Distributed versus central architectures in solar arrays

New inverter technologies offer installers the choice of central or distributed systems for PV arrays. Deciding which system is the most optimal to use isn't always based on the size of a solar system, writes Alvaro Zanon

Inverter technology has come a long way since the first solar installations, which typically featured a single central inverter. Today, designers are increasingly choosing a distributed approach – utilising multiple string inverters throughout a solar array. But now that a variety of choices exist, the challenge is to decide which is the most optimal architecture for a given PV array: distributed or central.

Larger utility-scale projects have tended to opt for large, central inverters due to the cost and utility interactive controls from a plant management perspective. Residential and small commercial projects have favoured the decentralised approach using micro-inverters, where the ability to install an inverter within the module is ideal for carports and multiple azimuth and angled applications. A relatively new approach to distributed architectures using string inverters has become increasingly popular in recent years, especially in the commercial and small utility-scale range. A number of factors influence this decision, and it's not as clear-cut as past tendencies may make it seem. Although the size of the PV system is important to inverter architecture decisions, it's not the only factor. In certain cases, a central inverter could be the better choice in smaller commercial systems, while smaller, distributed string inverters could be optimal for larger PV plants up to utility scale.

Given the potential of string inverters to be used in large commercial and utility-scale projects, such as in multiple cases throughout Europe, the goal of this article is to help decision makers choose between central inverters (central architecture) and string inverters (distributed architecture). The primary considerations for most developers are total cost and energy production. However, when total costs are comparable, deciding factors may include space constraints, system uptime, code compliance and other issues discussed at the end of this article.

Cost comparison study

To compare costs in an impartial fashion, Advanced Energy commissioned Blue Oak Energy to evaluate both system architectures in three PV systems ranging in size from a small commercial installation to a utility-scale installation. The results of this analysis are detailed below, and confirm what most designers may suspect: the distributed architecture with string inverters has a clear cost advantage in smaller arrays, while the central inverter begins to enjoy a slight cost advantage in the low 1 to 2MW range.

For the discussion here, the evaluation of inverter features is based on different models in Advanced Energy's distributed string and central inverter product lines, but readers also can easily use the considerations for comparing inverters from other vendors.

The choice between distributed and central PV system architectures is meaningful only for arrays where it becomes possible to utilise more than one inverter. In other words, when a PV system has only a single inverter, it uses by definition a "central" architecture. Conversely, the distributed architecture could use several string inverters, one for each sub-array of the PV array.

To make for a valid architectural comparison, this analysis conducted by Blue Oak Energy established a minimum array size of 100kW AC and a minimum string inverter size of 20kW AC for the distributed architecture.

To evaluate the effect of scale on distributed and central architectures, three different application scenarios were used in the comparison: a small commercial installation, a large commercial installation, and a utility-scale installation. To make the comparison representative of 'real-world' conditions, the study picked Newark, New Jersey as a location offering a realistic temperature profile. Sixty percent of the modules were south-facing at a 20° fixed tilt. The remaining 40% of the modules were west-facing at a 5° fixed tilt. These conditions, as well as the inverter and balance of system (BoS) configurations used, are summarised in Table 1.

The cost comparison was performed by creating electrical and mechanical designs for all of the systems, and then comparing the equipment, material, and labour costs associated with each design. The results of the analysis are summarised graphically in

Table 1. Summary of conditions and inverter/BoS configurations used in this comparison performed by Blue Oak Energy

	Centralized Architecture	Distributed Architecture
Location	Newark, NJ	
Site Latitude	40°±	
Max Dry Bulb (°C)	34°	
Min Dry Bulb (°C)	-15°	
Array Configuration	60% of modules: South-facing (180°) and 20° tilt	
	40% of modules: West-facing (270°) and 5° tilt	
Inverter Overload	130% approx	
Interconnection Voltage	480Y/277 V	

