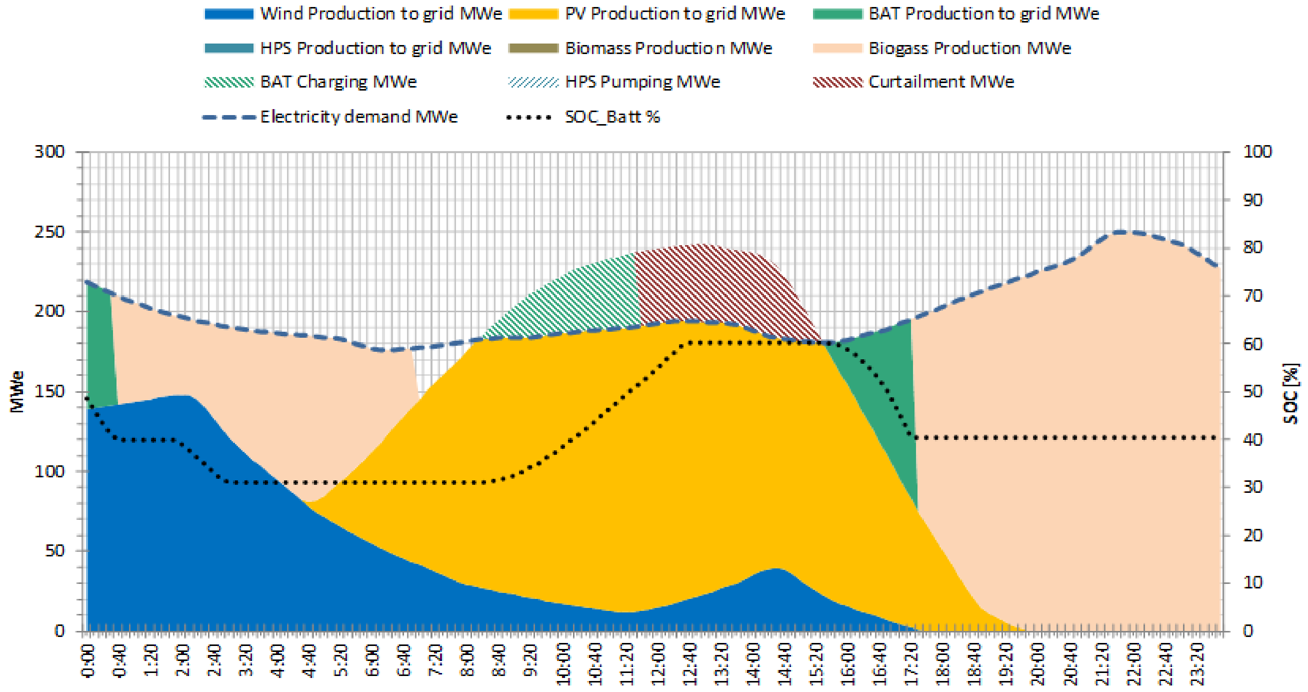

*Figure 6. AS requested at 10 pm (raising 65 MW for 1h). Generation profiles*

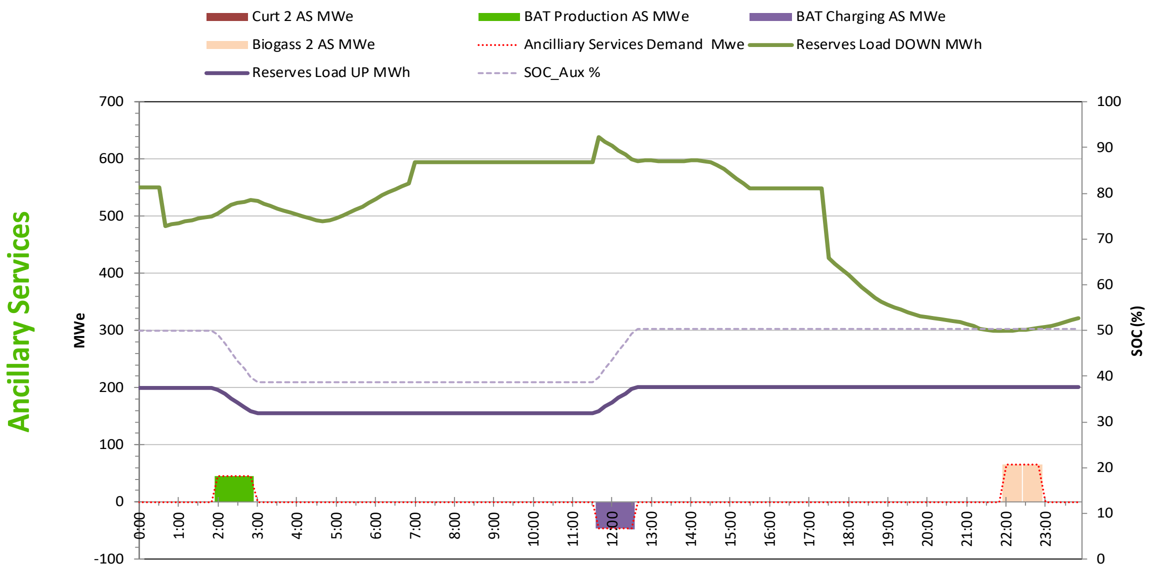

*Figure 7. Example with GT. AS requested at 10 pm (raising 65 MW 1h). Reserves status*

the battery with the surplus energy that the photovoltaic plant is generating at that moment (Figure 7). Therefore, from 11:40 the battery extends its charge (already started at 8:20) until 12:30. Thus, the SoC of the partition associated to reserve purposes is increased to 50%. If there no additional ASs are requested, the battery will have the desired capacity for reserves (required for the following day) at the end of the day.

Gas Turbine (GT) to provide as: The last mechanism that can be used to provide AS is the Gas Turbine (GT) allowing to maximize the penetration of non-dispatchable renewables due to their low costs, the biogas turbine is the last option.

GT has two essential features: a fast start-up time and independence from other external sources to operate (such as having surplus of energy from other technologies, as in the case of batteries). These two features make it the best option when no other solution can provide the AS requested. On the contrary, it must be highlighted that the biogas turbine can only make adjustments that involve an increase in the total power of the plant.

Regarding the algorithm that manages the GT operation, the main consideration is not to exceed the nominal power of the GT (considering the power used during the “normal operation”). Another consideration is the start-up time depending on the status of the GT and how long it has been since the turbine was used.

The Figure 7 refers to the abovementioned example considering that the HPP has an available GT of 300 MW.

