idealPV Core Inventions

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One of the core idealPV inventions is a way to eliminate reverse conduction in solar cells. Reverse conduction is a major problem in solar panels, and leads to reduced efficiency and early failure. idealPVs look and act like conventional solar panels. Their major differences are much lower cost, and a considerable relaxation of requirements for manufacturing, installation and maintenance.

idealPVs realize these benefits:

- Use of low cost silicon
- Elimination of reverse conduction: no hotspots
- Ability to use Portrait and asymmetric installation: high dirt and snow tolerance
- Module adaptation: tolerance for differences in power, light, shade and heading
- Greatly simplified assembly process with wide tolerances

When arrayed in series, idealPVs can each reach maximum power over a wide range of currents. With respect to Form/Fit/Function, idealPVs are mechanically and electrically standards compliant with a superset of a standard 60 cell solar panel.

Consider one practical result: idealPVs can be mounted on different headings in the same array.

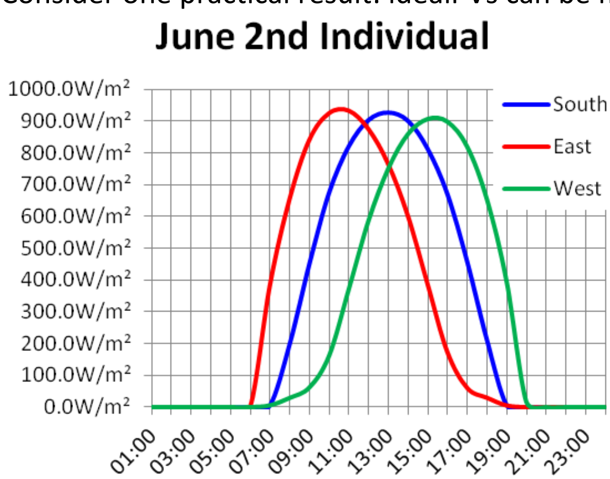

Figure 2:

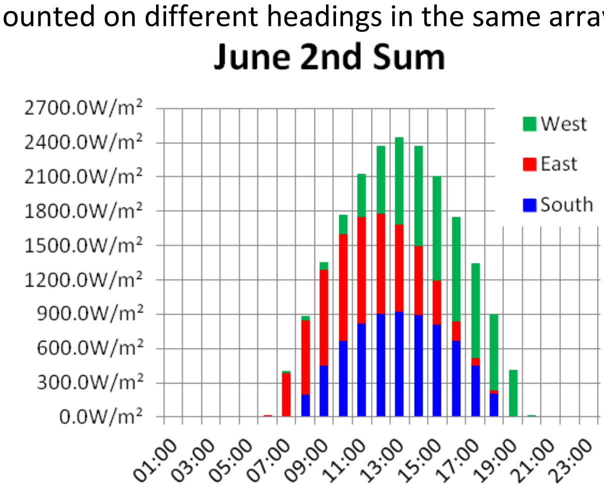

Figure 1

Consider an idealPV single series string totaling 3kWdc. 1kWdc each facing East, West and South.

Under California's EM-TOU Residential Time of Use Service, on this day, the value of the energy for the West facing part of the array is $1.63, South; $1.58 and East; $1.21. Even though the West facing portion produced the least total power, under EM-TOU, the peak value period is from 1pm to 7pm. If this had been an E-RSMART, "SmartDay Event Day" the West facing portion would have been worth over $4.

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In much of the US, home roofs have 4 approximately equal faces. In many cases the roof is on top of two or more stories making the roof small in proportion to the living area.
The charts above show the same data for a home at about 42N latitude. In addition to solar radiation, this data includes the effects of weather, air temperature and internal cell temperature at the site. The data has been normalized to the standard solar radiation of 1,000W/m². So a 220Wstc idealPV pointed east at 10am would produce 820/1000 or 82% of 220W = 180Wdc peak.