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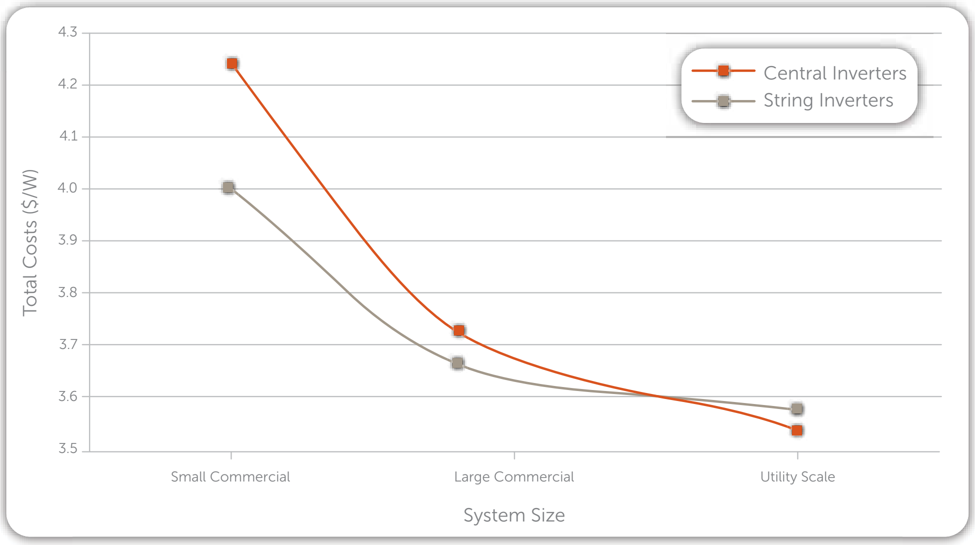

Figure 1. Total costs using distributed string and central inverters in systems ranging in size from small commercial to utility scale

Figure 1. As might be expected, the smaller string inverters enjoyed a clear advantage in total cost in the smaller arrays, with the distributed architecture being up to 5% less expensive than the central architecture. By interpolating the findings, the cost advantage appears to change in the low 1 MW to 2 MW range to the central inverter.

To evaluate real-world energy production, the effect of voltage and current mismatch was included with the introduction of inter-row shading on the south-facing array, and partial shading from trees on the west-facing array. A constant module-mismatch factor and a soiling factor that varied over the course of a year were also included in the simulations to make the energy production comparison as realistic as possible.

Again as might be expected, the distributed architecture, with its smaller strings or sub-arrays of modules, enjoyed a slight advantage in energy production based primarily on having the maximum power point tracking (MPPT) occur at what would be the combiner box level in the central architecture. While wiring losses were similar in both architectures, they came from different sources, with the AC losses of the distributed architecture being comparable to the DC losses of the central architecture. The distributed string inverter efficiency losses were slightly lower, however, compared to those of the central inverter, at ~2 and ~4%, respectively. The multiple array planes also gave the decentralised architecture a slight production advantage. The combination of these factors yielded in average a 1.5% higher performance ratio for the string inverters in all three scenarios.

It is worth noting that, in general, PV systems with multiple solar angles and/or partial shading benefit from the use of string inverters in a distributed architecture. This remains the case independently of the

Figure 2 Four-rooftop and 12-carport 855kW DC PV system utilising a distributed architecture design; installed at the VF Outdoor Coalition Campus, Alameda, CA. Source: Hawkeye Photography.

system's total capacity, which can easily exceed 1MW AC in campus settings. This means that string inverters might have a financial advantage in larger systems based on energy generation despite costing more than central inverters. Systems with arrays in multiple locations might also have space or weight constraints that favour the use of string inverters, which are much more compact and lighter than central inverters.

Other considerations in an optimal system design

In PV systems where the total costs and energy production are comparable between distributed and central architectures, creating an optimal design requires a more detailed evaluation of the specific capabilities or features of the inverter(s), as well as the site, any constraints and the overall monetary goals of the project. These considerations are assessed in this section, and because they are all necessarily product-specific, the discussion is based on Advanced Energy's TL-series string inverters and TX-series central inverters.

Although these considerations are mostly qualitative, some can have a significant effect on the quantitative economic analysis, and these are identified in Table 2 in the context of levelised cost of energy. As shown in Figure 4, the major differences are to be found in the BoS and the warranty period, which have an effect on the capital and operational expenditures, respectively. It is important to note that because the Blue Oak Energy study considered only the initial costs, the effect of the warranty and repair costs on ongoing operations and maintenance (O&M) expenditures could become an important consideration in the choice of architecture.

