WHITE PAPER

Microgrid and Battery Energy Storage

Enabling low-carbon operations with new revenue streams for data centers

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Executive summary

The world is experiencing a significant increase in network traffic. Digitalization has become imperative for every industry, especially with the growth of the internet of things (IoT). To enable that traffic, power is mission critical for data centers. The increase in network traffic demands massive amounts of energy which can have an impact on global energy consumption.

At the same time, data centers are aiming for 100 percent renewable energy and setting ambitious targets of 24/7 carbon-free operations. However, today, behind most data centers there is at least one diesel generator, if not a full set of them to protect against power outages.

Battery energy storage systems (BESS) are gaining momentum in the data center industry for their emission-free operation, back-up power capabilities, and ability to optimize renewable energy generation as well as enabling the participation to remunerated programs released by grid operators for new ancillary services. A BESS enables carbon neutrality by providing new revenue streams through energy storage-as-a-service (ESaaS).

This paper reveals how battery energy storage coupled with renewable generation can enable decarbonization and provide alternative revenue streams for data centers. The paper also shows the benefits of moving towards a microgrid-enabled data center comprising of battery energy storage.

Introduction

Increased network traffic driven by global digitalization such as cloud computing, IoT and digital assets connected to the internet, have resulted in an expected Compound Annual Growth Rate (CAGR) of 14.3% during the period of 2022 [1].

This substantial growth means data centers have become one of the key consumers of electricity worldwide. On the other hand, while internet usage has increased twelve-fold, energy efficiency improvements have helped data centers limit the electricity worldwide demand only to a 1 percent [2].

At the same time, due to the global push to boost decarbonization for a more sustainable future, adoption of 24/7 emission-free operations is a key focus.

In the race to decarbonization and to achieve sustainability in data centers, some goals are already set, moving ahead of probable future regulations. One of the initiatives is the Climate Neutral Data Centre (CNDC) Pact in Europe for a demand matched by 75 percent renewable by 2025 and carbon neutral data center by 2030 [3]. Some data centers are already planning to be carbon negative [4] and others have set up their targets to 100 percent renewable [5].

One path to achieve those targets on sustainability is going into power purchase agreements (PPAs) with the energy utility. However, the push of high energy consumers towards PPAs is leading to grid stability issues due to a higher penetration of renewables. The inherent variability of wind and solar, including potential imbalances in supply and demand and the changes in the energy flow patterns, are causing problems in the balancing on the existing grid. This goes against the primary requirement of any data center, a reliable power supply. The grid with more renewable generation is losing its electrical inertia and spinning reserve, which needs to be compensated in some way, for instance by energy storage.

On the way to decarbonization, it is important to mention that most data center operators are considering PPAs and installation of on-site renewable generation via Distributed Energy Resources (DER), however most data centers also have a diesel generator (DG) or gas turbine generator (GTG), in fact a set of them to protect against power outages.

Consider one generator in a data center will normally run idle 99 percent of the time, therefore it will not have a significant impact on sustainability. In this case, installation of on-site renewables and the use of biofuel can easily offset that carbon footprint. After all, diesel gensets are a cost with no return of investment as they only work under grid outages and maintenance purposes because they are not sustainable to provide energy.

On the contrary, energy storage allows data centers to manage energy costs by leveraging the power demand and optimizing the renewable generation by maximizing the self-consumption. At the same time, it offers the reassurance of power continuity, preventing revenue losses during grid outages and enables a new revenue stream for data center operators with the value of energy storage-as-a-service.

Energy storage can enable sustainable operations and additional revenue streams for data centers.

When talking about energy storage, there are different technologies that can be considered such as batteries, flywheels, ultracapacitors, compressed air energy storage (CAES) and fuel cells (FC). All of them have pros and cons in terms of safety, energy and power densities, lifetime, self-discharge rates, efficiencies, and ramp rates. The balanced compromise of battery performance and the drop in lithium-ion (Li-Ion) technology cost [6] are making battery energy storage easily accessible for data center operators.

Battery energy storage and data centers

Battery energy storage powered data centers present a viable option to provide grid services and to increase sustainability. This not only benefits the grid with increased stability needed due to the high penetration of renewable, but at the same time it opens a different revenue stream for the data center operator.