In the past, the conventional home in the Midwest or Northeast, utilizing conventional solar technology, could harvest only a small amount solar resource, if any. The limiting factor was that all conventional solar panels in a single series "string" had to be the same power, heading, tilt and temperature so that they could match their common current at the same power point.

The practical effect is to limit many homes to a theoretical 8 or less solar panels. Theoretical because eight conventional solar panels may not produce enough voltage to even start a standard residential power inverter, making application of solar power impractical.

idealPVs can utilize any heading from due East through South to due West and an unlimited number of mounting angles. This means that a home with only enough "prime south" roof for a theoretical 8 solar panels yielding a theoretical $269 a year can support 20 idealPVs yielding a respectable $580 a year (midwest power @12.7¢/kWh).

Notice the sharp climb and early high peak on the eastern facing (red) portion of the string. This is due to the low 43° temperature at dawn that morning.

Beyond making solar practical for the majority of homes in the US, this configuration has many economic and technical advantages.

Electricity has differing values over the course of a day. In many part of the nation, pricing is based on Time Of Use. West facing solar panels produce power late into the afternoon, capturing more high value power.

In the winter, the situation can be reversed where the low sun angle, cold mornings and low afternoon electricity rates favor the East facing part of an Array.

Technically, this energy production profile has a lower peak and a longer production day then a conventional, one direction array. This reduces peak loads on the inverter, holding its temperature down and extending its life.

The lower peak power has less chance of driving the utility service into an overvoltage condition which would cause an inverter shutdown and loss of production.

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A real stress on PV systems happens when cloud lensing occurs. On a day with scattered to broken bright white cumulus clouds, the sun can have a direct path and also a path reflected off the clouds and in the winter, the snow covered ground. With multiple headings within the array, the peak power and stress on the array, is reduced.

Details:

Eliminating reverse conduction removes over 50% of all the specifications of a solar cell. Reverse conduction and related parametric failure account for 2-3% of rejected cells for Semiconductor Grade feed stocks and up to 20% for Upgraded Metallurgical Grade. CaliSolar is a UMG supplier one might be familiar with from last year's Metal Center exercise.

Such cells are often referred to as "C" grade and are sold for 1/3 to 1/4 the price of "A" cells, if a buyer can be found.

Elimination of reverse conduction also eliminates bypass diodes and their internal buss bar connections. These simplify solar panel assembly.

Without the need of bypass diodes and buss bars, it is now practical to put more, shorter cells in series which reduces internal cell and panel currents and increases internal panel voltage. This allows for the use of large portions of cells with corner chips, local AR defects and cracks. This also allows solar cells to be made on lower cost 450mm wafer technology in the future.

With about 1/4 the current, interconnect losses become small. For various reasons, the losses are actually cut by a factor of 64 (4^3, not 4^2; the reduction is cubic). This eliminates the need for silver in solders, stringing ribbons and eventually even from the cells themselves. Soldering is now simpler, more defect tolerant and ribbons and solders become less costly.

With a larger number of cells, cell to cell matching becomes much less important (central limit theorem), which further simplifies assembly. Shorter cells experience less thermal mechanical stress making them more tolerant to soldering and laminating and more reliable in the field.

Reverse conduction is prevented by an idealPV multiphase power converter that isolates the cells within the panel from other solar panels in an array and the inverter. For example, the inverter induced 120Hz current ripple that can be up to 10% of the DC input current is effectively isolated from the current on the internal PV cells within an idealPV panel.

The idealPV DC converter converts high voltage at low current from two asymmetric subarrays of cells within the panel into a single, standard low voltage / high current profile on a standard pair of DC cables and connectors. This interface is interchangeable with conventional 60 cell format modules, cabling and standard inverters.

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Although standard, an idealPVs output Current / Voltage (IV) curve is much more compliant than solar panels in use today.

The power curve and IV curve for a conventional solar panel are on the left below. Power and IV curves for an idealPV of the same power are shown on the right.