In this case, by employing a large biogas turbine (300 MW), the hybrid plant can cover any required demand. Concerning the capacity to cover AS, it can be observed that the GT is now able to provide the tertiary regulation service, which previously could not be provided by the battery (Figure 8).

Finally, variations can be observed in the reserves that are available to raise power (green and purple trends). Such variations depend on the power (megawatts) that the GT consumes in normal operation.

## 5. Algorithm for demonstrating the functionalites of hybrid power plants after a zero voltage event

The purpose of the restoration service is to restore the power supply in case a disturbance (at national or regional level) appears. It is based on the ability of certain generators groups to start without any external power supply after a zero voltage in the installation. These singular groups (such as hydraulic power plants) can keep generating power in a stable way during the process of service restoration, acting as the auxiliary equipment that can be used to supply voltage and power after the disruption.

The resettlement plans establish the coordinated process of all the subjects involved in the management of the electricity system, in the case of a national or zonal incident in the electrical system.

In particular, concerning generation units, in the event of zero voltage, a process begins concerning the autonomous start-up of hydraulic power plants that, with strategies already established, proceed to the energization of certain axes with several objectives: i) to provide the auxiliary services of the thermal generation units in order to proceed with their start-up, ii) to ensure the process of safely shutting down nuclear power plants, and iii) To supply the priority loads and recover the interconnection with the European synchronous system.

Consequently, the contribution of hydraulic power plants in the process is indispensable, since they constitute the first step of energizing the system in the event of a national incident.