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MONETIZATION PROGRAMS

Different monetization programs are possible when talking about battery energy storage in data centers:

Time-of-use management

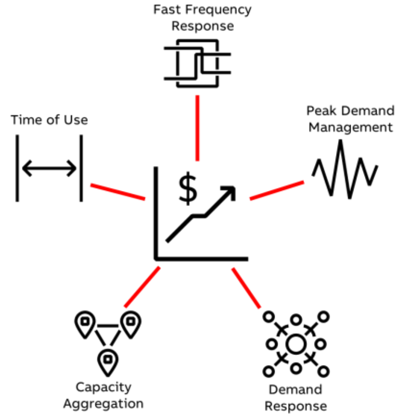
Renewable power generation excess or lack of enough generation can make utilities provide time-of-use structured rates. It is possible to monetize these programs as an energy storage owner by charging the batteries when electricity prices are low and discharging them when electricity prices are high. The data center operators can get the benefit of the utility pricing structure by performing load shifting. The program only requires scheduling operations based on the utility pricing structure. It should be noted that to provide proper remuneration incentive, the capacity of the battery storage needs to be big enough to cover the pricing structure.

Peak demand charge management

Most of the electricity bills have a type of charge based on the maximum power drawn during a period of time (normally 15 minutes) known as peak demand charge. Data center operators can discharge the energy storage during periods of high demand, reducing power and lowering the peak demand charge. Batteries will be recharged when the load is lower. This is an ideal monetization program for battery energy storage with an installed energy capacity up to 15 minutes, enough to cover the peak demand charge period.

Demand response

Data centers with battery energy storage can curtail their load to help reduce the demand from the grid. This is especially useful when there is an imbalance between generation and load in the grid. When this happens, grid operators can trigger a signal to the enrolled data center to reduce their demand and the data center then gets compensated.



Fast frequency response (FFR)

When there is a sudden imbalance between generation and demand, the frequency increases or decreases from the baseline. The frequency variations are due to the rotating machines setting up the frequency in the grid by spinning at higher or lower speeds. Due to the growth in renewable generation, the big rotating machines are disappearing. Battery energy storage can react immediately to sudden changes in frequencies by injecting or absorbing power. The programs for frequency regulation can start from few seconds up to the minute range. Fast frequency response, being the most lucrative grid service, is the most demanding for a battery energy storage and the required fast control.

Capacity aggregation

To increase participation in different programs, smaller assets can be aggregated virtually. Aggregation can be done for assets in different geographic locations. All assets are then controlled at the same time as an aggregated capacity.

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BATTERIES IN DATA CENTERS

When considering battery energy storage in a data center, there are two feasible options. The first one is to utilize the unused battery capacity of the UPS units with the possibility of increasing it. The second option is based on upgrading the system with a BESS. Both technologies, though very similar, have differences based on their different technologies and the best fit into the monetization programs.

Uninterruptible Power Supply

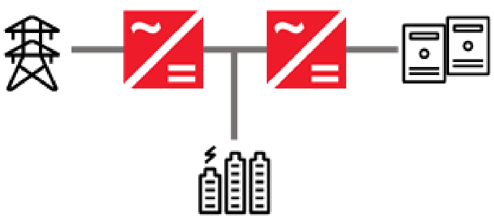
Actual data center power hierarchy already includes batteries powering the uninterruptible power supply (UPS) units with a minimum of 10 to 15 minutes of full load operation for a 1N topology and over 1 hour when partially loaded for a 2N redundant topology. A majority of the data centers are already moving from lead-acid to lithium-ion batteries due to the longer cycle/calendar life, higher efficiency and energy density. Due to the unused capacity, data center operators can take advantage of monetizing that battery energy storage to increase sustainability, and to reduce the risk of identifying possible latency issues in the batteries while cycling them.

In terms of UPS architectures, the state-of-the-art technologies are based on low-voltage (LV), or medium-voltage (MV) connected UPS. Available capacities to participate in monetization programs differ from both. LV UPS can participate with the power rating of the IT load while the MV UPS can participate with the full load when considering unidirectional energy flow, i.e., grid parallel. In the case of grid services requiring bidirectional energy flow, the limitation of maximum power varies from 20 to 70 percent, depending on the UPS technologies.