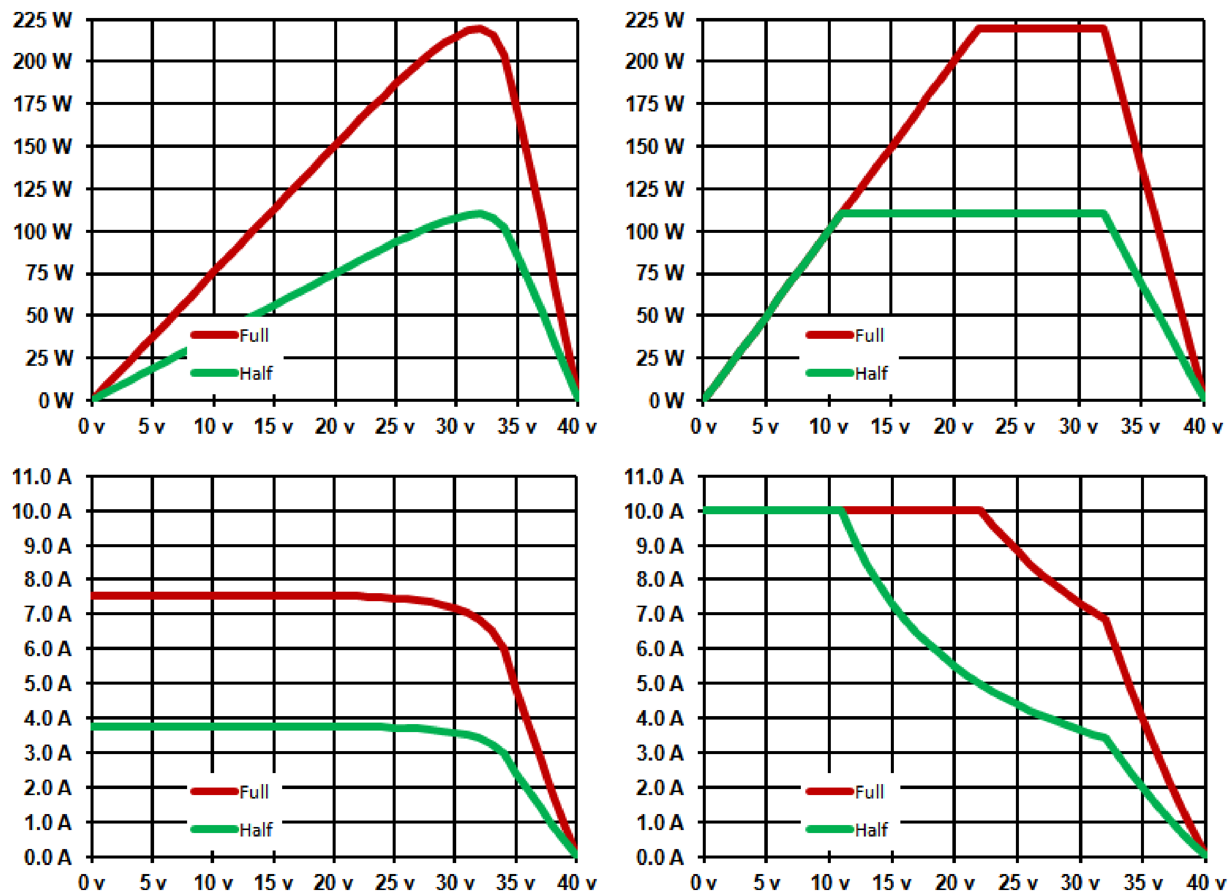

Figure 3

Notice that the curves for the conventional solar panel (above on the left) have a single maximum power point (mpp). This means that there is one voltage point for maximum power (Vmp) and one current point for maximum power (Imp).

