Solar micro-inverter

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A solar micro-inverter.

A **solar micro-inverter**, or simply **microinverter**, is a device used in photovoltaics that converts direct current (DC) generated by a single solar module to alternating current (AC). The output from several microinverters is combined and often fed to the electrical grid. Microinverters contrast with conventional string and central solar inverters, which are connected to multiple solar modules or panels of the PV system.

Microinverters have several advantages over conventional inverters. The main advantage is that small amounts of shading, debris or snow lines on any one solar module, or even a complete module failure, do not disproportionately reduce the output of the entire array. Each microinverter harvests optimum power by performing maximum power point tracking for its connected module.[1] Simplicity in system design, lower amperage wires, simplified stock management, and added safety are other factors introduced with the microinverter solution.

The primary disadvantages of a microinverter include a higher initial equipment cost per peak watt than the equivalent power of a central inverter since each inverter needs to be installed adjacent to a panel (usually on a roof). This also makes them harder to maintain and more costly to remove and replace (O&M). Some manufacturers have addressed these issues with panels with built-in microinverters.[2]

A type of technology similar to a microinverter is a power optimizer which also does panel-level maximum power point tracking, but does not convert to AC per module.

Contents

Description

Solar inverter

Solar panels produce direct current at a voltage that depends on module design and lighting conditions. Modern modules using 6-inch cells typically contain 60 cells and produce a nominal 30 V.[3] For conversion into AC, panels may be connected in series to produce an array that is effectively a single large panel with a nominal rating of 300 to 600 VDC.[a] The power then runs to an inverter, which converts it into standard AC voltage, typically 230 VAC / 50 Hz or 240 VAC / 60 Hz.[4]

The main problem with the "string inverter" approach is the string of panels acts as if it were a single larger panel with a max current rating equivalent to the poorest performer in the string. For example, if one panel in a string has 5% higher resistance due to a minor manufacturing defect, the entire string suffers a 5% performance loss. This situation is dynamic. If a panel is shaded its output drops dramatically, affecting the output of the string, even if the other panels are not shaded. Even slight changes in orientation can cause output loss in this fashion. In the industry, this is known as the "Christmas-lights effect", referring to the way an entire string of series-strung Christmas tree lights will fail if a single bulb fails.[5] However, this effect is not entirely accurate and ignores the complex interaction between modern string inverter maximum power point tracking and even module bypass diodes. Shade studies by major micro inverter and DC optimizer companies show small yearly gains in light, medium and heavy shaded conditions- 2%, 5% and 8% respectively- over an older string inverter.[6]

Additionally, the efficiency of a panel's output is strongly affected by the load the inverter places on it. To maximize production, inverters use a technique called maximum power point tracking (MPPT) to ensure optimal energy harvest by adjusting the applied load. However, the same issues that cause output to vary from panel to panel, affect the proper load that the MPPT system should apply. If a single panel operates at a different point, a string inverter can only see the overall change, and moves the MPPT point to match. This results in not just losses from the shadowed panel, but the other panels too. Shading of as little as 9% of the surface of an array can, in some circumstances, reduce system-wide power as much as 54%.[7][8] However, as stated above, these yearly yield losses are relatively small and newer technologies allow some string inverters to significantly reduce the effects of partial shading.[9]

Another issue, though minor, is that string inverters are available in a limited selection of power ratings. This means that a given array normally up-sizes the inverter to the next-largest model over the rating of the panel array. For instance, a 10-panel array of 2300 W might have to use a 2500 or even 3000 W inverter, paying for conversion capability it cannot use. This same issue makes it difficult to change array size over time, adding power when funds are available. If the customer originally purchased a 2500 W inverter for their 2300 W of panels, they cannot add even a single panel without over-driving the inverter. However, this over sizing is considered common practice in today's industry (sometimes as high as 20% over inverter nameplate rating) to account for module degradation, higher performance during winter months or to achieve higher sell back to the utility.

