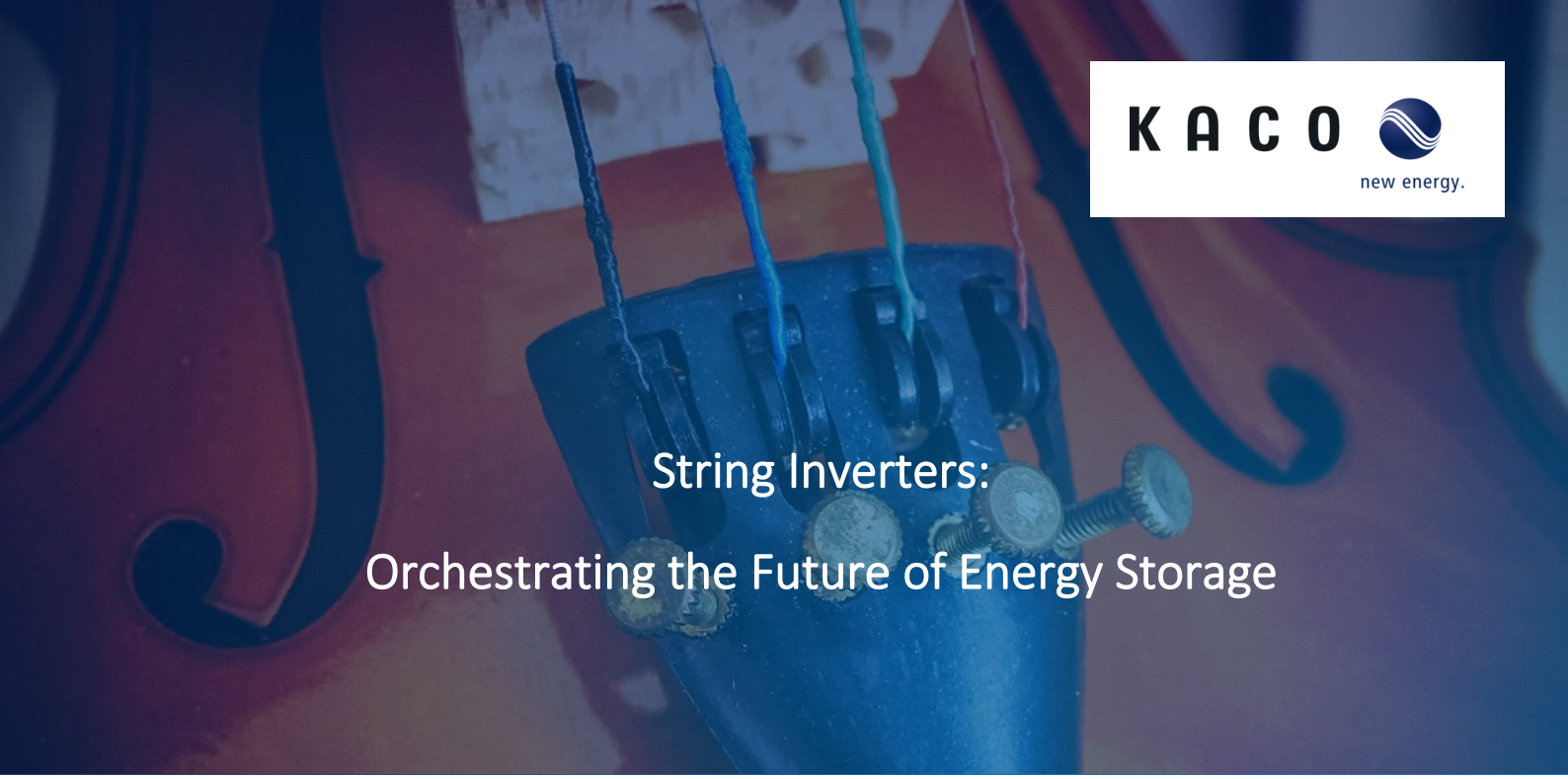


String Inverters:

Orchestrating the Future of Energy Storage

Boban Vujovic, Product Lifecycle Manager - KACO new energy

A single string can play no music… but many strings could orchestrate the energy transition.

The vital need for energy storage in our transition towards a carbon neutral future is becoming increasingly clear.