When this solar panel is placed electrically in series with other solar panels in an array, the current through each solar panel is the same. Because the currents in each panel are the same, maximum power for the array is only achieved if each solar panel happens to have the same Imp. This means that each solar panel must be matched with every other and be on the same heading and angle so as to receive the same sunlight and be at the same current.

For two conventional solar panels in series, there is no current where both panels can be operating at their Mpp when one is receiving half (or lesser) illumination than the other.

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This can be seen by attempting to draw a horizontal current line that intersects both the full and half power curves at the maximum power point for each curve. Conventional panel IV curves are shown above on the lower left.

Where a conventional solar panel has operating points, an idealPV has operating regions. Notice that the idealPV curves (right side above) have a wide maximum power region (Mpr). There are corresponding Vmr and Imr regions. When idealPVs are placed in series, there are a range of currents that produce maximum power from each idealPV solar panel. The idealPV IV curves are shown above on the lower right.

For two idealPV solar panels in series, there is a range of currents where both panels can be operating at their Mpp when one is receiving half (or lesser) illumination than the other.

Looking at the graph, one can draw a horizontal line of current that intercepts both the half and full illumination curves within the Mpr of each. In fact, any equally or lesser illuminated idealPV will match within the Ipr (7 to 10A) of the fully illuminated idealPV.

The practical implications of this are that idealPVs may be arrayed in series over of wide difference of maximum powers, pointing angles and shadows, with each idealPV reaching the full power available to it.

This compliant nature of the idealPV power curve makes installations much less demanding and utilization of much more roof area with a single inverter. In ground installations, alternate rows of panels can be deliberately installed 5 to 10 degrees off axis to "peak shave" the power rating of the inverter improving inverter conversion efficiency and/or life time and/or reducing inverter cost.

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The following drawings explain the shade and dirt tolerance of idealPV technology. The diagram on the left is the how an industry standard 60 cell module is internally connected.

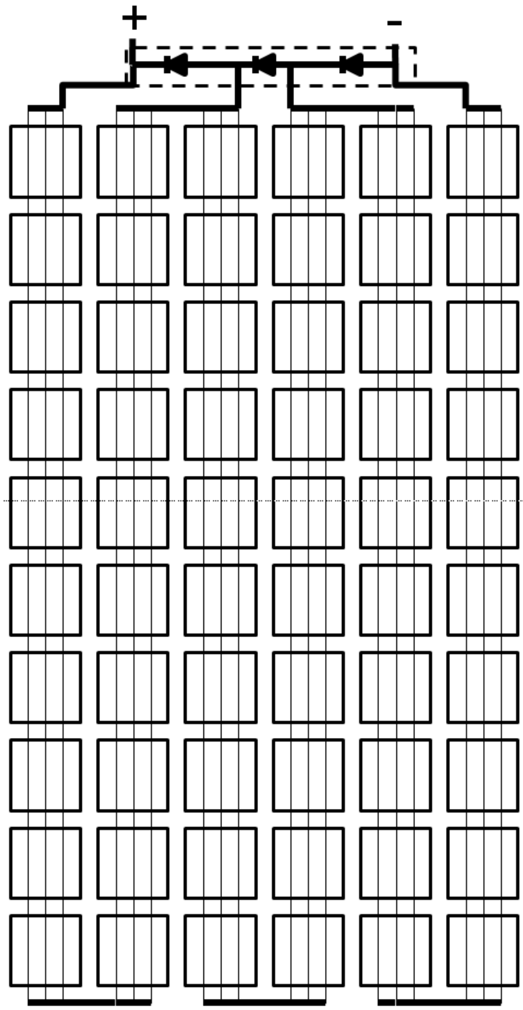

Figure 4: Conventional 60 Cell Panel

The four heavy connections at the top of Figure 4 connect into the junction box.

The two heavy lines (+ and -) are the two cables that connect this solar panel to others in the array. Each internal substring of twenty cells are in series, so if a shadow is cast across the bottom of the panel, two cells in each string produce less power. This cripples the entire module. Row to row shadows fall naturally fall across the bottom row, as does dirt and snow.

