Battery augmented biomass and waste power plants – A new approach to provide grid services

Konstantin Dinkler and Jürgen Peterseim

Kurzfassung

Batteriegestützte Biomasse- und Müllheizkraftwerke - Ein neuer Ansatz für die Bereitstellung von Netzdienstleistungen

Entsprechend dem Pariser Klimaschutzabkommen ist die Begrenzung des Klimawandels anerkannt mit unterschiedlichen Ansätzen in der Umsetzung. Erneuerbare Energien wie Photovoltaik (PV), Wind, Bio- und Geothermie werden ein wesentlicher Bestandteil des zukünftigen Energiesystems sein. Während Bioenergie, Wasserkraft und Geothermie grundlastfähig sind, sind die überwiegend neu hinzugekommenen Kapazitäten Wind und PV intermittierend. Ohne Energiespeicherung erfordern hohe Wind- und PV-Durchdringungsraten sehr flexible Energiesysteme, um Ausfälle oder Übererzeugungen auszugleichen 1. Derzeit wird die flexible Kapazität durch Pumpspeicherwasserkraftwerke, Gasmotoren-/Turbinenanlagen und einige Batterieanlagen bereitgestellt. Vor allem bei großen Batteriesystemen wird die Technologie ihren Wachstumspfad aufgrund von produktionsbedingten Skaleneffekten, Verbesserungen der Lernkurve und weiterer Forschung und Entwicklung fortsetzen.

Während die beiden augenfälligen ersten Optionen Batterien mit Wind und PV kombinieren, sind auch Biomasse- und Müllverbrennungsanlagen von Interesse. Solche Anlagen können jederzeit Batterien für die Erbringung von Netzdienstleistungen auf- und entladen und so ihre wirtschaftliche Attraktivität über die festen Grundlastpreise hinaus erweitern.

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Introduction

As the Paris agreement shows, limiting climate change is a worldwide acknowledged necessity and even though the approaches vary it is widely accepted that renewable energies, such as solar photovoltaics (PV), wind, bio- and geothermal energy, are a vital part of the future energy system. Renewable energies are supported by many governments and over the last decade its costs have decreased to grid parity in many regions. While renewables, such as bioenergy, hydro energy and geothermal are base-load capable, the predominantly added new capacities are wind and PV, which are intermittent. Without energy storage high wind and PV penetration rates require very flexible power systems to compensate potential shortfalls or peak generation, see Figure 1. Currently, flexible capacity is provided by pumped hydro, gas engine/turbine plants, and some battery installations. Of these, large battery systems are least mature but many commercial installations operate successfully and the technology is set to continue its growth path due to production related economies-of-scale, learning curve improvements and further research and development.

At the moment standalone battery systems predominantly use the grid's electricity mix, with some being directly connected to wind or PV plants. The global electricity mix is still fossil fuel dominated in the majority of countries and dispatchable renewable power is a necessity to change this. While the two logical green energy combinations are batteries with wind and PV, biomass and waste to energy plants are of interest too. Such plants can charge/discharge batteries at any time required to provide grid services, thus expanding their revenue stream beyond fixed base-load power prices.

Biomass and waste to energy is divided into two main conversion technologies, one being digestion (biogas plants) for high moisture organic materials, such as food waste or manure, and the second being thermal conversion (biomass plants) for solid and lower moisture materials, e.g. wood or municipal solid waste. Due to the system inertia, such as fuel input, digestion times and thermal inertia, biomass and

