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Growing from 1000VDC PV Systems to 1500VDC; Why and How?

Why did the industry move from 600 volt solar arrays to 1000 volt solar arrays? The answer is simple, to reduce system costs. The value of increased system voltages is realized in infrastructure savings, reduced installation costs, and end-to-end efficiency improvements. That is the same reason that the industry is now moving from 1000 volt systems to 1500 volt systems. Central inverters have led the way, but Sungrow has just introduced a 1500V string inverter that promises a complete industry shift.

Although 1000VDC-rated BOS equipment was generally more expensive than 600VDC equipment, those costs were more than offset by the cost reductions throughout the overall system. As the volume of the higher voltage rated components and wire increased, the installed costs were reduced even further. Again, the story is repeated with the move towards 1500VDC systems. The primary reason is the 31% to 37% decrease in DC current for the same power.

Higher array voltages mean fewer strings, connections and terminations, reduced cabling, lower system losses, decreased inverter cost for a given capacity and increased energy throughput. However, a move from 1000VDC to 1500VDC is not that easy to accomplish. The availability of BOS components and solar panels that are rated for 1500VDC is still limited even after more than a year since the first 1500VDC systems were installed.

Challenges in stepping up to 1500VDC

One might ask why stop at 1500VDC? Why wasn't it 2000V? The short answer is the solar panel, switchgear, fuse, and circuit breaker manufacturers weren't ready to work with an increase of 1000V, so the acceptable challenge was a 500V step above the 1000VDC rating.

1500V rated wire is not the problem. Switchgear, fuses, surge protectors, circuit breakers and other BOS components are still being introduced and certified. The reduction of current is the advantage, but the corresponding disadvantage is the conductor spacing (creep). Spacing must be greater for the higher voltages so the equipment gets correspondingly bigger and takes up more room. Internal arcing becomes a bigger concern so the design standards for these components become more complex and costly.

Cooper Bussmann announced 1500VDC fuses in late 2012 and ABB announced their line of 1500VDC disconnect switches, molded case switches, contactors, surge protective devices and sensors in late 2014. Other manufacturers have joined in and the competition to supply the industry with the full range of 1500VDC rated components has both kept prices in check and increased the range of available product options. However, the list is still limited compared to those rated for 1000VDC.

The inverter manufacturers have a longer list of internal changes to take their products from 1000VDC to 1500VDC. The ratings for all the components that are exposed to the higher DC voltage have to be compatible so this means changes to the electrical as well as the mechanical designs. In many of cases, new suppliers have to be found and qualified. The good news is that at any given power capacity, with the increase in voltage, the current is reduced. Inverters are power conditioning units that essentially, “push” current at a fixed voltage. The higher the current, the higher the heat and the higher the stress on current carrying components and switching devices. So a reduction in current is, in general, a good thing from the inverter’s perspective.

Going to the higher DC voltages does not impact the ability of the inverter to meet UL1741. As long as the components used in the inverter are certified to meet UL standards for the voltage and current, and the inverter itself passes the UL tests to the appropriate IEEE standard, it can be certified for grid connected applications

Efficiency and cost considerations for 1500VDC PV Systems

Higher output power levels can be obtained from essentially the same IGBT stacks if the current is reduced.The catch is that to work at the higher voltages, IGBTs have to be rated at the higher peak operating voltages. This means more expensive devices and higher switching losses. Some inverter manufacturers have had to accept lower efficiencies (usually .5% lower) compared to 1000VDC inverters. Sungrow has been able to maintain the same CEC energy conversion efficiencies in their line of 1500VDC inverters as they do in their line of central and string 1000VDC inverters (98.5%).

There are cost savings on the AC side of the inverter as well. With the increase in DC input voltage, the inverter can be designed for a higher AC output voltage. This reduces the AC current and allows for smaller gauge wire to be used for the wire runs from the inverters to the transformers. For example, a change from an output voltage of 480VAC to 600VAC reduces the current by 20%. For the same distance between the inverter and the point of connection to the transformer, this can mean a reduction of two wire sizes in most cases (example: 3/0 wire to 1/0 wire). Staying at or

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below 600VAC allows all the wire, switchgear, and circuit protection to be standard, 600V rated components and avoids the premium of going to a 1000V rating.