Figure 6 is a patent pending idealPV.

Terminals A, B and C connect into the idealPV junction box (not shown). As above, two standard cables with standard connectors at standard voltages and currents come out of the idealPV junction box.

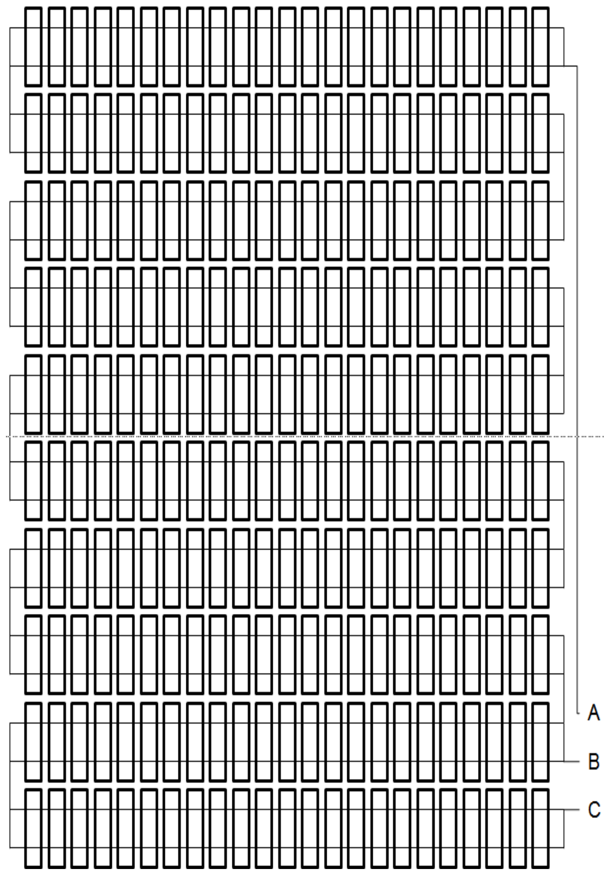

Figure 5: idealPV “60 Cell” equivalent

Notice that the idealPV is wired horizontally and has two asymmetric substrings.

The lower string represents 20% of the modules' power, which minimizes the effect of the natural shade and dirt that happens here.

Internally, the idealPV converter combines the power from each sub string into an industry standard electrical interface.

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Figure 7

The main activity of idealPV assembly is soldering flat copper ribbons onto solar cells (Fig 6). Stringing ribbon wires are soldered from the top of one cell to the bottom of the next cell, placing the cells in series. When the cells are jigged, the soldering motion is smoothly done from left to right. This means that for manual assembly, the length of the move determines throughput and is independent of the number of cells.

Reasons for the idealPV's design include simplification of layout, ability to ignore most vent pipe shadows, tighter row to row ground spacing and low maintenance.

Figure 7 is a contrast enhanced photo is of standard dust distribution on a test array.

The normal action of gravity and dew tends to move dust down even under dry roof top conditions.

Figure 8

Figure 9

Figure 8 is from a moister climate showing a normal dirt pattern at the bottom of a panel caused by dew transporting dust down the panel each morning before evaporating as well as splash from the structure below the panel.

In this conventional panel, with conventional vertical busing and symmetric internal substrings, this dirt pattern shades two cells of every substring. This would result in this panel producing essentially no power (nominally >200W loss).
In full sun, there may be significant heating of the partially shaded cells as well. An alternative might be to mount this panel in landscape mode however, production would still be down over 30% and roof utilization would be lower.

A dirt pattern like this on an idealPV causes about a 6% drop in power (nominally ~14W loss) due to its Patent Pending horizontal busing and asymmetric internal substrings. These features are also designed to result in earlier spring production as snow and ice tend to clear from the top of the panel first.

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For conventional solar, the four partially shaded panels would produce almost zero power.

