Plant design and the age of the large-format module

System design | The introduction of large-format modules promises to pose both benefits and challenges to developers. Christopher West, head of central engineering at Solarcentury, explores the many considerations PV designers must bear in mind now large-area modules are on the market.

In 2019, an interesting trend started to appear in the PV market, in which the increase in module peak power was not being driven by significantly improved cell efficiencies, but instead by simply making the PV modules bigger. Over the course of 2019 and 2020 modules of over 400W started to appear, with some astonishing powers being announced by module manufacturers, including a module of over 800W making its debut at the 2020 SNEC trade fair in Shanghai.

But while in the past we were seeing incremental increases in power within the same size of module as the quality and technology of the cells improved, now we are seeing very dramatic increases in power being brought about simply by having larger module sizes. The 800W high power module, for example, has a surface area of almost $4m^2$, while up until the current trend began, the standard 72 cell modules were about $2m^2$ and were pushing close to 400W in peak power.

It is tempting to look at this trend and think that there is nothing really innovative about all of this. Haven't module manufacturers essentially just stuck two modules together? It seems as unimaginative as jumbo-sized bars of chocolate; the same chocolate, just bigger! But scratch beneath the surface, and the reality is that none of this could have happened without some important technological advances that happened previously, and that what we are seeing in the market right now is a phase of permanent readjustment to module sizes that simply weren't possible before. In particular, split-cell, multi-busbar and dense interconnection strategies have opened the doors to numerous possibilities of connecting cells together in a PV module, and this has led us to the baffling range of modules now available in the market.

The use of these large format modules does allow for some important cost savings on the module itself, since one large module uses less metal framing than two smaller modules, and there are some important Balance of System (BOS) savings when constructing a utility-scale PV farm, particularly with respect to cabling and racking systems. These must be traded off against some critical design considerations that arise as a consequence of the increased module size, especially regarding wind-loadings, electrical sizing and planning considerations. But all indications are that the use of the large-scale format genuinely reduce the costs of building utility scale PV plants, and right now they are being rapidly adopted into new PV plant designs. The large-scale format is definitely here to stay.

Although this phase of readjustment is disruptive, all major manufacturers are now embracing the new large-scale formats and are settling around certain

Credit: Nextracker

The combination of large-format panels with trackers will pose some challenges for PV system designers.

Credit: PV Tech

A selection of the 550W+ panels on display at SNEC 2020.

standard cell and module sizes. There are signs that the market will start to consolidate around a couple of new 'standard' module sizes for utility plants, reducing confusion for installers, and that once again we will start to see incremental increases in power driven by innovations in efficiency, along with an increasing trend towards bifacial modules.

Development of large-format modules

The main technological driver pushing the new large format PV modules has been the changing sizes of wafers, which have increased in size from the original standard 156mm sizes up to the two new competing cell sizes in the market, which are 182mm and 210mm respectively. In the past using such large cell sizes would have been problematic because of higher losses deriving from the higher currents, but the last few years have seen the innovation of split-cell modules. With split-cell technology, the cells are cut into two or three pieces, and the current is divided throughout the three pieces, recombined at a common busbar later on. This reduces the thermal losses and increases the overall thermal performance of the cell.

Additionally, there have been important technological advances such as multi-busbar technology, which has in turn led to methods of reducing or eliminating the distances between cells such as paving, tiling and shingling. These methods greatly reduced the gaps between the cells, and sometimes the cells can even overlap each other. These technologies reduce the resistance of a cell, as well as the resistance between cells, and therefore the larger format modules are not quite as large as they otherwise might be.

These technological innovations ultimately opened a floodgate that have allowed module manufacturers to try out different cell sizes, cutting them up and recombining them in various ways, creating a myriad of new module sizes and types, while still keeping the current and voltage parameters within manageable values for system designers. In some cases the module voltages are even less than those of the 72 cell modules, potentially allowing module manufacturers to use longer string lengths in their design.

All this has led to a somewhat confusing proliferation of different modules in the market, and different manufacturers made their bets on different cell sizes, trying to guess which technology and combination will be the best in the long term. This makes it a confusing time right now for system designers who are being marketed a number of different products, but find it difficult to know which one is really best for their project.

The good news is that module manufacturers have now invested a lot of money in their manufacturing lines to cope with the new cell sizes, and the current state of play is that most manufacturers are now banking on either the 182mm or 210mm size cells. Additionally, all these changes have been disruptive to suppliers further up the supply chain, who need to produce ingots for the new cell sizes, as well as glass, backsheets and other balance of material items to handle the new module sizes, and the more they can standardise, the cheaper the product becomes. This means there is a strong motivation now for manufacturers to consolidate around just one or two module sizes, since it is in the interest of the entire supply chain servicing the production of PV modules to standardise as much as possible, and hopefully the choice will be reduced in favour of economy.