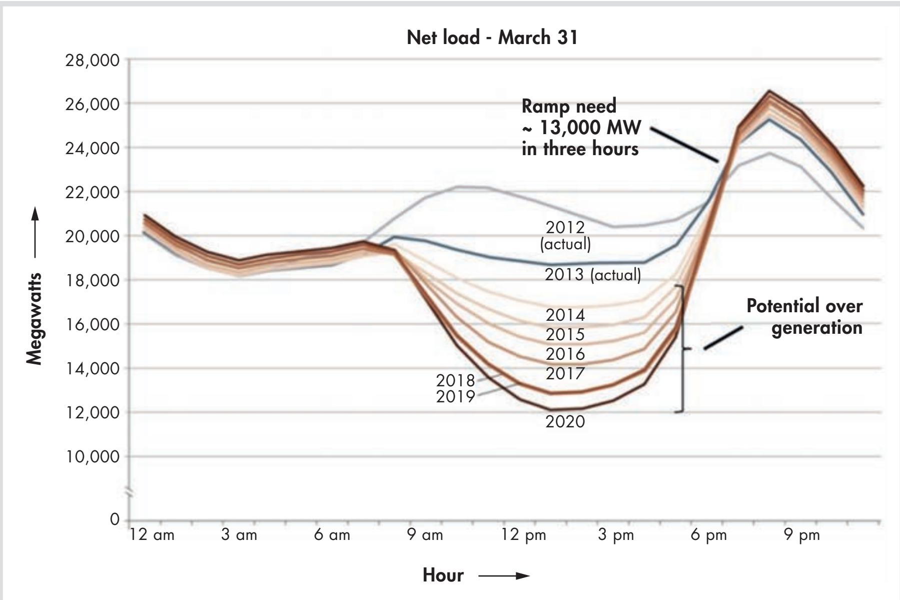

Fig. 1. "Duck curve" illustrating the discrepancy of load and production on the 31.03.2012 in California [1].

waste plants react slowly to load changes with ramp rates of 2-6 %/min., which is similar to coal fired plants [2]. Typically, the electricity from such plants cost, depending on fuel price, plant investment and finance conditions, between US$ 30/MWh to US$ 140/MWh [3]. However, the prices for balancing power and other grid services can be significantly higher, e.g. in Germany the maximum value in 2015 was 6,344 €/MWh [4]. Currently, neither biomass nor waste to energy plants participate in the balancing power market but if they could it would be an interesting option to maximize revenue. Hence, its hybridisation with batteries is worth exploring in more detail.

Hybridisation and its benefits

With the amount of wind and PV generation rising significantly worldwide, storage is essential and coupling it with biomass or waste power plants would be beneficial to further use existing infrastructure, buffer intermittent generation and create new revenue streams for plant operators. Hybridisation can realise this at competitive cost. The specific investment cost reductions of biomass hybrid power plants are already proven in some installations, such as with solar thermal in the 22.5 MWe Borges power plant in Spain [5] or with geothermal as in the 18 MWe Cornia 2 power plant in Italy [6]. In both plants the energy sources are hydraulically connected.

Augmenting a biomass or waste to energy plant with a battery is significantly less complex because the hydraulic integration of water/steam flows is not necessary. Instead, only the electrical interconnection is required. Furthermore, the battery hybrid provides a number of advantages for the grid and the plant:

- For limited periods the battery can be used to significantly raise the plant capacity to meet peak demand, increasing revenue by taking part in the balancing power market.
- Battery can serve as both, load and capacity for the grid. That means that during periods of over-capacity and low/negative prices the generated electricity of the thermal power plant can be stored and supplied to the grid when prices recover, again enabling balancing power market participation.
- Adding a battery to the thermal power plant provides black-start capability.
- The battery system adds renewable capacity to the existing plant. The combined capacity can participate in the day-ahead market.
- When the grid is unstable the addition of a battery to the biomass power plant ensures a secure ramp down of the plant into the battery, e.g. during a grid breakdown. This would reduce material stress from emergency shutdowns and extend equipment lifetime.
- Use of existing grid connection infrastructure for the thermal plant and the battery system.

The necessity to provide these mentioned grid services will vary greatly depending on the energy mix. In a grid with high wind and PV penetration, such as the German or Californian grid, fossil fuel plants are forced to severely throttle production. At the moment bioenergy as a renewable energy source still has the right to feed in but this may change in the future. Figure 1 shows how severe this problem can get. The potential over generation shown refers to the ramp need thermal plants would have to provide for high PV inputs during a sunny day with a prediction up to 2020. The resulting "duck curve" illustrates how far thermal plants, potentially including biomass and waste plants, have to throttle their generation in a grid with high penetration of intermittent renewables. However, it also shows that without major investments in energy storage these plants will still be necessary for supply security during low radiation periods. Hence, flexible thermal generation and/or mature and large capacity storage are a necessity in the future. Hybridisation can be one piece of the puzzle to accelerate the implementation of currently high cost energy storage technologies.

Types of batteries

To describe the battery types, it is important to understand the dynamics of a power grid. The grid demand fluctuates over time with predictable as well as unexpected highs and lows. In this article the highs in the morning and afternoon will be called peaks. They last over a couple of hours and arise due to the increasing power demand before and after a typical workday. The unexpected short-term fluctuations will be called spikes. They are punctual sharp increases and drops in demand that last from seconds to several minutes and result in a distortion of the overall smooth demand changes.