Several research providers are predicting that the decade of energy storage has arrived with forecasts ranging from 411 GW (AC) of storage installations by 2030[1] up to 500 GW (AC) by the end of 2031[2]. A similar forecast expects the storage inverter market to grow to $6.8 billion cumulated between 2022 and 2025[3]. These figures, although impressive are not surprising. We have known for some time that we will need enormous amounts of energy storage if we are to have a chance of achieving our net zero targets. Supply chain as well as geopolitical issues have only exacerbated the urgent need for energy storage to firm up renewables and stabilize local grids as well as energy prices. Coupling solar, the cheapest form of power generation on earth, with battery storage is a logical and necessary decision.
This white paper explores the real and innovative advantages string inverters provide through their high performance, extraordinary flexibility, and ease of use. Hence, we believe that they will become part of the best practise when it comes to building high value, long lasting energy storage projects.

The Shift to String

We have already seen string inverters take the mantle as the preferred power electronics platform in the PV space. The residential as well as the C&I segments, due to the relatively small nature of systems, have traditionally been string inverter dominated. However, we are now seeing a clear transition towards string inverters in the utility segment.

As string inverters with higher power ratings were introduced to the market over the course of the last decade, large-scale utility PV

projects which were built with string inverters were done so because of their superior performance and ease of maintenance even though it meant a higher capital investment.

Fast forward to the present and string inverters are still the preference because of their technological advantages and higher energy yields. In many cases, on a plant level, they have now become just as economical if not cheaper to build than central inverters, as they are able to be built in a so-called virtual-central design.

The same shift in preferred inverter platform is currently gaining traction in the storage segment as well. Future innovation is bound to put further pressure on prices, hence we expect string inverters to continue gaining popularity and market share.

CAPEX Costs

Although string inverters typically cost more in initial capital costs, they are almost always the cheaper option in the long term. This acknowledgement is being felt in the industry with EPC's, integrators, project developers and operators alike focusing more on long term performance and operational aspects of their projects.

The goal at KACO new energy was never to build the cheapest storage inverter possible but rather to focus on providing a high performing, technologically sound, flexible product which fits the needs of our customers and creates additional value for the short as well as long term.

Keeping with the string metaphor, violins can be mind-bogglingly expensive. Although factory made violins can be a great option for beginners, they will undoubtably not last anywhere near as long as a carefully hand-crafted piece. The sound quality of a mass-produced violin will also degrade over time, whereas the sound of a well-made violin actually improves with age. This is what we at KACO new energy strive to provide to our customers - added value over the entire lifetime of the energy storage asset.

String inverters can in many cases actually reduce overall capital costs simply due to their smaller size compared to central inverters. A smaller building block allows for finer project sizing compared to a central inverter. Central inverters come in multi-MW power classes with oftentimes the smallest inverter having a 2 MW power rating or higher.

Let's say that you are looking to build a 2.5°MW (AC) storage system. If you wish to use central inverters, you would need to purchase two 2.0 MW inverters and run them at well below their nominal output. This would represent a large over-expenditure compared to what is actually needed. The alternative would be to use 27 KACO blueplanet gridsave 92.0 TL3-S string inverters which would not only bring us much closer to the project size needed but also be the more economical choice, now and in the future.

Availability & Uptime

The consequence of a central storage inverter experiencing a catastrophic failure or needing to be taken off-line for maintenance is a multi-MW block not generating any power (or revenue) until a qualified technician and the right parts are flown in.

String battery inverters require no maintenance, and should one go off-line a much smaller percentage of the total generation power is unavailable. Additionally, the nature of string inverters allows them to be swapped quickly and easily by a local technician. Swap inverters can be stored on

site or with the operations entity for this purpose and thus drastically reduce any downtime.

Being able to quickly replace an inverter is particularly important in applications such as local microgrids where the inverters are needed to meet local demand. Their high availability is also important when providing critical system services.

	Central Inverter	KACO String (AC coupled)	KACO String (DC coupled)
Desired project size: 1.5 MW	1x 2.0 MW (smallest available)	1.47 MW (16 x 92 kW)	1.47 MW (16 x 92 kW)
Repair time of a catastrophic failure	7 days	24 hours	24 hours
Energy lost: 1 unit, 100% loss	21 MWh	184 kWh	0 – 184 kWh (application dependant)
Revenue lost @30c/kWh	6300€	55.2€	0 – 55.2€

The above calculation assumes an operation of one full cycle – 100% charge and 100% discharge – per inverter, per day. Although a string inverter can realistically be replaced relatively simply within 24 hours, the seven-day repair time for the central inverter is very optimistic, especially if parts or a technician need to be flown to site.

Battery Management & Safety

A prerequisite for the long-term success of storage systems is the health of the battery. To ensure minimum degradation of the battery asset, battery balancing on a stack level is recommended. This is unfortunately not possible with a lot of central battery inverters and could potentially result in accelerated degradation of the battery.

String inverters offer a more granular level of both real-time and historical battery performance data. This allows potential issues to be identified quicker and to consequently take proactive steps in order to mitigate those issues.