Other challenges associated with centralized inverters include the space required to locate the device, as well as heat dissipation requirements. Large central inverters are typically actively cooled. Cooling fans make noise, so location of the inverter relative to offices and occupied areas must be considered. And because cooling fans have moving parts, dirt, dust, and moisture can negatively affect their performance over time. String inverters are quieter but might produce a humming noise in late afternoon when inverter power is low.

Microinverter concept

Microinverters are small inverters rated to handle the output of a single panel. Modern grid-tie panels are normally rated between 225 and 275W, but rarely produce this in practice, so microinverters are typically rated between 190 and 220 W. Because it is operated at this lower power point, many design issues inherent to larger designs simply go away; the need for a large transformer is generally eliminated, large electrolytic capacitors can be replaced by more reliable thin-film capacitors, and cooling loads are reduced so no fans are needed. Mean time between failures (MTBF) are quoted in hundreds of years.[10]

More importantly, a microinverter attached to a single panel allows it to isolate and tune the output of that panel. For example, in the same 10-panel array used as an example above, with microinverters any panel that is under-performing has no effect on panels around it. In that case, the array as a whole produces as much as 5% more power than it would with a string inverter. When shadowing is factored in, if present, these gains can become considerable, with manufacturers generally claiming 5% better output at a minimum, and up to 25% better in some cases.[10] Furthermore,a single model can be used with a wide variety of panels, new panels can be added to an array at any time, and do not have to have the same rating as existing panels.

Microinverters produce grid-matching power directly at the back of the panel. Arrays of panels are connected in parallel to each other, and then to the grid. This has the major advantage that a single failing panel or inverter cannot take the entire string offline. Combined with the lower power and heat loads, and improved MTBF, some suggest that overall array reliability of a microinverter-based system is significantly greater than a string inverter-based one. This assertion is supported by longer warranties, typically 15 to 25 years, compared with 5 or 10 year warranties that are more typical for string inverters. Additionally, when faults occur, they are identifiable to a single point, as opposed to an entire string. This not only makes fault isolation easier, but unmasks minor problems that might not otherwise become visible – a single under-performing panel may not affect a long string's output enough to be noticed.

Disadvantages

The main disadvantage of the microinverter concept has, until recently, been cost. Because each microinverter has to duplicate much of the complexity of a string inverter but spread that out over a smaller power rating, costs on a per-watt basis are greater. This offsets any advantage in terms of simplification of individual components. As of October 2010, a central inverter costs approximately $0.40 per watt, whereas a microinverter costs approximately $0.52 per watt.[11] Like string inverters, economic considerations force manufacturers to limit the number of models they produce. Most produce a single model that may be over or under-size when matched with a specific panel.

In many cases the packaging can have a significant effect on price. With a central inverter you may have only one set of panel connections for dozens of panels, a single AC output, and one box. With microinverters, each one has to have its own set of inputs and outputs, in its own box. Because that box is on the roof, it has to be sealed and weatherproofed. This can represent a significant portion of the overall price-per-watt.

To further reduce costs, some models control two or three panels from a single box, reducing the packaging and associated costs. Some systems simply place two entire micros in a single box, while others duplicate only the MPPT section of the system and use a single DC-to-AC stage for further cost reductions. Some have suggested that this approach will make microinverters comparable in cost with those using string inverters.[12] With steadily decreasing prices, the introduction of dual microinverters and the advent of wider[13] model selections to match PV module output more closely, cost is less of an obstacle so microinverters may now spread more widely.