Large conventional power stations usually need an external source of energy (in the form of power from the grid) in order to restart. If the grid cannot supply the necessary power, then an on-site auxiliary generator can be used for a so-called black start. However, within the developed HPP concept this external energy source will be the Battery Energy Storage System (BESS), which is daily used to provide grid stability and to smooth the output from non-dispatchable renewable power sources.

In this respect, the BESS does not provide start-up power, but rather converts it, allowing the Biomass plant (and its steam turbine generator) to achieve synchronisation. Besides, the BESS can help to energize the auxiliary systems of the Hydro Pump Plant or the Biogas turbine.

Apart from the need for an external source to start-up, these synchronous generators are characterised by their start-up curve.

For the Biomass plant or Steam Turbine, three different start-up curves of the turbine were considered: Cold start-up is applied if the turbine was in the stand-by state for more than 24 hours, a medium start-up is applied in case the turbine was in a stand-by state for between 4 and 24 hours and, finally, a hot start-up is used if the turbine was in the off-state for less than 4 hours.

For the Biogas Turbine, a power increase ramp rate of 15MW/min has been considered (although this variable can be changed by the final user). This generator can, in just one-time step (10min), reach 150MW of output power. The figure below demonstrates this rump-up curve:

Finally, concerning BESS, since it does not require any mechanical movement, battery storage power plants allow extremely short start times, in the range of a few tens of a millisecond at full load.

### *5.1 Methodology and main algorithms.*

The methodology detailed in this section corresponds to the adequate management of the different assets, the Hybrid Plant consists of, in order to provide a quick response after a local or national blackout.

The algorithm associated with this functionality is based on the need to support the system operator in restoring the electrical system, as soon as possible after a failure. In this respect, as introduced in the previous section, the hybrid plant has different generators that can assume a different role, depending on their particular characteristics:

a. BESS will serve as an external source to supply the auxiliary systems which are necessary for the HPS plant to operate, as well as the synchronous groups (Biomass/Biogas). Thus, the battery will provide energy to systems such as the Distributed Control System (DCS), the feeding pumps or the motorized valves of the HPS plant. To do it, the algorithm automatically reserves a specific part of the battery (X%) to be employed in case a black start is required. By default, this percentage, X%, will be the sum of 2% of the Nominal Power of the Biogas Turbine, 2% of the Nominal Power of the Hydro Pump Plant, and 10% of the Nominal Power of the Biomass plant.

b. HPS will be used as the main source to restore network operation. Due to its particular characteristics (fast response and low need of external energy supply), the hydraulic turbine can be quickly synchronized to start feeding other system loads which are critical (e.g. hospitals) or to feed auxiliary systems of other generation plants (e.g.: recirculation pumps of nuclear power plants). After the blackout announcement, the algorithm immediately starts-up the HPS at its maximum power. By default, this requirement is maintained until the reserves in the upper reservoir fall to the minimum possible volume.

c. The thermal equipment (biomass and biogas) will begin operating, according to the heating ramp that corresponds to them at that moment. The gas turbine can reach its maximum power in less than 10 minutes, however, the steam turbine may need 10 to more than 90 minutes, depending on the time it has not been used, in order to reach 100% of its nominal power.

d. The battery will be charged with the generation of non-dispatchable sources (PV and Wind), as long as the battery can tolerate such an operation at the time examined. To reduce the relevant curtailment, the operator should reduce the generation of these assets as much as possible (for example, varying the pitch angle of the wind turbines). Nevertheless, it has been considered, by default, that 40 minutes after the incident in the system occurred, the hybrid plant will be able to inject the production of these assets into the grid network. Similar to other parameters defined “by default”, the user may modify these values in the future to adapt the model to the real requirements of the simulated plant.

Finally, it has been assumed that a restoration time of more than 24h will be required by the system operator to re-establish the system. Consequently, the algorithm assumes that once the demand curve has gone to zero, the plant is no longer required to follow a demand command for the rest of the day’s hours. After a blackout, the only mission of the plant will be to inject all the energy it can provide into the grid.

### *5.2 Results based on historical data.*

Figure 8 indicates how the generation profile of the plant changes after a blackout. In this example, the failure occurs at 6:50 am, when the BESS was charged with part of the energy produced by non-dispatchable technologies and when the HPP was discharging part of its initial reserves to cover the demand that could not be covered by the PV or Wind assets.