By dividing a large installation into smaller blocks using string inverters, system integrators are inherently minimizing any potential problems that may arise. Smaller systems not only mean that we are dealing with smaller faults or short-circuit currents but also that any local faults can be better isolated and dealt with.

Reliable and Robust

KACO new energy has a history of almost 30 years in the PV segment. Having inverters installed in challenging locations and exposed to some very harsh elements, has allowed us to gain valuable experience and develop inverters that perform reliably in such environments.
Many central storage inverters are not manufactured for such challenging environments, this is often reflected in an

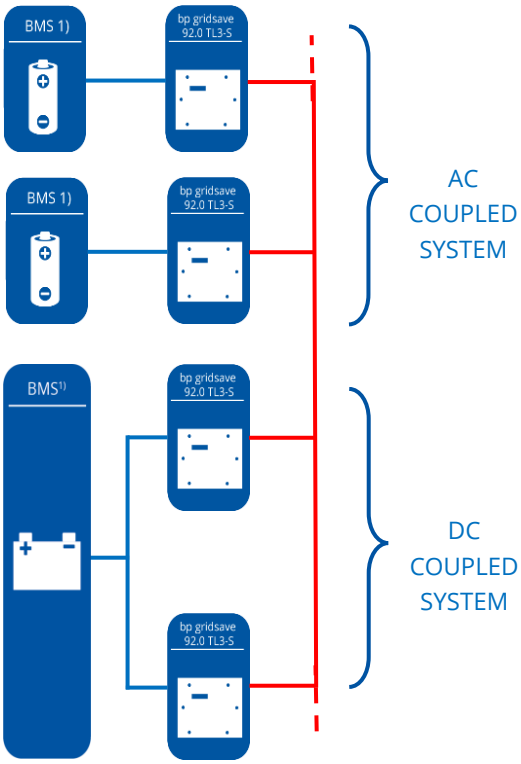
ingress protection rating of IP54 or lower, a maximum altitude of 1000m ASL and a large footprint, making them at times hard to handle and install.
In comparison our current gridsave string storage inverters, carry an IP66 / NEMA 4X rating and can be installed in altitudes of 2000m ASL without derating and at a maximum altitude of 3000m ASL.

String inverters, be they photovoltaic or storage inverters, are also much easier to transport to site. Due to their smaller size, no costly, special equipment is needed to transport, unload or install the inverter.

	IP Rating	Max installation altitude	Power density
Central storage inverter	Typically IP54 / NEMA 3S	Typically 1000m ASL	Typically 0.4 – 0.9 kW/kg
KACO string storage inverter	IP66 / NEMA 4X	3000m ASL	1.15 – 1.7 kW/kg

The power density of an inverter might not sound like an all too important metric however, many storage systems are being installed in a lot of commercial and industrial zones. Office and commercial buildings, logistic centres and factories tend to have service rooms or cellars which are ideal places to install storage systems. Most of these spaces however do not have large access points which makes installing central inverters either extremely difficult or impossible.

Value Stacking with KACO new energy



KACO has been able to take the learnings out of our very successful silicon-carbide-based PV inverters and develop an optimal string inverter series for the storage market.

Using silicon-carbide transistors as well as implementing our one-step (no DC-DC booster) topology within these inverters has meant that we are able to achieve stable operation and simultaneously very high performance.

The newly released storage inverter range includes several power classes, to ensure an optimal fit for all system sizes as well as most regions around the world. Let us take a closer look at some of the additional advantages that these new storage inverters have to offer.

Flexibility

The latest blueplanet gridsave storage inverters, offering power ranges of 92 kW, 110 kW and 137 kW can be coupled on the AC side as well as on the DC side of the storage system. Given that different applications can have vastly different requirements these string inverters offer the necessary flexibility needed to execute even the most challenging of projects.

AC Coupled Systems

AC coupling consists of connecting a single battery rack to a single inverter. The inverters are then coupled together on the AC side and generally share the same point of connection to the grid. Coupling multiple inverters on the AC side allows for easy expansion of the BESS.

DC Coupled Systems

When we talk about DC-coupled systems in the context of a standalone battery inverter, we are talking about connecting multiple inverters to a single, often larger, battery rack. All the inverters share the same DC bus in such a system. This system configuration allows for several advantages.

One of the biggest advantages is that the battery capacity always remains available, even if one of the inverters should go offline. This gives such systems a level of inherent redundancy.

As an example, let's say we have built a BESS with two blueplanet gridsave 92.0 TL3-S storage inverters. This would give us a system size of 184 kVA which we have connected to a 250 kWh battery in a DC-coupled system. Should one of those inverters be taken offline, the power of the system reduces to 92 kVA but the 250 kWh battery capacity remains available and can be used. This further increases the resilience of a DC-coupled storage system.