There are of course some risks that data center operators must bear in mind when monetizing the batteries of the UPS which are related on how data center operators decide to do it:

- Component stresses which may jeopardize the main functionality of the UPS.
- Impact on the UPS batteries warranty, lifetime, and reliability.
- Oversizing of the UPS battery capacity to participate in monetization programs.
- Possible additional costs based on equipment upgrades to achieve grid parallel and/or bidirectional modes.
- Cost of the additional control to implement monetization with grid services.
- Fulfillment of the grid codes when operating bidirectionally.

From the above, needed certification processes according to relevant standards such as UL 1741 or IEC 62109, time and agreements needed to fulfill national grid codes, and the higher stress on the batteries impacting lifespan and warranty terms, often make the utilization of a UPS for bidirectional monetization programs not the most optimal. Parallel operation with the grid, with low stress on the batteries, enables flexibility in the load and monetization via demand response, peak demand management and time-of-use management. The cost of upgrade is mostly based on software updates and the time of deployment is minimum.



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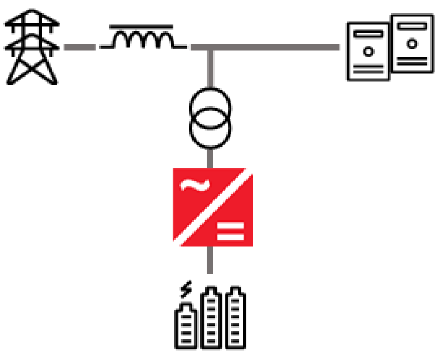
LV UPS double conversion simplified single line diagram



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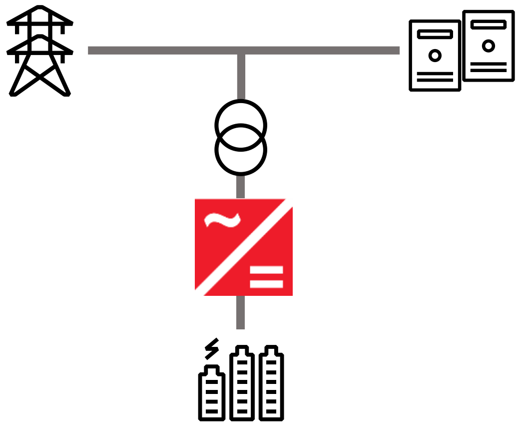
MV UPS simplified single line diagram

Battery Energy Storage System

When talking about battery energy storage, what usually comes to mind is the well-known BESS. This system, parallel connected to the grid, is independent from the UPS units and can provide optimal services that an oversized UPS, in capacity or power, is not able to offer in the most feasible way.

The nature of the BESS architecture with certified energy back-feeding and grid code compliance~~,~~ make it the ideal component to provide grid services. These services are based on bidirectional energy flows to balance supply and demand in a data center under grid-tied condition or to act as a generator under a grid outage, providing power continuity and protecting loads.

While grid-tied, the BESS helps to keep the data center operator in full control of the power sharing. When there is a grid outage and the data center turns into island mode, the BESS becomes a virtual generator which keeps the voltage and frequency of the islanded grid under specifications. At the same time, it allows the operator to parallel other generators such as diesel and other DERs.