As indicated in Table 2, some peripheral considerations can have a profound impact on PV system economics. Such considerations may include the availability and cost of an O&M agreement, or the desire to minimise energy loss due to inverter failures. Or a plant designed to maximise the capacity factor with a high DC:AC ratio would require an inverter capable of supporting these higher ratios, as shown in Table 3. There are also scenarios where costs can become secondary to an inverter's ability to meet critical system design requirements. For example, Advanced Energy's central inverters operate at 60Hz, so only the TL series string inverters are suitable for a 50Hz system. Or in a system that requires very wide voltage trip settings, Advanced Energy supports this feature only in the TX series inverters currently. These and other 'feature factors' are identified in Table 3 as general design considerations.

Other specific factors to consider:

Uptime: The decentralised design reduces lost output in the event of inverter failure. Typically, string inverters are replaced with new ones, or repaired offline. In most cases, it's recommended that spares are kept on site to reduce downtime. While the repair time of a central inverter may take several days, the uptime can be increased with a service plan. The decision between a distributed generation and centralised generation approach can sometimes be driven by the skill of the labour available and by the mean time to repair (MTTR). Thus, the decision between distributed and centralised generation will be impacted by the experience and capabilities of the inverter manufacturer or service provider.

Reliability: To best assess the reliability impact of the system as a whole, it's impor-

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Figure 3. 500kW ground-mount PV system utilising a central architecture design; installed at the City of Greeley Water Pollution Control Facility.
Source: City of Greeley.

tant to carry out a reliability study to evaluate the respective failure rate of central and string inverters, and the number of inverters that will be used in the project.

O&M: The decentralised approach can reduce maintenance, given that string inverters do not require the preventive maintenance that is typical for central, such as inspection of the cooling system and thermographic imaging.

Investment performance: In order to capture all of the financial advantages and disadvantages of both the decentralised and the central approaches, the system designer may calculate several financial metrics, including return on investment, LCOE, internal rate of return or net present value.

Space constraints: System designers need to ask a range of questions to determine if a decentralised or central approach best fits a project's space limits. For example, they need to consider whether there is only room for a wall mount, or if there is room for a pad. Also, is there a requirement to mount it on a roof, or is there room on the ground? For carport applications, is there room on the ground, or can it be mounted on a post?

Code compliance and interconnect requirements: System designers need to consider the varying codes and utility requirements for each project location and select an inverter that meets those requirements.

Market conditions and future trends

The conditions and requirements discussed here indicate that growing demand for string inverters is likely, with increased utility-interactive control requirements for them. In the past, lack of familiarity was a significant roadblock to the utilisation of string inverters. Growing interest will likely