DC-coupling enables the easy implementation of system 'blocks' whilst also reducing some of the balance of system (BOS) costs associated with the batteries.

Contrary to belief, the communication for such a system does not need to be as complicated as it too often is. Thanks to a well-thought-out development from KACO new energy there is no communication necessary between the inverters themselves. The communication between the inverters and battery is performed solely by the overarching Energy Management System (EMS) and ensures safe and reliable operation of the system.

Application: Energy storage systems participating in the capacity market. If an energy storage asset is being paid to be on standby and hold energy ready, then we want to make sure that energy is available when it is required. With a DC coupled system the total battery capacity is always available – even if one of the inverters should need to be taken off-line.

Energy arbitrage is a popular application where the market conditions allow for it. Having a high uptime and access to the storage system's battery capacity is important for all applications, but it is of particular importance for applications where the business case is so heavily time dependant. Having a DC-coupled system means that the system can always participate in the market with its full battery capacity and charge and discharge energy exactly when the prices are right.

Pre-Charge Unit

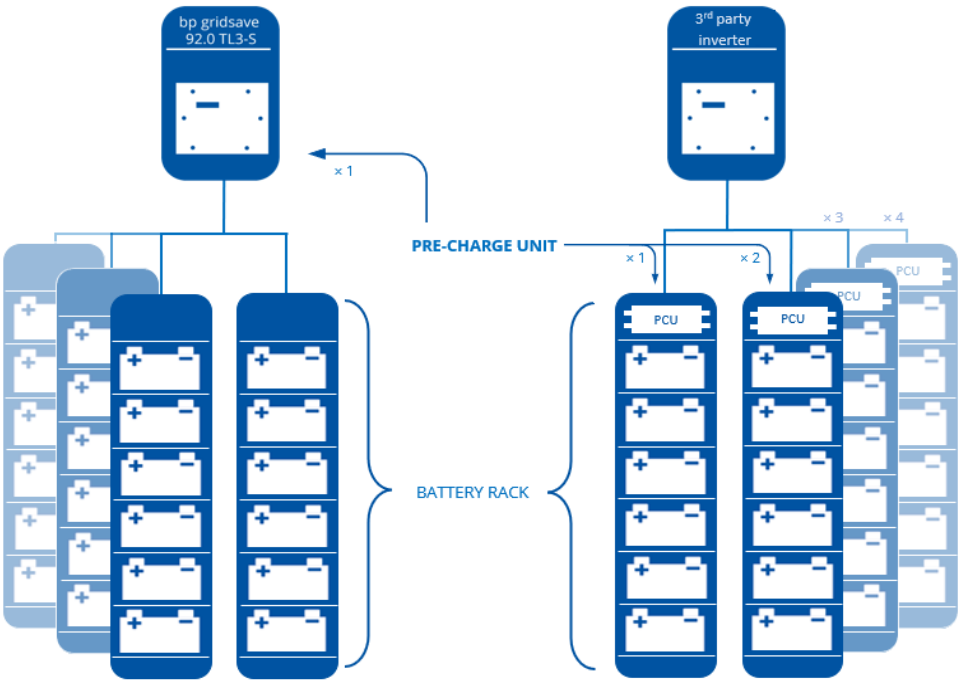
With the growth of the storage market EPC companies and developers will have an increasing amount of potential component suppliers to choose from. Not only are more inverter manufacturers developing storage inverters but the number of batteries on offer is increasing rapidly. EPCs, integrators and project developers not only need to choose their preferred cell technology, but they also need to address several other important design decisions.

One particular point is whether battery racks with integrated pre-charge units are to be used or not.

For projects where larger or multiple battery racks are to be connected to each inverter, integrating the pre-charge unit within the inverter could make a lot of sense. Not only does it reduce costs, but it simplifies the overall communication concept. In this case the EMS does not need to communicate with both the battery and inverter in order to pre-charge the system and bring it online. The system complexity would increase if the EMS had to use different communication protocols between the battery and inverter.

Using the Modbus TCP/IP open communication protocol within our inverters on the other hand greatly simplifies this task.

In order to make sure we can provide our customers with a suitable solution regardless of their battery choice, our latest series of storage inverters comes with the option of having the pre-charge unit integrated or not.



Application: All storage systems which are intended to cover loads for multiple hours and have multiple battery racks connected to one inverter. The system costs would be cheaper and the operation of the system would be simpler.