General principles of design

The use of large format modules can potentially provide important savings on the balance of system costs when building a utility-scale plant, particularly on the racking systems and the cabling.

A good example can be illustrated by looking at trackers. A tracker is designed to carry a certain quantity of modules, and it can generally be compatible with larger sizes than the 72 cell with minimal adjustments. If a tracker has been designed to carry 84 modules that are 2 metres long, it's not that difficult to adjust that tracker to cope with 2.2 metres long, and you have a situation where almost the same tracker, with the same motor, is now handling a greater power. Less modules also mean less fixings, bolts or clamps on the frames, for both fixed and tracker systems.

There are also important potential savings on cabling: string cables are generally designed with plenty of spare current carrying capacity, with system voltage being the limit of how many modules a string is coping with. If a module has suddenly jumped up from 400W to 600W, but the string voltage is essentially the same, then suddenly the same cable is dealing with 1.5 times the amount of power, meaning less cabling for the same peak power.

Both of these lead to a potential reduction on installation cost as well, since there are fewer trackers to assemble, fewer modules to mount and fewer strings to crimp and connect.

However, for the PV plant designer, the use of large format modules introduces some interesting challenges, and there are a few key points to bear in mind. Firstly, it is very important to understand that the additional power of these modules is not driven by efficiency, but by size, and so when a designer is looking at their current portfolio of project designs, they cannot simply think they are going to replace all their 360W modules with 800W modules, and have a PV lant with more than double the capacity.

Up until the advent of large format modules, a plant designer could keep the pitch between module rows exactly the same, and an increase in power would simply mean a potential premium to be paid for a more efficient module, but this is no longer the case – the PV designer needs to increase the spacing between mounting structure rows in proportion to the increase in size of the modules in order to keep the ground-cover ratio the same. If they do not do so, then there is the impact of increased inter-row shadings on a fixed system, and increased shadings of the diffuse sunlight on a tracker system.

This is also important when considering planning applications. If a developer has achieved planning consent on a tracker system, for example, by assuming the maximum height reached by 72 cell PV modules when the tracker is at maximum rotation, then they might well be restricted in the use of the large-format modules, because these modules will attain a higher height when the tracker is fully rotated. Therefore, designers and developers alike should consider the maximum size of any modules they are potentially going to use early on in the planning process, in order to avoid problems of planning compliance later on.

Additionally, the height and weight of the modules produce interesting physical challenges during installation. Something that might only have required one person to handle might suddenly require two people instead. On a ground-mount installation, this is definitely manageable, but on a commercial rooftop under windy conditions, this can open up important Health and Safety implications – when carrying these larger modules on a roof, an installer is essentially walking around at height with a massive, heavy sail in their hands. Extra care must always be taken for safe working practices and anti-fall protection when working at height, but this is especially true when using large format modules.

Wind design

Wind considerations are of particular importance for ground mount tracker systems. Over the last few years, there have been a number of wind incidents that have caused large amounts of damage. There have been quite extreme incidents where entire PV plants have been wiped out by hurricanes, but additionally quite a lot of destruction has been caused by relatively low wind speeds on some tracker systems. Under certain wind conditions, resonant vibrations can be set up on dynamic systems such as trackers, and these resonances can cause destructive effects such as torsional galloping along the torque tubes of the trackers, tearing the system to pieces under wind speeds that aren't particularly violent themselves.

> "One should definitely consider whether sufficient spare modules have been considered to last the lifetime of the project."

Luckily, over the last couple of years, tracker manufacturers have made massive improvements in their understanding of the dynamic wind effects upon their product, but the larger surface area of the new generation of PV modules means that the force of the wind upon them is greater, making them even more vulnerable to such effects. Therefore, it is very important to engage the tracker manufacturer early on in the design process, since they might need to make some important adjustments to the proposed design in order to accommodate the modules.

A PV designer might consider designing the entire plant using trackers that can hold three strings of 28, so 84 modules each. However, the tracker manufacturer may well see that the extra wind load caused by using the large format modules will mean that the tracker cannot withstand the increased wind load, especially around the edges and corners of the PV plant where wind effects are stronger. They might say that the trackers in those locations should only carry two strings instead of three, ie: 56 modules instead of 84. This could eliminate the BOS advantage of using the large-format modules in those locations, and it may even make the overall installation more expensive. Therefore, it is very important to understand the wind speed of a site early on, and to discuss the implications of larger format modules with the tracker manufacturer, otherwise estimated cost savings might be significantly over-estimated.