Microinverters have become common where array sizes are small and maximizing performance from every panel is a concern. In these cases, differential in price-per-watt is minimized due to the small number of panels, and has little effect on overall system cost. The improvement in energy harvest given a fixed size array can offset this difference in cost. For this reason, microinverters have been most successful in the residential market, where limited space for panels constrains array size, and shading from nearby trees or other objects is often an issue. Microinverter manufacturers list many installations, some as small as a single panel and the majority under 50.[14]

An often overlooked disadvantage of micro inverters is the future O&M costs associated with them. While the technology has improved over the years the fact remains that the devices will eventually either fail or wear out. The installer must balance these replacement costs (around $400 per truck roll), increased safety risks to personnel, equipment and module racking against the profit margins for the installation. For homeowners, the eventual wear out or premature device failures will introduce potential damage to the roof tiles or shingles, property damage and other nuisances.

Advantages

While microinverters generally have a lower efficiency than string inverters, the overall efficiency is increased due to the fact that every inverter / panel unit acts independently. In a string configuration, when an panel on a string is shaded, the output of the entire string of panels is reduced to the output of the lowest producing panel. This is not the case with micro inverters.

A further advantage is found in the panel output quality. The rated output of any two panels in the same production run can vary by as much as 10% or more. This is mitigated with a string configuration but not so in a microinverter configuration. The result is maximum power harvesting from a microinverter array.

Monitoring and maintenance is also easier as many microinverter producers provide apps or websites to monitor the power output of their units. In many cases, these are proprietary; however this is not always the case. Following the demise of Enecsys, and the subsequent closure of their site; a number of private sites such as Enecsys-Monitoring [15] sprung up to enable owners to continue to monitor their systems.

Three-phase microinverters

Efficient conversion of DC power to AC requires the inverter to store energy from the panel while the grid's AC voltage is near zero, and then release it again when it rises. This requires considerable amounts of energy storage in a small package. The lowest-cost option for the required amount of storage is the electrolytic capacitor, but these have relatively short lifetimes normally measured in years, and those lifetimes are shorter when operated hot, like on a rooftop solar panel. This has led to considerable development effort on the part of microinverter developers, who have introduced a variety of conversion topologies with lowered storage requirements, some using the much less capable but far longer lived film capacitors where possible.

Three-phase electric power represents another solution to the problem. In a three-phase circuit, the power does not vary between (say) +120 to -120 Volts between two lines, but instead varies between 60 and +120 or -60 and -120V, and the periods of variation are much shorter. Inverters designed to operate on three phase systems require much less storage.[16][17] A three-phase micro using zero-voltage switching can also offer higher circuit density and lower cost components, while improving conversion efficiency to over 98%, better than the typical one-phase peak around 96%.[18]

Three-phase systems, however, are generally only seen in industrial and commercial settings. These markets normally install larger arrays, where price sensitivity is the highest. Uptake of three-phase micros, in spite of any theoretical advantages, appears to be very low.

History

The microinverter concept has been in the solar industry since its inception. However, flat costs in manufacturing, like the cost of the transformer or enclosure, scaled favorably with size, and meant that larger devices were inherently less expensive in terms of price per watt. Small inverters were available from companies like ExelTech and others, but these were simply small versions of larger designs with poor price performance, and were aimed at niche markets.

Early examples

In 1991 the US company Ascension Technology started work on what was essentially a shrunken version of a traditional inverter, intended to be mounted on a panel to form an *AC panel*. This design was based on the conventional linear regulator, which is not particularly efficient and dissipates considerable heat. In 1994 they sent an example to Sandia Labs for testing.[19] In 1997, Ascension partnered with US panel company ASE Americas to introduce the 300 W SunSine panel.[20]

Released in 1993, Mastervolt's Sunmaster 130S was the first true microinverter.

Design of, what would today be recognized as a "true" microinverter, traces its history to late 1980s work by Werner Kleinkauf at the ISET (*Institut für Solare Energieversorgungstechnik*), now Fraunhofer Institute for Wind Energy and Energy System Technology. These designs were based on modern high-frequency switching power supply technology, which is much more efficient. His work on "module integrated converters" was highly influential, especially in Europe.[21]

In 1993 Mastervolt introduced their first grid-tie inverter, the Sunmaster 130S, based on a collaborative effort between Shell Solar, Ecofys and ECN. The 130 was designed to mount directly to the back of the panel, connecting both AC and DC lines with compression fittings. In 2000, the 130 was replaced by the Soladin 120, a microinverter in the form of an AC adapter that allows panels to be connected simply by plugging them into any wall socket.[22]

Another early microinverter, 1995's OK4E-100 – E for European, 100 for 100 watts.

