Executive Summary

Which is the better architecture in a photovoltaic (PV) array: distributed or central? The question is a legitimate one, but the discussion often gets muddled by parties who have a vested interest in one of the architectures. As a vendor of both distributed and central inverter solutions, Advanced Energy is in a position to provide an unbiased assessment and objective recommendations.

The answer to the question of whether to use a distributed or a central architecture for a particular PV project is, as might be expected: “It depends.” That is not an attempt to dodge the question; it really does depend on a myriad of considerations, and how these are prioritized in the form of objectives or desired outcomes for a project. There are both quantitative and qualitative ways to evaluate those considerations, and that is the purpose of this white paper.

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 100 kW-AC to 500 kW-AC. The results of this analysis are detailed in the first section, and confirm what most designers might suspect: the distributed architecture with string inverters has a slight cost advantage in smaller arrays, while the central inverter begins to enjoy a slight cost advantage in arrays over 350 kW-AC.

When total costs are comparable, other factors become more important for choosing between string and central inverters. These are explored in the second section, where specific inverter capabilities are assessed as design considerations in PV systems, some of which do have cost implications that go beyond what Blue Oak Energy considered in its analysis. 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 can easily use the considerations for also comparing inverters from other vendors.

Armed with the findings and analyses provided in this white paper, PV system designers will be able to make a more fully-informed decision about whether a distributed or a central architecture is more suitable for a PV project. And in those cases where either architecture will suffice, designers will enjoy the peace of mind of knowing that, whatever the choice, the system will be cost-effective and perform well.
Cost Comparison in Commercial Solar Arrays

The choice between distributed and central PV system architectures is meaningful only for arrays where it becomes possible to utilize 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 extreme case for distributed architectures could be considered the use of a micro-inverter for each and every solar module.

To make for a valid architectural comparison, this analysis conducted by Blue Oak Energy established a minimum array size of 100 kW-AC and a minimum string inverter size of 20 kW-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: 100 kW-AC, 260 kW-AC, and 500 kW-AC. 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 with rooftop mounting for minimal obstructions and shading. The remaining 40 percent of the modules were west-facing at a 5° fixed tilt with carport mounting to experience some partial shading. These conditions, as well as the inverter and Balance of System (BoS) configurations used, are summarized in Figure 1.

The cost comparison was performed by creating electrical and mechanical designs for all of the systems, and then comparing the equipment, material and labor costs associated with each design. The results of the analysis are summarized graphically in Figure 2. As might be expected, the smaller string inverters enjoyed a slight advantage in total cost in the smaller arrays, with the distributed architecture being up to 5 percent less expensive than the central architecture. By interpolating the findings, the cost advantage appears to change around 350 kW-AC 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 rooftop array, and partial shading from trees on the carport 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 line 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 percent, respectively. The multiple array planes also gave the decentralized architecture a slight production advantage. The combination of these factors yielded a 1.5 percent 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 system’s total capacity, which can easily exceed 500 kW-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 favor the use string inverters which are much more compact and lighter than central inverters.
4 rooftop and 12 carport 855kW DC PV system utilizing a distributed architecture design; installed at the VF Outdoor Coalition Campus, Alameda, CA. Photo courtesy of Hawkeye Photography.

500 kW ground mount PV system utilizing a central architecture design; installed at the City of Greeley Water Pollution Control Facility. Photo courtesy of the City of Greeley.
Other Considerations in an Optimal PV 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, and TX and NX 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 Levelized Cost of Energy. As shown, the major differences are to be found in the Balance of System (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 operational and maintenance (O&M) expenditures could become an important consideration in the choice of architecture.

<table>
<thead>
<tr>
<th>LCOE Considerations</th>
<th>TL</th>
<th>TX</th>
<th>NX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
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<td>✓</td>
<td>✓</td>
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<tr>
<td>Balance of System Benefit</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>No DC Combiner</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated Sub-combiner</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Integrated Breaker</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combiner-level PV Tie for Long Home-runs</td>
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<td>✓</td>
<td></td>
</tr>
<tr>
<td>Revenue Meter</td>
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<tr>
<td>3P Monitoring</td>
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<tr>
<td>Inverter 1st Cost (Project Size)</td>
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<td>&lt; 350 kW</td>
<td>&lt; 350 kW</td>
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<tr>
<td>Reliability</td>
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<td>✓</td>
<td>✓</td>
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<tr>
<td>On-Site Service</td>
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<tr>
<td>Remove and Replace</td>
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<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Extended Warranty (up to 20 Years)</td>
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<td>✓</td>
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</table>

Table 1 – 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.
As indicated in Table 1, some peripheral considerations can have a profound impact on PV system economics. Such considerations might include the availability and cost of an O&M agreement, or the desire to minimize energy loss due to inverter failures. Or a plant designed to maximize the capacity factor with a high DC:AC ratio would require an inverter capable of supporting these higher ratios.

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 60 Hz, so only the TL series string inverters are suitable for a 50 Hz system. Or in a system that requires low voltage ride-through, Advanced Energy supports LVRT only in the NX series inverters currently. These and other “feature factors” are identified in Table 2 as general design considerations.

<table>
<thead>
<tr>
<th>Design Considerations</th>
<th>TL</th>
<th>TX</th>
<th>NX</th>
</tr>
</thead>
<tbody>
<tr>
<td>High DC/AC Ratio</td>
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<td>LVRT</td>
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<td>✔</td>
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<td></td>
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<tr>
<td>Voltage Control</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>600 V DC</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>1000 V DC</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<td>Wide MPPT</td>
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<td>Multiple Angles or Shading</td>
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<td>✔</td>
<td></td>
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<tr>
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<tr>
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<td>Grounded</td>
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<tr>
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<td>✔</td>
<td>✔</td>
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<td>Ontario FIT Compliance</td>
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<td>✔</td>
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<td>480 V AC</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>600 V AC</td>
<td>✔</td>
<td></td>
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</tbody>
</table>

Table 2 – 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.
Conclusion

Which is the better architecture in a PV system? As shown here, the answer really is: “It depends.” The size of the project might make a compelling economic case for either a distributed or a central architecture. For systems below 350 kW-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. It depends.

To learn more about PV system design considerations, as well as Advanced Energy’s TL series string, and TX and NX series central inverters, please visit Advanced Energy on the Web at www.advanced-energy.com/solarenergy, or contact an Advanced Energy sales representative at sales.support@aei.com or by calling 877-312-3832.