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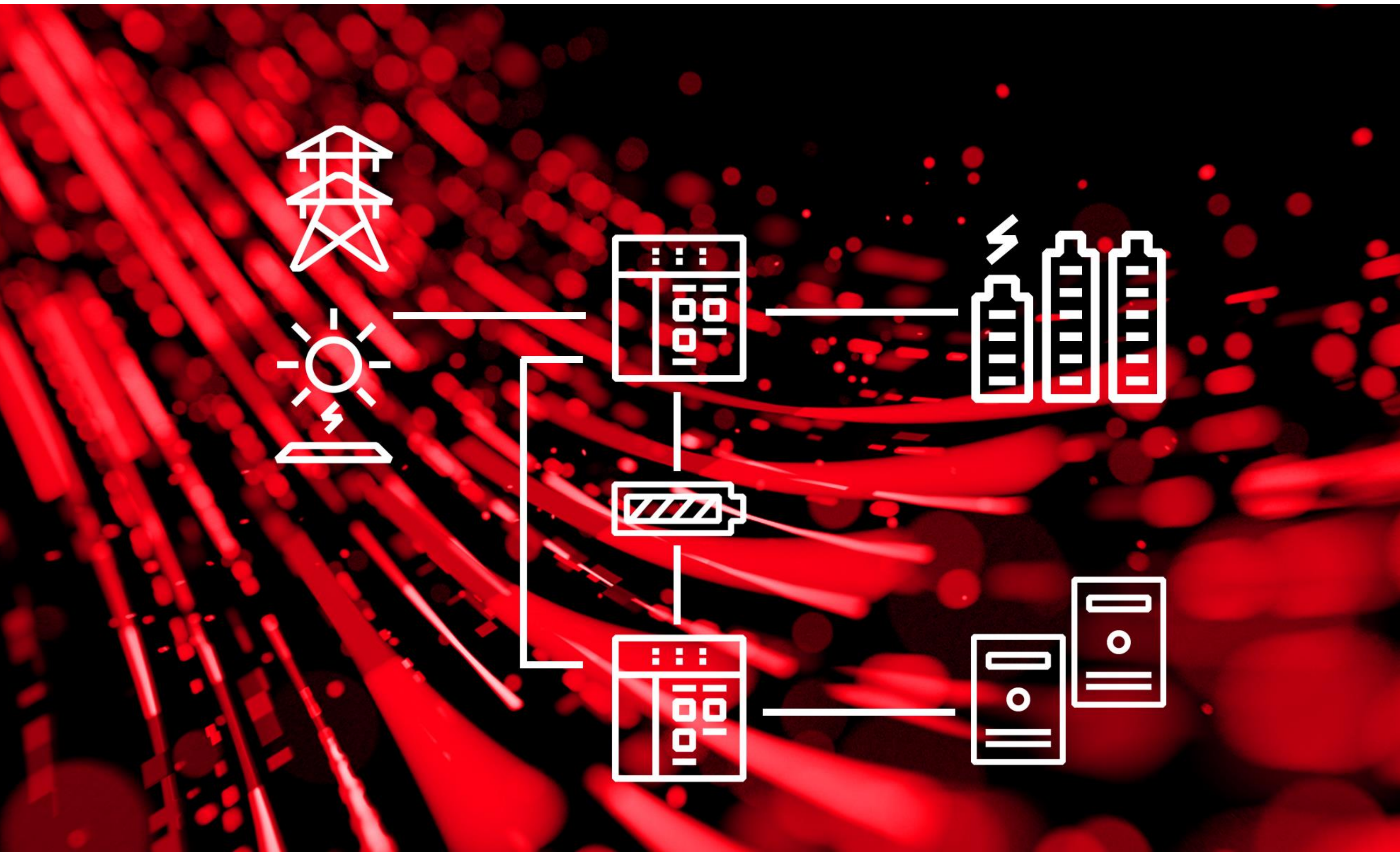
Battery Energy Storage System simplified single line diagram

The downside of a BESS is that it takes a longer time to isolate from the grid, depending on the physical opening of the main feeder circuit breaker. This can lead to not fulfilling the IEC 62040-3 UPS standard and potentially putting critical loads under risk of de-energization in the transition from grid-tied to island condition. To overcome this situation, a downstream UPS can keep the critical loads powered during the transition of the system to island condition.



Microgrid-enabled data centers

Historically, the data center power hierarchy has been defined by a grid connection backed-up by UPS units for redundancy and high availability. Loads are fed from back-up power diesel generators via an automatic transfer switches (ATS) and a distribution panel to supply the loads under grid outages.

The future of energy in data centers is becoming a mix of sources coupled with battery energy storage within a microgrid as the availability of power is not to be relied only in one source.

As depicted above, factors such as a greener image, sustainability targets, high reliability and cost optimization are prevailing the microgrid development in data centers. Microgrid-based data centers can operate off-grid (island) or paralleled with the grid (grid-tied). Different functionalities among active and reactive power control of the system as well as optimization of the renewable generation by demanding less from the grid become a reality together with monetization programs of the battery energy storage.