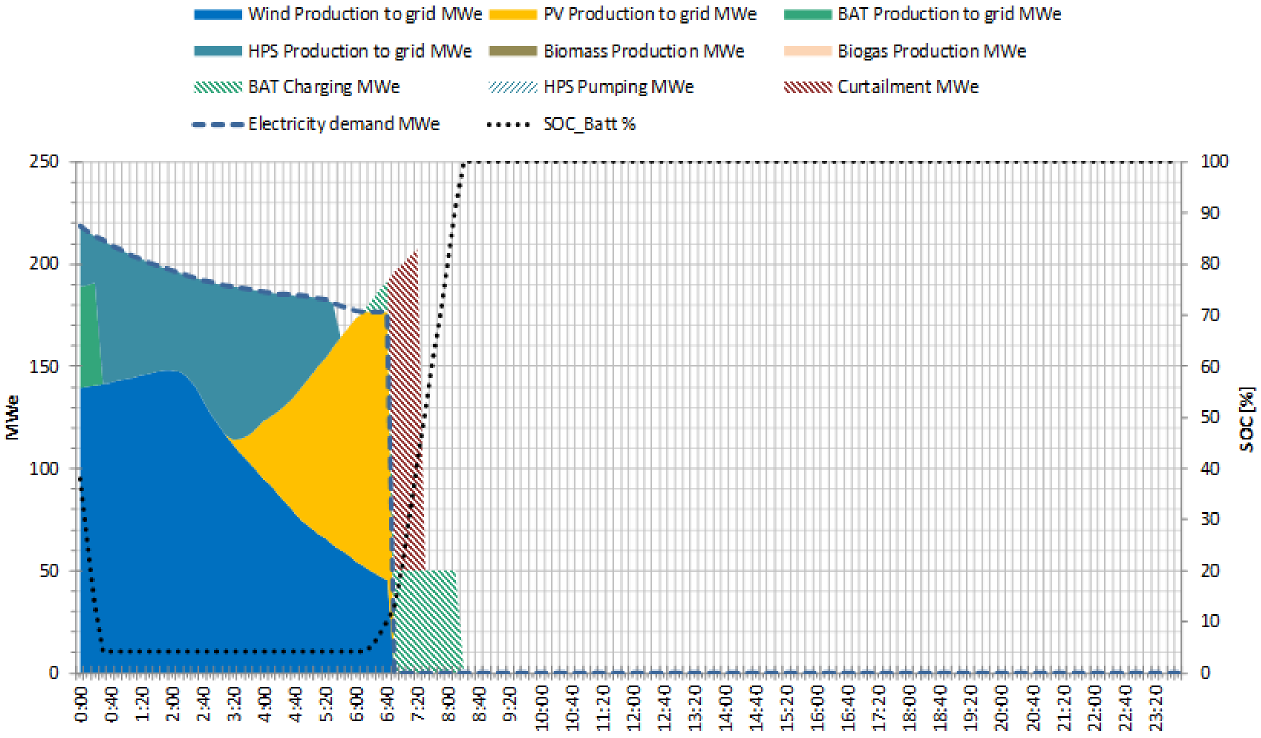

*Figure 8. Generation profile during a day with blackout*

It can be observed that the agreed production schedule is terminated once the failure occurs in the system. Next, the BESS automatically tries to charge with the energy production from the photovoltaic and the wind plant, at maximum charging power, until it achieves its maximum capacity. The energy production that the BESS cannot absorb is called curtailment.