For renewable energies the peaks are problematic because they arise when intermittent sources, such as PV and wind, do not generate at full capacity. The generated electricity needs to be shifted from around noon into the peak periods. Therefore, there is a tendency to combine grid connected PV power plants with battery storage to bridge the production gaps at night and shift the peak production into the peak demand periods.

Recent prominent examples for battery installations are the 100 MW battery system in South Australia (Figure 2) [7] and the world's first battery augmented gas turbine power plant in Southern California with a 10 MW battery capacity [8]. In Germany, even a coal fired power plant is planning to add a 45 to 50 MW battery storage to further flexibilise electricity output to the grid [9].

While many articles refer to Lithium Ion batteries as the future of energy storage it is mostly neglected, that this technology includes a large variety of different cell types with different chemical compositions and hence a different electric behavior. It is not the goal of this paper to differentiate between all variations, however, in order to understand why batteries are advantageous for hybridisation and put them in the right perspective it is important to understand that two types of specialized batteries exist.

The first type is the energy cell. It can be found almost everywhere in our digitized world. These cells power our smartphones, laptops, tablets, electric bicycles and much more. They are designed to be charged and discharge over extended periods of time with a low output, resulting in low C-rates (ratio of capacity and power output) of up to max. 4C. Charging these cells takes equally long. They cannot handle high power outputs because it leads to accelerated aging. Energy cells are common for the combination with PV and help cover the demand peaks where they can be slowly discharged during the morning and afternoon and charged around noon.

Power cells on the other hand are designed with the opposite goal. They can be charged and discharged very quickly, re-

Fig. 2. 100 MW Battery storage in Australia installed by Tesla; Picture by TESLA [7].

sulting in high C-rates above 4C to 10C. The different chemical composition of power cells allows such fast charge/discharge rates without accelerated aging but with the downside of a higher specific investment, € per kWh. Since such batteries can provide more power at once without being damaged, less installed capacity is needed to reach high power outputs compared to an equivalent energy cell battery. Due to their high C-rates they are perfectly fit to cover sudden demand spikes and smoothen out the load curve.

In summary, without detailing its different subcategories, power and energy cells are readily available from multiple suppliers. The choice of a battery storage system and the project business case strongly depends on the application and the local conditions. At this point in time more energy cells are being installed but with increasing intermittent generation this might change in the near future.

Technical concepts

As can be seen in Figure 3, the integration of a battery system into an existing or newly build power plant is simple because only the electrical connection behind the generator needs to be considered and the battery can be placed where space is available. Containerised and building integrated battery storage solutions are available. At the grid connection of the power plant a splitter is installed. From an electrical point of view the battery and the grid are now two parallel loads for the power plant. Between splitter and power plant a switch is installed to connect and disconnect the battery as desired. Most of the time only the grid will serve as a load and the battery is idle and disconnected as indicated by the green switch and arrows in Figure 3. In case the electricity demand in the grid drops, the plant can continue to generate at full capacity while the battery serves as a temporary load. The blue arrows in Figure 3 show that during demand peaks/spikes the battery can serve as additional capacity and feed into the grid parallel to the power plant. In case of a grid interruption (red X in the diagram), which would normally result in an emergency plant shutdown, the battery can serve as a buffer, winning the operators time to allow a save shutdown of all equipment. This is indicated by the red arrow in the drawing. The dashed square shows the position of the switch for each scenario.

Case studies

Battery storage solutions differ a lot depending on the project requirements. Hence, there is no single solution and case studies are an appropriate way to demonstrate the different benefits. The following two case studies consider different solutions for a waste to energy plant in Germany and a biomass plants in Fiji.