In 1995, OKE-Services designed a new high-frequency version with improved efficiency, which was introduced commercially as the OK4-100 in 1995 by NKF Kabel, and re-branded for US sales as the Trace Microsine.[23] A new version, the OK4All, improved efficiency and had wider operating ranges.[24]

In spite of this promising start, by 2003 most of these projects had ended. Ascension Technology was purchased by Applied Power Corporation, a large integrator. APC was in turn purchased by Schott in 2002, and SunSine production was canceled in favor of Schott's existing designs.[25] NKF ended production of the OK4 series in 2003 when a subsidy program ended.[26] Mastervolt has moved on to a line of "mini-inverters" combining the ease-of-use of the 120 in a system designed to support up to 600 W of panels.[27]

Enphase

In the aftermath of the 2001 Telecoms crash, Martin Fornage of Cerent Corporation was looking for new projects. When he saw the low performance of the string inverter for the solar array on his ranch, he found the project he was looking for. In 2006 he formed Enphase Energy with another Cerent engineer, Raghu Belur, and they spent the next year applying their telecommunications design expertise to the inverter problem.[11]

Released in 2008, the Enphase M175 model was the first commercially successful microinverter. A successor, the M190, was introduced in 2009, and the latest model, the M215, in 2011. Backed by $100 million in private equity, Enphase quickly grew to 13% marketshare by mid-2010, aiming for 20% by year-end.[11] They shipped their 500,000th inverter in early 2011,[28] and their 1,000,000th in September of the same year.[29] In early 2011, they announced that re-branded versions of the new design will be sold by Siemens directly to electrical contractors for widespread distribution.[30]

Enphase has subscribed an agreement with EnergyAustralia, to market its micro-inverter technology.[31]

Competition

Enphase's success did not go unnoticed, and since 2010 a host of competitors have appeared. Many of these are identical to the M190 in specs, and even in the casing and mounting details.[32] Some differentiate by competing head-to-head with Enphase in terms of price or performance,[33] while others are attacking niche markets.[34]

Larger firms have also stepped into the field; OKE-Services updated OK4-All product was recently bought by SMA and released as the SunnyBoy 240 after an extended gestation period,[35] while Power-One has introduced the AURORA 250 and 300.[36] Other major players included Enecsys[b] and SolarBridge, especially outside the North American market. The only USA made microinverter in production is from Chilicon Power. Since 2009, several companies from Europe to China, including major central inverter manufacturers, have launched microinverters—validating the microinverter as an established technology and one of the biggest technology shifts in the PV industry in recent years.[37]

Price issues

The period between 2009 and 2012 included unprecedented downward price movement in the PV market. At the beginning of this period, panels were generally around $2.00 to $2.50/W, and inverters around 50 to 65 cents/W. By the end of 2012, panels were widely available in wholesale at 65 to 70 cents, and string inverters around 30 to 35 cents/W.[38] In comparison, microinverters have proven relatively immune to these same sorts of price declines, moving from about 65 cents/W to 50 to 55 once cabling is factored in. This has led to widening losses as the suppliers attempt to remain competitive.[39]

See also

- Solar inverter
- Grid tie inverter
- Inverter (electrical)
- Power optimizer
- Three-phase micro-inverter

Notes

a. Since 2011 an increasing number of panels and inverters are rated to 1000 V instead of the older 600 V standard. This allows longer strings to be created, lowering system cost by avoiding the need for additional "combiners". This standard is not universal, but is being rapidly adopted As of 2014
b. Which is now in administration.

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