Solar panel manufacturers who want to offer solar panels that are rated at 1500VDC have to change some of the materials (backsheet), spacing of insulating materials, manufacturing processes and testing limits in order to produce solar panels that can be used in 1500V strings. This actually causes a price increase for the 1500VDC rated panels over the 1000VDC panels of around 5 cents per watt. This premium will vary with manufacturer, so the 5 cents mentioned here is just an order of magnitude estimate.

One of the largest cost reductions in 1500VDC systems is the ability to put more solar panels in each string, reducing the number of strings along with reducing the number of string combiner boxes. This reduces the wiring cost, string combiner box installation costs, and trenching costs for the home runs to the inverters. More solar panels per string increases the range of solar array operating voltages but the current remains the same as with 1000VDC strings. This means that the string wire gauge stays the same. For normal string wiring, 10 AWG USE-2 wire can still be used.

Comparing the number of strings required for a typical, large scale, 1000VDC solar power system to one of the same capacity at 1500VDC yields some interesting results. There is a 37% reduction in the number strings required which translates into a 37% reduction in the number of combiner boxes and the number of home runs to the inverter DC cabinet. This corresponds to a 12% savings in hardware costs, 22% savings in wiring costs, and a 10% savings in labor costs. These are estimated averages that will vary from project to project.

From an O&M standpoint, there should not be any significant cost impact between a 1000V system and a 1500V system. This goes for the inverters themselves as well. The number of man-hours required for normal operation and maintenance tasks would be the same.

From a Field Service and safety perspective, there is an impact. Arc flash is a topic that presents a concern, especially a DC arc flash. All Field Service personnel have to be aware of the higher voltages and the added risk for arc flash and adhere to the applicable safety procedures. It is typical for site owners to conduct an arc flash study on the equipment and place the warning labels on the equipment.

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Looking ahead: What 1500VDC means for the solar industry

So where are the real savings? If there is a premium for 1500VDC rated solar panels, and the 1500VDC rated BOS components have a premium, will that offset the savings in wire, labor, and other installation costs? If the inverter has a lower CEC weighted efficiency that results in a lower energy throughput, then the answer will be a resounding "maybe". To some degree, the savings will be site specific, but with the high cost of wire and labor in the US, there will definitely be a reduction in the cost of the installed system. This is verified by the fact that virtually all utility scale project developers and EPCs are going with 1500VDC systems.

A recent survey showed that the over-all savings estimates for 1500VDC system installations by experienced EPCs were in the range of 20% to 25% compared to 1000VDC systems. The variables include the cost of the wire (changes with the market price of copper), the local labor rates, union or non-union, system architectures, use of trackers, and the choice of inverters.

So where will the industry go from here? It may move to even higher DC voltages, but the costs required to design and manufacture key components that can handle say, 2000VDC, may be too daunting. Most, if not all of the innovations and design changes have been incorporated based on their ability to reduce costs somewhere in the BOS components, installation, or O&M processes. Large volume orders and competition among 1500VDC component suppliers will continue to drive BOS costs down.

Proof that 1500VDC systems are the new standards for the PV industry is Sungrow's introduction of a 1500V string inverter. This is the world's first string inverter with the higher DC input voltage range, but as with other firsts, others will follow. This inverter puts 125kW of capacity in a suitcase-sized cabinet that weighs about 130 pounds. Designed to be a lower installed-cost, high efficiency alternative to the integrated, central inverter systems being built today, the 1500V string inverter has the potential to be a true "game changer" for utility scale system designs going forward.

For more and more cases, there is a solid basis for cost reductions when string inverters are designed into the system in place of large capacity, central inverters. There are always trade-offs, so the comparison has to be done on a case-by-case basis, to take into consideration factors like terrain, array geometry, site access, and proximity to service personnel. However, it is likely that this may be a near term path to further reductions in system costs.

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