White Paper

A Guide to Choosing Central Versus String Inverters

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Shareables

- Currently, the cost of string inverters are higher than central inverters, but that gap may close by 2020.
- The operations and maintenance of central inverters may provide less headaches in plant availability in the near-term.
- String inverters can capture performance in more detail than central inverters; this may lead to improved performance for sites with irregular terrain and additional plant diagnostic capability.

Executive Summary:

In recent years, new design methods have been employed in utility scale solar photovoltaic (PV) systems to allow developers to continue lowering cost installation and operating costs. The choice of central inverters versus string inverters can have a measurable impact on the capital cost, operating cost, and potentially the energy yield of today's PV systems. As the PV industry continues to search for opportunities to reduce the costs associated with capital and operating expenses the choice between the two designs will become more important. A PV system designer needs to weigh the advantages and disadvantages of each approach to plant performance while the project developer balances performance against implementation costs.

In the end, inverter component, balance of system, commissioning, operating and maintenance, and replacement/refurbishments costs all must be evaluated when choosing the system design for a specific project.

Plant Design and Installation

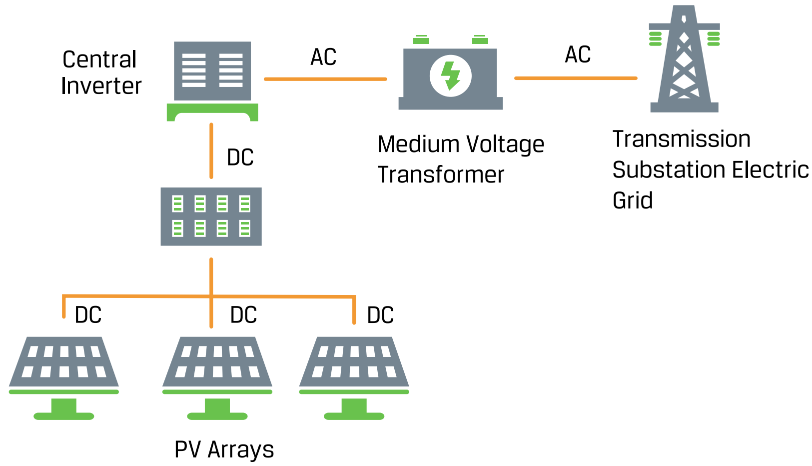
In both plant architectures, PV modules are arranged in strings where the modules are connected in series with each other. The number of modules in a string can vary and will depend on the specific module voltage and whether the system is designed for 1,000 V-DC or 1,500 V-DC. In order to connect to the grid, the output from the inverters passes through a voltage transformer to match the voltage of the grid at the point of interconnection. Table 1 compares a number of attributes from both inverter types.

TABLE 1: INVERTER COMPARISON

Attribute	Central Inverter	String Inverter
Capacity	Up to 4 MW-AC	25 to 125 kW-AC
Installation	Concrete pad or steel skid, crane lift	Rack mountable, 2 person lift
Design	Isolation Transformer, typically grounded, air or liquid cooled	Transformer-less, typically floating ground, air or convection cooled
Cable losses	Shorter AC cable runs	Shorter DC cable runs
Grid Interaction	Advanced Inverter Functions (e.g. frequency/voltage control, reactive power compensation, etc.)	
Unplanned Maintenance	Service failed component in the field	Remove failed component, send to factory for possible refurbishment
Design Life	10 to 25 yr with refurbishment	+20 yr, limited (or no) field service
Maximum Power Point Tracker (MPPT)	Single or Multiple	Multiple
Warranty	~5-10 year	~10 year

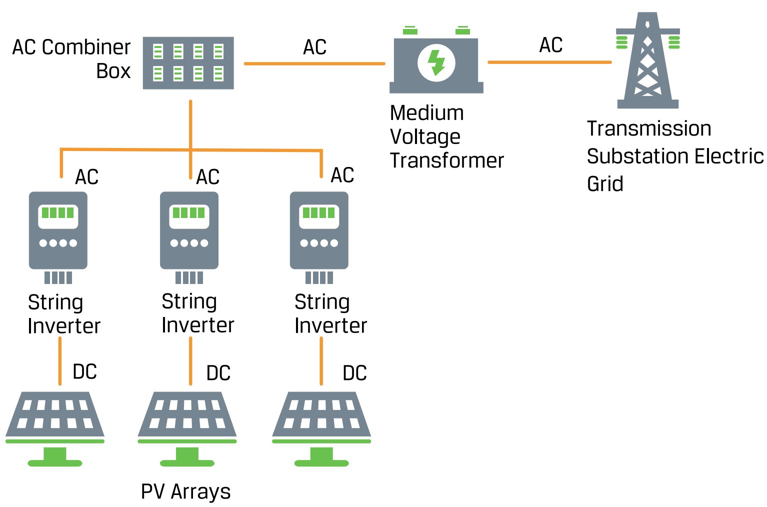
In architectures utilizing central inverters, module strings are combined in parallel using DC combiner boxes before connection to the inverter, an example of this architecture is shown in Figure 1. In larger designs, the central inverter will be integrated into a skid that may include a medium voltage transformer, meteorological station, data acquisition panel, and auxiliary power.