Additionally, something that is true for all tracker projects, but especially so when using large format modules, is that it is important to perform *site specific detailed dynamic wind load studies*, including wind tunnel testing, for the tracker/module combination with an established wind consultant, and not just rely on static wind load reports. Failure to do so means that

Credit: TrinaSolar

The addition of larger, heavier modules to existing tracker designs will require more thought when it comes to wind.

the projects will be potentially vulnerable to torsional galloping and vortex lock-in.

Electrical design

The large format modules have been designed in such a way as to keep the voltages as similar as possible to the 72 cell formats designers are used to. In some cases, open-circuit voltages have increased slightly from 45 to 50V, but in other cases they have stayed the same, and some designs have even reduced the open-circuit voltage down to 40V. This is very important with respect to the string lengths that can be selected for a particular site, and in the latter case allows for string lengths of longer than 30 modules on a site, which can reduce cabling costs.

The fact that voltages are controlled means that the increase in power is driven by increases in the current, and ampacity of cabling becomes very important, especially so when considering bifacial modules. String cable typically has plenty of spare capacity, however, DC cabling running from string combiner boxes back to central inverters may need larger cross-sections than expected in order to cope with the higher current.

There are some important caveats with respect to the electrical design. Firstly, the existing generation of trackers are typically designed with strings of up to 30 modules in mind, and so pushing the string length over 30 may not yield any benefit, especially if such an increase in the number of modules exacerbates the problems with wind loadings. Therefore, before the BOS savings of large format modules can be fully achieved in the market, it is important for tracker manufacturers to develop products that can cope with longer string lengths and that are more resilient to wind effects.

Secondly, a large number of PV plants are being built with string inverters, that typically have a maximum number of strings that can be connected. The power rating of these inverters has been optimised for 72 cell modules. For example, in the market there is a 185kW inverter that can receive up to 18 strings. If the designer uses 400W modules in strings of 28, this adds up to 201kWp, giving an oversize ratio of 1.08, which is reasonable. But if the module used is 600W in strings of 28, this gives a total of 302 kWp, and an oversize ratio of 1.6, which is pretty excessive for most designs. If a designer wanted to achieve the same oversizing ratio as the 400W modules, only 12 strings would

PV system designers will have to consider how the large-format modules will affect DC/AC oversizing ratios on inverters, and manufacturers may need to develop products more compatible to the new modules.

Credit: Huawei

need to be connected to the inverter, but this means the other inputs and available MPPTs that are available are being wasted. The problem is exaggerated even more when using strings of longer than 30. Inverter manufacturers have a tricky job to guess which large-format design is going to win out, and to create products that are better tuned to the new generation of modules.

Large-format modules in the long term

One final important question is the long-term reliability and maintainability of these products. These products have been in the market a very short time, and although they have undergone the same testing as other PV modules, there are questions over whether larger cell sizes will be more vulnerable to mechanical stresses and therefore micro-cracking, and whether the denser interconnection methods will put more stress on the PV cells than the older designs.

Although these sorts of problems are covered by manufacturer warranties, there is an additional factor to consider: with such a large variety of module sizes and electrical characteristics suddenly available, and with market consolidation likely to happen quite soon, how easy will it be in the future to obtain replacement modules of the same type for covering guarantees or replacing breakages? Modules should only be replaced in a string if the voltage and currents roughly match those of the original modules, and the combinations currently available in the market are very diverse. Therefore, until the market has settled on a new standard size, there is always the risk that the large scale PV module that's been chosen for a project is the one that will go out of fashion in a year or so, and limit the options for fixing problems in the future. For imminent projects, one should definitely consider whether sufficient spare modules have been considered to last the lifetime of the project, just in case it is a challenge to find them in the future.

It is certain, though, that these large format modules are here to stay, and they are quickly becoming the new normal for utility scale PV plants, since the potential advantages they bring are quite significant. Most of the disadvantages that these modules cause are more about the disruption to an existing supply chain, and to designers of trackers and inverters who have built their products around the 72-cell module. However, the good news is that as these manufacturers adapt to the new reality, the BOS costs have a continued pathway to drop further. Hopefully the large-format market will consolidate and settle down to a new 'standard' module size, both in terms of size and electrical characteristics, in order to give clarity to the rest of the supply chain about which direction to develop their products, and in order for asset owners to feel comfortable about the long term maintainability of their projects.

Beyond the large-scale module there continue to be interesting innovations that will continue to improve cell efficiencies, and in parallel there is also a trend towards using bifacial modules. It is very likely that the module of choice in the near future for utility scale projects will not look at all like the 72-cell modules we've been used to for some time. The module of the future will be larger and it will be bifacial, and it's just the exact dimensions of this module that we are all holding our breath to see. ■