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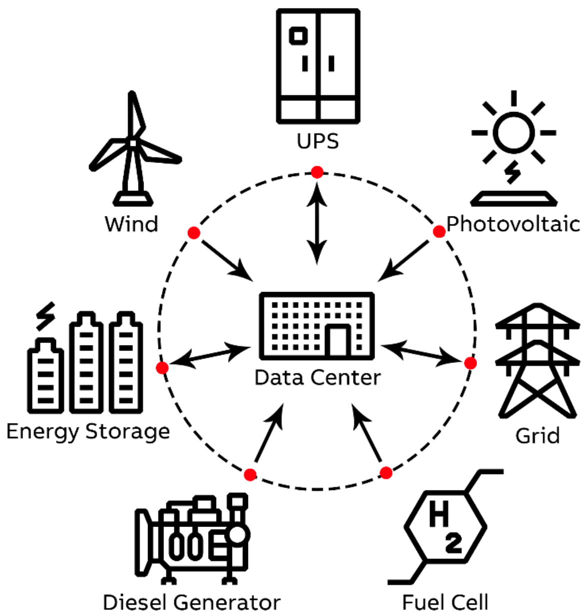
MICROGRID BENEFITS

Increased uptime and reliability

Because of the variability and intermittent nature of renewable energy, a microgrid-enabled data center architecture requires reliable technologies and intelligent control to ensure a proper power sharing under grid-tied conditions and reliable power during islanding.

Transitions from grid-tied to islanded operation and vice versa can be initiated automatically or by an operator. The control system of the microgrid is responsible for isolating from the grid and resynchronizing. UPS will support the IT load during the transitions until the BESS and renewable or DGs are able to supply the load. A BESS prevents large frequency deviations under islanded conditions and performs a full black start, if needed.

In the event of islanded operation, the BESS will manage setting up the voltage and frequency of the microgrid. When the state-of-charge (SoC) of the BESS is under a predefined value and the islanded condition is still needed due to grid outage, the control system will initiate the start of the DG, GTG or FC ensuring at any time the demand and generation are matched.



Reliability of the UPS is increased when its batteries are cycled. For example, performing demand management can help data center operators discover latent failures that can´t be discovered when the UPS units stand idle most of the time in.

Microgrid architectures in data centers that integrate a BESS and the microgrid control system can comply with the grid codes. The architecture can tolerate voltage and frequency deviations as well as to provide ride-throughs capabilities, which are of paramount importance to prevent nuisance shutdowns or unintentional islanding. Active and reactive power controls help to support the frequency and voltage of the grid while grid-tied or to keep them within safe and reliable conditions while islanded.

Improved Sustainability

Regardless of the steps taken to use more efficient equipment and to conserve energy within a data center, the challenge that remains is the transitioning to clean renewable energy. This transition is enabled by a microgrid architecture that controls the energy mix within the facility through renewable on-site generation coupled with BESS to optimize efficiency.

Implementing fuel cells for on-site generation within a microgrid in a data center, particularly with methane from landfills, hydrogen from the future pipelines or on-site generated hydrogen from cracked ammonia makes using renewable energy a reality. This enables data center operators to use non-fossil fuels as their long-run back-up power generators and puts them closer to achieving a net-zero operation.

Another feasible way that a microgrid can help increase the sustainability of a data center is by replacing the lithium-ion batteries of the UPS with ultracapacitors. This is possible when a BESS is responsible for providing the back-up power after an outage. The time required for the BESS to pick up the load is below 1 second and can be covered by the energy stored in ultracapacitors. This change in technology generates less losses in the energy storage increasing the efficiency of the UPS and requiring less cooling power. It removes limitations on battery cycle-life and lifespan, increasing safety and efficiency of the UPS. At the same time, it also requires less footprint which leads to a more contained cooling in a more efficient way. Improved cooling and energy efficiency lead to a better power usage effectiveness (PUE), one of the main indicators of sustainability in data centers.