FIGURE 1: CENTRAL INVERTER ARCHITECTURE



String inverters have multiple inputs where the module strings can connect directly to the inverter without using DC combiner boxes, an example of which is shown in Figure 2. Typically, string inverters will be clustered in groups at the end or back of one of the module arrays. AC combiner boxes are utilized to collect the various string inverter outputs and feed into a medium voltage transformer.

FIGURE 2: STRING INVERTER ARCHITECTURE



Impact of Inverter Choice on Plant Costs

Capital Costs

Over the last few years, the gap between the component level average selling price (ASP) of central and string inverters has closed dramatically.

In fact, it is expected that cost of string inverters will be only slightly higher than central inverters by 2020[1].

[1] S. Moskowitz, "Will String Inverters Completely Replace Central Inverters in the US Solar Market?," Greentech Media, June 30, 2016, https://www.greentechmedia.com/articles/read/will-string-inverters-completely-replace-central-inverters-in-the-us-solar.

The main driver for closing this gap is the economy of scale that manufacturing of electronic components benefit from as their adoption increases. Additionally, component costs will decline as inverter capacity and capabilities increases.

The balance of plant (BOP) costs also have to be considered for each approach. BOP costs may include the integration of components into a skid, combiner boxes, various connectors and cabling for routing DC and AC power, as well as the installation labor for those components. Depending on the particulars of the design, savings may be realized by implementing a string inverter approach over a central inverter one.

Several steps are involved in inverter commissioning: visual inspection, de-energized/energized checks, programming, component turn on, component turn on, plant level controller commissioning, and equipment online verification. The specific commissioning processes, time, and cost will be plant design and manufacturer dependent. Additionally, central inverters typically have a more involved commissioning process than string inverters. Some string inverter manufacturers claim that the commissioning time and costs can be significantly decreased with their design. Once EPC or developer staff are trained by the string inverter supplier, the EPC or developer may be able to execute their own commissioning process for future projects potentially saving time and labor. When contemplating a central or string approach, this is another factor to consider as these cost reductions may only be realized over a number of projects.

Operating Costs

The main difference between central and string inverters originates from their power capacity or nameplate rating. This difference in capacity leads to design changes that impact the economics of operating and maintaining the inverter during its life.

The large power capacity of central inverters leads to the need for active cooling. Inverter cabinets are constructed with fans, filters, and vents to allowing cooling of the power modules that convert the DC electricity to AC electricity. In order to ensure proper operation of the inverter, these critical components must be maintained. Additionally, the power module and certain control boards may need to be replaced during the expected life of the plant. The central inverter is designed to be serviced in the field. Typically, spare parts will be kept on site, in a regional storage facility, or on the truck of the operating and maintenance (O&M) service technicians. Maintaining stock of those spares is critical to ensure the desired high availability. When problems arise, skilled technicians are required to diagnose and fix the troubled inverter.

The smaller capacity of string inverters eliminates the need for active cooling. Layout of the inverter components inside the enclosure allows for the heatsink to share one wall of the enclosure so that outside air will passively cool the device. Therefore, fans, air filters, and vents are not required. The low power-per-component nature of the string inverter leads to a design life of 20 or more years.

String inverters are maintenance free, typically, and not designed to be field serviceable. If a unit fails, it is replaced with a new one. Replacement requires a licensed electrician and an additional person to help remove the old inverter and lift the new one in place. Additionally, storing spare inverters either on site or in a regional facility is required, however, no other inverter related components are needed. String inverter failure rates and labor rates associated with inverter replacement should be investigated to understand the impact on O&M costs.

Major maintenance reserves are impacted as well. It is common for central inverter based projects to plan for a major inverter refurbishment or replacement event in years 10 and 20 to ensure continued performance. If replacement is required, due to the central inverter company going out of business, it may be difficult for the project owner to find an adequate replacement. Because of this, additional and unexpected conversion costs may be incurred. With a design life of 20 or more years, the major maintenance reserves must be adapted to provide for adequate spare inverters and then potential replacement in year 20 of the project. Most string inverter manufacturers suggest stocking a small number of inverters in case of unexpected failure. This is a decision point for the developer which depends on a number factors including the desired availability of the plant.