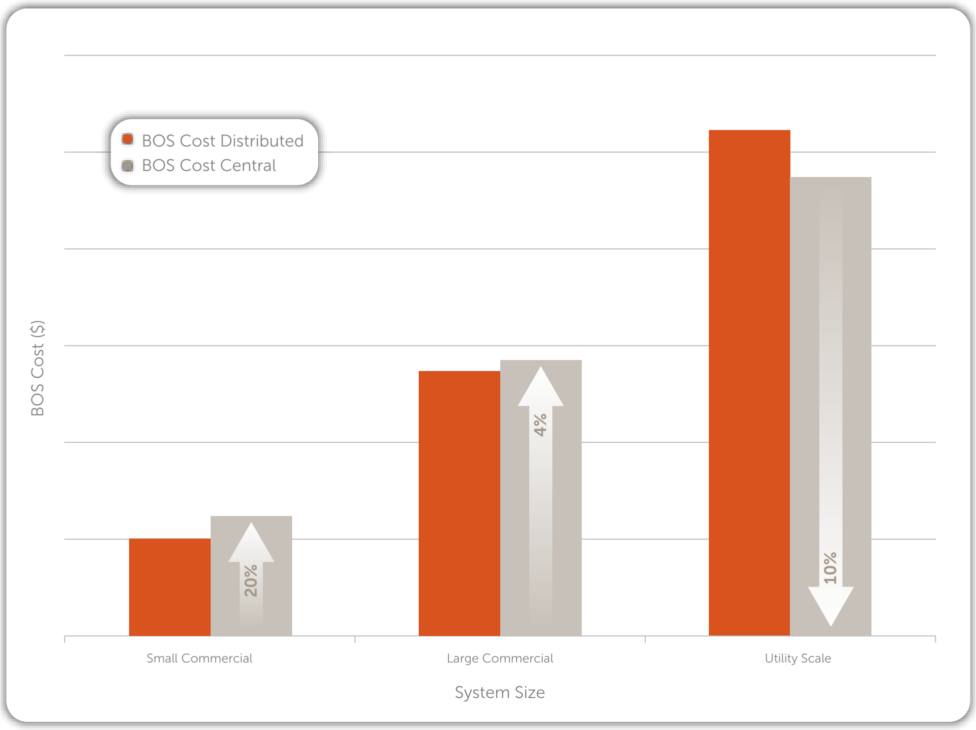


Figure 4. Balance of system cost analysis

LCOE Considerations	TL	TX	NX
Efficiency	✔	✔	✔
Balance of System Benefit			
No DC Combiner	✔		
Integrated Sub-Combiner		✔	
Integrated Breaker		✔	
Combiner-Level PV Tie for Long Home-Runs			✔
Integrated Revenue Meter		✔	
Reliability	✔	✔	✔
On-Site Service	✔	✔	✔
Remove and Replace	✔		
Standard Warranty (Years)	5	10	5
Extended Warranty (up to 20 Years)	✔	✔	✔

Table 2 . These inverter considerations all have at least some effect on the total cost of a PV system, especially on the BoS, as well as on the operational and maintenance costs.

Design Considerations	TL	TX	NX
High DC/AC Ratio	✔	✔	✔
Advanced UIC			
LVRT	✔ (IEC only)		✔
Expanded Trips		✔	
Voltage Control		✔	✔
600 VDC	✔	✔	✔
1000 VDC	✔		✔
Wide MPPT	✔	✔	✔
Multiple Angles or Shading	✔	✔	
Medium Voltage Interconnect	✔	✔	
Architecture	Floating	Grounded	Bipolar
50 Hz	✔ (IEC only)		
60 Hz	✔	✔	✔
Ontario FIT Compliance	✔ (UL only)	✔	✔
208 VAC		✔	
400 VAC	✔ (IEC only)		
480 VAC	✔ (UL only)	✔	✔
600 VAC		✔	

motivate developers/installers to implement them in solar arrays at an increasing rate, despite the fact that past successes with central inverters likely will continue to drive the use of central architectures as well.

The availability and successful use of string inverters increases their perception as a highly viable and competitive option for large commercial and small utility-scale projects, which have traditionally used central inverters. For example, string inverters were proposed for a recent 20MW-AC ground-mount project.

Distributed architectures also expand the possibilities for solar installations in remote areas of Latin America and Africa, and in small island locations. These locations aren't traditionally served with central inverters for three main reasons:

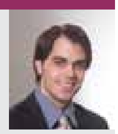
- Difficulty and cost for servicing central inverters in these locations
- Lack of local labor with experience installing central inverters
- Large cost of transportation of central inverters

Which is the better architecture in a PV system? As shown here, it depends on a number of factors. The size of the project might make a compelling economic case for either a distributed or a central architecture. For systems below 1MW-AC, a distributed architecture with string inverters normally incurs a lower capital expenditure; above that size, central inverters are usually (but not always) more cost-effective. But in many if not most situations, other factors will need to be considered to achieve an optimal system design.

So while project size does matter, it should not dominate the design. For a variety of reasons (or maybe only a single one) a central inverter designed for large-scale applications could be the better choice in relatively small commercial systems, while smaller, distributed string inverters could be optimal in some utility-scale plants. As described here, it depends on a number of factors, which must be evaluated on a case-by-case basis. ■

Table 3 (bottom). These inverter considerations can become determinative factors in the design of some PV systems, and may have an indirect effect on total costs or energy production.

Author



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