Lowered carbon footprint

The capacity installed in a BESS integrated within the microgrid of a data center provides the needed back-up power without starting the DG or GTG immediately after a grid outage. The critical loads will be fed by the UPS until the BESS is brought to nominal power. Once the BESS has picked up the load, the data center facility is running in islanded mode and there is no need to start the fossil fuel generators until the SoC (stored energy in the BESS) does not reach a low threshold. Carbon footprint is therefore reduced as the BESS supplies the load without the need of DG or GTG.

In case the SoC has reached the low threshold, the DG or GTG are to be started. During the process of starting up the DG or GTG, the BESS can automatically provide voltage droop to accommodate the ramp-up of the generators without the need of operating an ATS. Once the generators are brought to nominal power, load sharing between the BESS and the generators is optimized by the control system, allowing the microgrid to run the DG or GTG in the most optimal operating point while the BESS controls the frequency and voltage.

This concept prevents partial load, increases efficiency and lifetime, and reduces fuel consumption and CO2 footprint.

Centralized monitoring and control

Integrated energy management systems of the microgrid and smart software solutions can track how all the interconnected assets of the microgrid-enabled data center perform and ensure there is no wasted energy.

In addition to protection and control, the control system of the microgrid helps to balance the active and reactive power flows and determines how to dispatch the resources based on supply and demand.

Artificial Intelligence (AI) and Machine Learning (ML) technologies support the optimal operation of the microgrid by learning consumption and generation patterns and adapting to the needs of those. They can also increase the lifetime of the battery energy storage and enable better preventive maintenance, thus boosting the reliability of the system.

Optimized costs and energy use

A microgrid-enabled data center comprised of different DERs and BESS can perform time-of-use optimization. Operators can take advantage of the off-peak periods importing and storing energy from the grid when the prices are low, and the on-site generation is not enough to supply the loads. In this way, the data center operator purchases lower-cost energy when renewables are not generating enough to cover the data center load.

Peak demand charges can be easily reduced by utilizing the unused capacity of the UPS by a simple software update if batteries have been dimensioned for this purpose. This will allow the operator to save month over month in their electricity bill.

Renewable on-site generation can be maximized with the BESS without generation curtailment by storing excess energy during peak generation and providing it to the loads when needed. In a microgrid comprising FCs, the renewable energy can be used to generate H2 for the FC with no need to increase power demand from the grid.

New revenue streams

Different monetization schemes for additional revenue streams or cost savings are possible due to the versatility of the microgrid for data centers. Either by additional streams or by cost cutting, the ROI (Return on Investment) of a microgrid-enabled datacenter can be readily realized.

Grid services can be easily provided by having a BESS within the microgrid concept in terms of reactive power support and fast frequency response. This automatically enables additional revenue to support the operations of the core business of the data center.

Aggregation of services is possible by performing different functionalities in various equipment. For instance, the BESS can be running fast frequency response services at the same time the UPS is providing peak demand management.

Ease of scalability

The power architecture of a microgrid, including energy storage and on-site renewable generation, can be easily scaled considering modular manufacturing and deployment. This enables a flexible response to the evolving requirements and trends in decarbonization ahead of new modernization programs.

Conclusions

Battery energy storage powered data centers present a viable option to provide back-up power enabling grid services and increasing sustainability.

With lithium-ion batteries easily accessible for data center operators, monetization of the energy storage as well as improvements in sustainability can be obtained by utilizing the unused capacity of the UPS or through a BESS.

Monetizing grid services which require unidirectional energy flow are best addressed by UPS technology. It only requires a simple software update of the equipment helping at the same time to remove latency problems within the batteries. Bidirectional grid services are best addressed with a BESS due to its nature to back-feed the electrical grid, the ease of certification processes and a low risk profile to participate in monetization programs.

Coupling both technologies within a microgrid, the data center operator can obtain increased reliability and an additional revenue stream. At the same time, it enables better PUE leading to an increased sustainability.

The future of energy in data centers is becoming a mix of sources coupled with battery energy storage comprised within a microgrid. Data Center microgrids provide an electrical architecture to allow data centers to operate as consumer or prosumer. Bidirectional energy flow allows a data center to work in grid support mode and create additional revenue streams. The Microgrid controller ensures proper control and operation modes to enable data centers to shift from a dependence on the utility grid.

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