Additionally, the loss of 4 of 12 modules when shaded might prevent the inverter from reaching its minimum strike voltage resulting in no power production when this shadow is present.

For an array of idealPVs, the four partially shaded panels would produce over 80% of nominal power.

Figure 11: Vent pipe shadow

In conventional PV shown from the back in figure 11, shaded cells absorb power from the lit cells and become hotter.
In an idealPV cells that are shadowed produce less power and become cooler.

On this conventional panel, the partially shaded cell (white) was not able to produce as much current in forward bias as the other cells in its substring. In this thermal image, the other substring cells are shown in cooler pale green above the hot cell along the right side and the next column immediately to the left.

Why is this one cell reaching over 109°C (228°F)?

Figure 10: Row to Row Shading

Installers are taught to avoid placing solar panels where vent pipe shadows are present.

Figure 10 shows an approximately 4 x 4 inch shadow which may reduce the power of a conventional solar panel by 33%.

Under the same conditions an idealPV module might produce about 10% less power. This is because the shadow would only compromise about half the power from the lower 20% string.

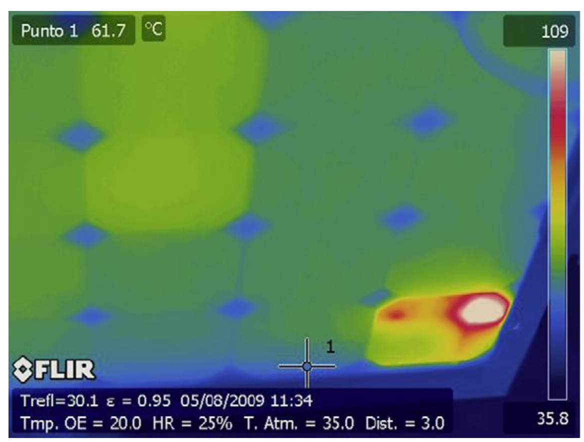

Figure 12: Hot cell in Conventional PV

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Consider this scenario:

The solar panel has 60 total cells arranged in the conventional three substrings strings of 20 cells. As is normally done, each substring has a bypass diode connected across it.

The hot cell can only produce 6A due to partial shade in the lower left corner of the solar panel. The rest of the cells in this panel and the 14 other panels in series with it are not shaded and can produce 7A.

The Maximum Power Point algorithm of the inverter (not shown) finds that more power is available when the string voltage of the array, which includes this panel, is lowered by about 10V because the overall current is higher.

For 15 panels, the MPPT must choose between a string voltage of 450V, current 6A (limited by this partially shaded cell) for a total of 2,700W. However, at 440V the current goes to 7A for total power 3,080W.

By selecting the lower voltage, current can flow through a bypass diode around the substring containing the weak cell (6A) so that 7A is available from the other two substrings in this panel and the other 14 panels in series with it.

The reason this cell gets hot is because it is still producing a photo current of 6A but the voltage across it has moved from a nominal +0.5V to -10V (supplied by the other 19 cells in its substring) increasing the partially shaded cells' power dissipation by a factor of 20. Another way to look at this is that the single partially shaded cell is being forced to dissipate the power produced by the other 19 unshaded cells in its substring. Either way, its temperature has reached over 109°C (228°F), more than 30°C hotter than the other cells in this array.

By Arrhenius, this cell is aging between 8 and 16 times faster than other cells in the module. The cell will age into its lower output condition, even in full sun, in one to two years. At that point, even though the panel power will be down over 30% in the field, this module will usually not be covered under production warranties because its field test for Isc and Voc will be normal and its flash test will be only 1A low at nominal Vmp (-15%).

In time the conventional module shown above may fail catastrophically as increased day night thermal cycles may cause solder fatigue, microcracks or worse.

idealPVs eliminate the possibility of hot spots by eliminating reverse conduction. This results in large cost savings and simplifications through the entire chain from panel fabrication through installation.

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