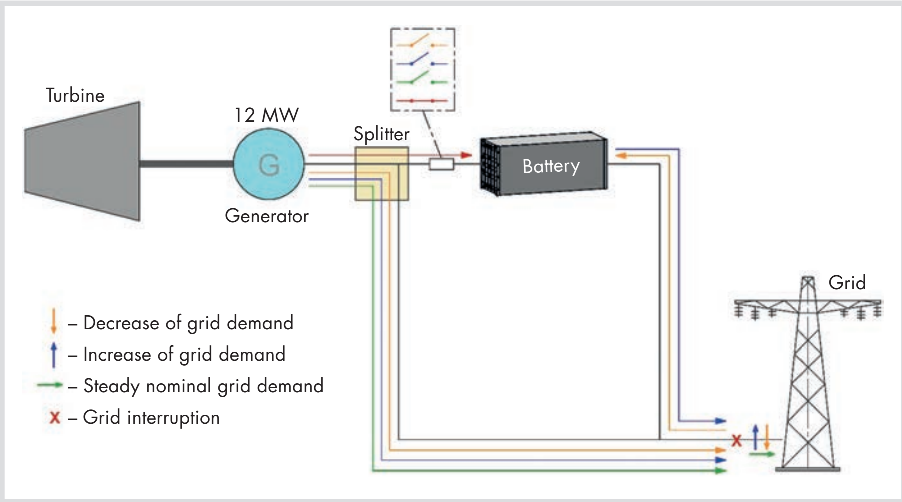

Fig. 3. Simplified electrical integration of a battery into a steam power plant.

Case study Germany

In Germany the share of PV and wind energy capacity increased significantly from 12.3 GW in 2002 to 99 GW in 2017 [10]. While both substitute fossil generation its intermittent nature is a challenge for grid operators. As mentioned, the only non-fluctuating renewable energies independent of weather conditions are biomass, hydro- and geothermal energy. The latter two being rather scarce in Germany. Furthermore, PV and wind energy cannot provide the same system services as biomass plants do, especially the spinning reserve.

PV and wind energy supplies can and do collapse or rise randomly. Despite good weather forecasts it remains a challenge to meet this oscillation of generation in short intervals with a conventional grid structure. Even modern gas turbines, being the fastest reacting power plants, require at least 10 minutes to reach full capacity [11]. This leads to a distortion of the supply graph that can only be seen when looking at minutely or 15 minutely intervals. Battery augmented biomass and waste to energy plants find themselves in a good position to partly polish said oscillations within the grid. The distributed nature of these plant enables grid response on a regional level close to potential bottlenecks.

With an integrated battery such plants could participate in the intraday market where energy prices and margins are much higher than in the day-ahead-market or in fixed power purchase agreements. Additionally, they could participate in the balancing power market by quickly reducing capacity (charging the battery) or adding capacity (discharging the battery). Participating in this market can create additional revenue. For example, typical WtE electricity prices are fixed within a range of 20-30 €/MWh. However, intraday prices can be significantly higher. Figure 4 shows the week 52 of 2017 where electricity prices reached 125 €/MWh. Such price fluctuations occur regularly and are likely to increase with continuous deployment of wind and PV without energy storage.

Battery systems are modular which is a commercialization benefit as operators can test the technical integration at small scale before entering into larger financial commitment. Depending on the storage requirements a combination of energy and power cells might make sense to maximize profit.

Case study Fiji

Fiji, like many other island states, sets itself apart from Germany in two ways. Firstly, the share of fluctuating renewable energy

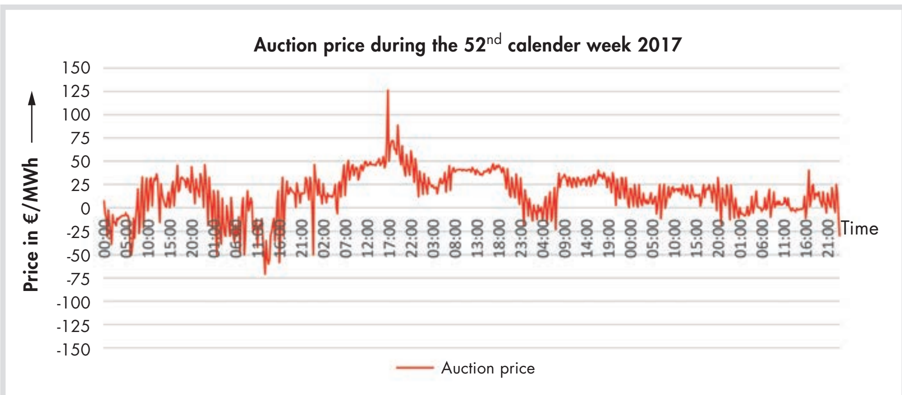

Fig. 4. Drastic price fluctuation during week 52, 2017 on the EPEXSPOT intraday auction market [12].