For DC-parallel systems: If a pre-charge unit is installed in the battery rack instead of in the inverters, it becomes much more difficult to disconnect a single inverter when needed. All the inverters would need to be disconnected from the battery before a single inverter can be turned off.

Efficiency

Calculating a valid business case for renewable projects can still, to this day, be a difficult task. In high performing PV projects, a well thought-out design as well as qualitative, high-efficiency components can make all the difference.

The use of a highly efficient inverter is even more important in storage applications. This is because the energy needs to travel through the inverter twice – once to charge the battery and the second time when the battery is discharged.

Using an efficient inverter will mean that system operators have more energy at their disposal, which will result in a better return on investment in the long term. A difference in efficiency between 0.3% - 1.0% might not sound like much but considering the lifetime of the asset it provides an undeniable advantage to the business case.

Having an energy storage system with string inverters during times of variable load conditions, allows for the load to either be distributed across all inverters or for several of the inverters to be taken off-line in order to find the most efficient operating point.

Application: Battery energy storage systems are very well suited to a range of grid services. Although the storage segment is still in its infancy, competition for grid services is fierce and it will only become more competitive as the installed base grows. Having a system that gives you access to more energy than a comparable system will guarantee a positive impact on the return of investment.

Looking at it from another angle, storage systems built with highly efficient string inverters will be able to provide the same amount of energy for a particular service without discharging the battery quiet as deep as comparable systems. Taking the long-term health of the battery into account and the thousands of cycles it is expected to perform throughout its lifetime makes this a significant advantage.

Battery Independence

Our latest storage inverters have a unique communication concept whereby they do not communicate with the batteries directly. This task is performed by the EMS which in turn communicates with the inverters in order to provide the required power settings.

This means that the inverters can be implemented in projects with various battery technologies. This is not only advantageous for different applications but also for future expansions of existing projects. Should a new battery technology emerge with a better performance or better economics, as long as the EMS can communicate with that battery, our inverters will fit into the expansion just as easily as they did into the original project.

Using the open source and well-established Modbus TCP/IP communications protocol within our inverters ensures that we are compatible with a wide range of EMS providers today and into the future.

Together with the option of having an inverter with, or without an integrated pre-charge unit means that our customers are able to plan suitable solutions regardless of their preferred battery technology and topology.

Application: As the number of EV's on our roads increases into the future we will need to build significantly more charging infrastructure as well as bolster existing charging stations to keep up with the number of EV's.

Their ease of installation, minimal footprint and open communication protocol means our string inverters are perfectly suited not only for new charging stations but also for the expansion of existing infrastructure. This is still the case even if, years after the initial commissioning of the project, the battery technology proposed for the expansion is different to that of the original project.

Case Study

A German supermarket chain has recently made the decision to look towards solar power and storage for its energy needs by installing a microgrid storage system at one of their fruit ripening facilities.

The project objectives include:

- Minimizing dependency on the grid
- Reducing electricity costs
- Reducing CO2 emissions

The microgrid consists of a 405 kWp solar array on the roof of the warehouse. High voltage batteries were used in the project with a total capacity of 870 kWh.

The system was built using 13 of our **blueplanet gridsave 92.0 TL3-S** storage inverters. The flexibility the string inverters bring with them are perfectly suited for the multiple applications for which the system is being utilized.

"Our AI software, which is used to control our customers' microgrids, requires very high software stability and efficiency from the inverters. In KACO, we have found a partner whose inverters reliably meet our high requirements in this regard - even in complex setups with multiple and computationally intensive software applications" - says Philipp Kleinhans, responsible for business development at Frequenz.

Since being commissioned, the project has achieved **48%** less grid consumption, the electricity costs have been reduced by **50%** and **53 tonnes** of CO2 emissions have been prevented from entering the atmosphere.

Conclusion

There is no doubt that in the highly changing and rapidly growing storage landscape everything from revenue stream models, associated applications, battery and inverter technology as well as regulations around energy storage might - and probably will - change.

With this in mind, it should be clear that the most valuable energy assets in a highly renewable grid will be assets that offer the most flexibility. Considering string inverters offer the most versatile and scalable approach to meeting future needs, and with further innovation to come, it is our expectation that string inverters for energy storage solutions will become best practise within the industry.

[1] https://about.bnef.com/blog/global-energy-storage-market-to-grow-15-fold-by-2030/

[2] https://www.woodmac.com/news/opinion/global-energy-storage-staggering-growth-continues--despite-bumps-in-the-road/

[3] IHS Markit Energy Storage Inverter (PCS) Market Overview 2020

KACO new energy GmbH – A Siemens Company
Werner-von-Siemens-Allee 1
74172 Neckarsulm
Germany
kaco-newenergy.com