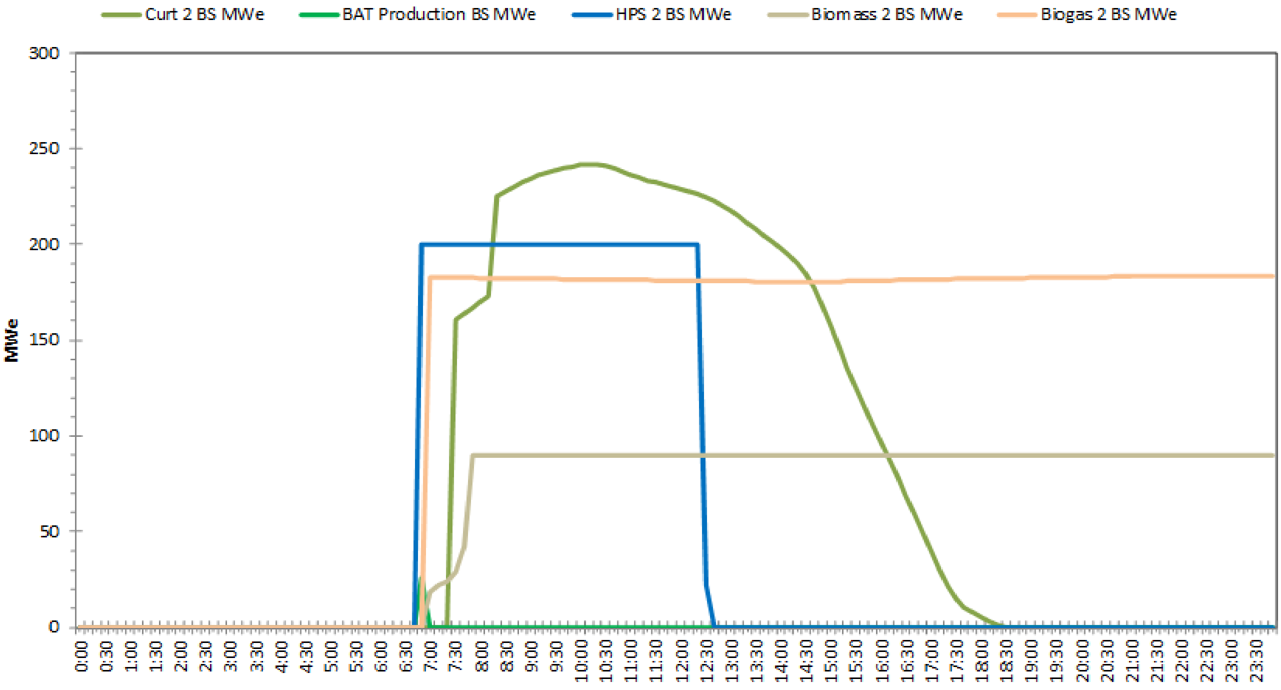

*Figure 9. Black start sequence of the Hybrid Plant. Separate profiles.*

This key information must be used by the plant operator to reduce the output power of these assets, in order to avoid as the most possible amount of the energy named as curtailment. The ability to reduce this curtailment will depend on the technology installed in each plant (inverters, wind turbines, etc.).

On the other hand, Figure 9 shows the start-up curve of each technology and how the Hybrid Plant could contribute to restore the electric system.

As indicated before, it has been considered that, after a failure, the system will require 24h to return to normal operation. This means that after a blackout, the main aim of the algorithm will be to produce as much energy as possible.

Thanks to this utility, the plant operator will know how much energy the plant will be able to supply to the system at any given time and, thus, to follow the production instructions of the system operator.

The Biomass plant requires 1h to reach its maximum power (90MW). As explained before, the steam turbine, as well as most of the elements of the Rankine cycle, needs to follow their internal ramp-up curve, which depends on the time that has passed since the plant has been stopped.

In this case, the aim of the tool for this use case is not to predict the power plant's production profile for the rest of the day, but to inform the plant operator about the energy what technology can be provided at each time. With this tool, the operator will have, in a few minutes, the information he needs to know if his plant can or cannot comply with the TSO's instructions to restart the system.

## Conclusions

ME4HP has demonstrated its functionalities and highlights the adaptability of the RED-DU to different plant configurations and operation modes. In addition, the integration of dispatchable RES, non-dispatchable RES and energy storage in an advanced control system is analysed and the application under different use cases is presented. Moreover, the ME4HP can have a significant role in the operation stage by sending the optimal PPPs to the HPP operator, which can be adapted to fulfil various aims.

## Acknowledgements

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