in the grid is much lower with fifty-five percent of electricity deriving from hydro energy and fourty percent from diesel and heavy fuel oil (data from 2015) [13]. Secondly, the power plant portfolio is much smaller, less diverse and less redundant. Additionally, there is no opportunity to compensate electricity shortfalls or surplus through extended grid infrastructure. Typically, the diesel generator fleet covers peak and augments base load. Hence, they are oversized to cover peak demand needed only for a couple of times a year. This results in frequent part-load operation. By investing US$ 45m in its first 12 MW biomass plant (see Figure 5), the island has shown its willingness to further commit to renewable energies and take advantage of its natural resources. This investment made sense, considering that the feed-in tariff of the plant lies at US$ 155/MWh, which is US$ 56 /MWh below the cost of diesel generation.

By making the biomass plant flexible, the need to install spare diesel generator capacity would be reduced. The plant could charge the battery during low demand periods, such as at night, and the battery can discharge during sudden demand spikes, substituting high cost and carbon intense diesel generation, while benefiting from higher electricity prices during these short periods. With such a technology combination the typical load profile of Fiji's main island, see Figure 6, could be satisfied with demand spikes being partially covered by the battery. The very fast response time of milliseconds would enhance frequency control as well.

For the operator another benefit can be realised. The grid in developing nations is often unstable, leading to frequent blackout. Blackouts force plants into emergency shutdowns, increasing wear and tear of the plant components and subsequently rising maintenance costs. For the 12 MW plant a 6 MWh battery would be sufficient for a 30 minute shut down procedure. This is needed to store the electricity otherwise wasted

Fig. 5. 12 MW biomass fired plant in Fiji.

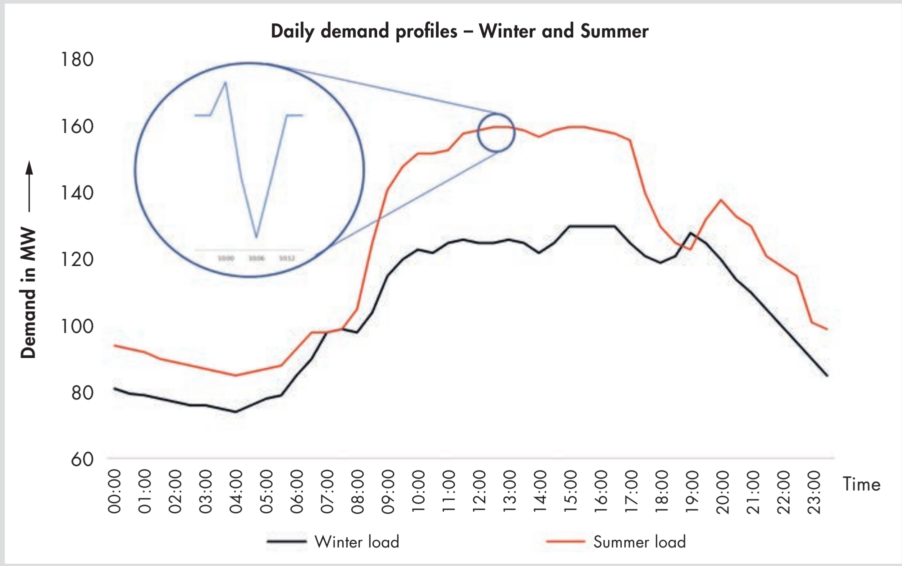

Fig. 6. Representative load profile of a day in Fiji and typical spikes in an electricity grid.

during an emergency shutdown. Additionally, the battery can black-start the plant.

Summary

Battery storage solutions are likely to find wider implementation in future energy systems as standalone and hybrid solutions coupled to various energy sources, including PV, wind and gas turbines. First installations are already in operation and many more in planning stage.

Battery augmented bioenergy and waste to energy plants have the unique opportunity to increase revenue by shifting production from low and high price periods and providing ancillary grid services. This represents an expansion from the typically fixed power purchase agreements. Furthermore, the more flexible operation can reduce operation and maintenance costs by reducing material stress during ramp up/down procedures.

At the moment the economic case for such a solution strongly depends on the electricity price fluctuation, like in Germany, or particular location conditions, such as weak grid infrastructure and high cost diesel generation as is the case of Fiji. Right now, battery costs are still comparatively high and projects often require additional financial support. However, battery prices are decreasing rapidly and it seems very likely that standalone and hybrid battery solutions will soon be of interest for a broad range of applications.

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