Plant Performance

In both the central and string inverter plant designs , the output power of the various inverters can be adjusted dynamically to maintain optimal performance of the attached arrays while meeting any power exporting requirements at the plant point of interconnection. In the string inverter case, more granular control is achieved as each inverter has a much small number per MPPT. Therefore, if the performance across arrays varies due to non-uniform shading, arrays with different tilt angles or orientations, or damaged modules, the performance of each array can be optimized at the array level such that output of the system is maximized. The specifics of the installation location and site must be evaluated to determine if an energy yield enhancement would be gained.

One of the more obvious performance impacts in PV plants occurs when an inverter fails. Due to the centralized nature of power conversion, if a central inverter goes offline, a significant portion of the plant's output is lost until functionality is restored. The distributed nature of the string inverter approach, meanwhile, results in only a small number of arrays going offline if an inverter fails. Depending on the specific availability requirements of the project, a distributed approach may provide an advantage.

Other Considerations When Choosing an Inverter Approach

Interaction with Modules

The design of central and string are different in one key area: central inverters employ the use of an isolation transformer in their component architecture where string inverters are transformer-less. The impact on plant design is such that central inverter based systems will allow for the negative side of the module arrays to be grounded where in the string inverter based design, the negative side will be floating. In the string inverter case, this means the modules could be exposed to potential induced degradation (PID). PID has been shown to lead to severe degradation if the modules are not designed to be PID resistant[2]. Most manufacturers design their modules to be PID resistant and some even claim their modules are "PID free." Although the mechanism causing PID can be slowed significantly, all modules have some susceptibility to PID when installed in a floating ground system. It is important that the developer of a system using string inverters investigate the PID resistance of the modules to be used in the project by reviewing the manufacturers internal and/or third party test data.

Plant Availability

Plant availability or "uptime" for central inverter based systems are well understood. To achieve high availability, developers have established detailed O&M plans and procedures through adherence to inverter supplier recommendations for preventative maintenance, spare unit storage, and technician training. This results in minimal unplanned maintenance and high central inverter uptime for the plant. String inverters have a limited track record at the utility scale, but have been used in commercial and residential rooftop installations for more than a decade. Typically, the O&M procedures employed for commercial and residential spaces are very different in nature with potentially lower availability targets and less documentation, giving an unclear picture of the true availability. The ease of replacement of string inverters in the field may lead to improved availability but more operating data is needed.

O&M Planning and Replacement

Although string inverters typically have a design life of 20 years or more, that lifetime has yet to be proven at the utility scale. Additionally, the end of life failure rate is not clear. Because of this, long term O&M planning can be a challenge for a project. String inverter suppliers will provide guidance on the number of units that should be kept on site or a central storage facility during the initial period of performance, however, often they will not be able to provide definitive guidance for extended useful life. This can be a challenge for projects that plan to operate past 20 or 25 years. Planning for an inverter replacement late in the project may be a method to minimize this risk; one mechanism for this may be a major maintenance reserve allocation for the project to fund this replacement.

[2] For example: https://en.wikipedia.org/wiki/Potential_induced_degradation.

Replacement options for either central or string inverters after 20 or 30 years is another area to be considered. The main concern in both cases is compatibility with the existing electrical design and controls system of the project. The original supplier may not be in business when needed and unable to supply direct replacements. This may require the use of voltage converters to match the array voltage to the inverter as well as the inverter output voltage to the medium voltage transformer. Additionally, the new inverter may have a different communication method as well as a different protocol. This would require replacement of some control equipment as well possible redesign of the control system.

Final Thoughts

There are many things to consider when choosing between a central or string inverter approach to a given project. Early in the design phase, the choice of inverter has an impact on the number and type of components required in the balance of plant, the layout of the overall plant, how various power losses are rolled up, and the installation logistics. Cost is the bottom line for solar systems and every aspect of capital and operating costs should be evaluated in order to determine the optimal approach for a given project. Labor, equipment, quantity of components, maintenance requirements, commissioning, and replacement costs are some of the inputs that make up the overall cost picture for the project. Lastly, string inverters provide the ability to capture the performance of the system in more detail than central inverters, allowing for the possibility to optimize and monitor the performance at the array level. This feature may lead to improved performance for sites with irregular terrain and additional plant diagnostic capability.

About the Author

Todd Tolliver has over thirteen years of experience in the field of photovoltaics working in the research of and manufacture of photovoltaic materials, solar cells, and modules. He supports clients through technical due diligence and owner's advisory services and has leveraged his knowledge of solar materials, technology, and manufacturing to support 500 megawatts of solar photovoltaic projects. Mr. Tolliver specializes in component technology reviews, system performance modeling, and project management for photovoltaic and energy storage systems in support of project finance and other asset transactions.

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