PV and Batteries: From a Past of Remote Power to a Future of Saving the Grid

by David K. Click

For much of the first century of electrification, the power generation and delivery system has been set up in a relatively straightforward manner. Utilities have built increasingly large centralized power plants to supply what has been a generally increasing demand for electricity, with about 6000 power plants operating in the U.S. today with a nameplate rating of at least 1 megawatt (MW).[1] The vast majority of electricity production occurs at fossil fuel-burning power plants with a nameplate capacity of over 100 MW, with each plant serving an average of 50,000 people. This infrastructure focused on cities and towns with a concentrated population, before rural electrification began in earnest in the 1930s.[2] For most customers on the electric grid, the price of electricity from the grid was generally far less than the cost they would pay to own and operate their own electricity generation unit. For many years, the only option for many people looking to generate their own power was to burn some kind of fuel in an engine—this remains a difficult task economically as the costs reduce dramatically at scale. And even if a customer had been able to generate their own power, it would have been technically difficult to interconnect that system to the electric grid while maintaining the safety and stability of the system.

In parallel, there was some research into how solar power photovoltaic (PV) systems could help supply the electric energy required by society. After Charles Fritts built the first solar cell in 1883, he quickly learned that his cells of less than 1% efficiency couldn't readily compete with the coal-fired power plants being developed by Thomas Edison. After a few decades, Bell Labs produced a 6% efficient cell in 1954.[3] Further development led to PV finding a niche as a power source in remote applications, such as the Vanguard 1 satellite launched in 1958 and telecommunications repeater stations or navigation buoys back on Earth.

After the energy crisis of the 1970s, the Public Utility Regulatory Policies Act of 1978 (PURPA) created, among other things, a market for power from generators that were not utilities. In 1980, the first house in the U.S. was built featuring a PV system that was utility-interactive—using the energy generated from the PV system first and then drawing power from the utility system whenever more power was needed.[4] The worldwide PV industry produced less than 10 MW of modules ("solar panels") in the year 1980;[5] to put that number in perspective, in 2014 the U.S. PV industry installed nearly 20 MW every day. Several decades ago, the low amounts of production and associated high costs rendered grid-connected PV systems a tough sell for most customers. However, home and business owners in remote areas without reliable grid service started to find PV economically viable even back in the 1980s. Customers in some rural areas found that electric utilities may charge them hundreds of thousands of dollars to run a dedicated power line to them; a PV system with integrated energy storage (often deep-cycle lead acid batteries) proved cost effective compared with this option, and more attractive than a noisy fuel-powered generator. A 3 kW PV system with lead acid batteries and wind turbines, located at a residence in Westcliffe, Colorado, is shown in a 2001 picture in Fig. 1.

The PV industry got its footing in supplying power to these remote applications. Even today, it's common to see PV integrated into remote highway signs or even traffic signs in urban areas where the cost of a dedicated grid connection didn't make economic sense. Rural electrification, which used to mean either noisy generators nearby, or a very long power line to some distant, noisy generators, is now a market being served around the world by PV systems and batteries (and, it should be said, generators as an occasional backup). In 1987, 24.9 MW of PV was installed worldwide.[6] A surprising 96% of that capacity was not grid-connected. This percentage decreased over time as shown in Fig. 2. The year 2000 was the first year in which grid-connected systems exceeded the number of off-grid systems in remote applications. Sometime in the early 2000s, the majority of systems no longer included batteries, opting for a simpler (and cheaper) system. Today, at least 90% of PV systems within the U.S. do not include energy storage, though that trend is changing as storage solutions become increasingly competitive.

A typical grid-interactive PV system installed in the U.S. today will operate whenever the electric grid is operating normally within certain voltage and frequency parameters. That system will, in fact, only operate when that location on the grid is experiencing normal operation. Most PV systems are subject to local utility requirements designed to disconnect PV systems from the grid whenever there is stress on the grid—perhaps a fault at a steam turbine within a power plant, or times when generation capacity can't fully meet the loads—leading to brownouts or blackouts. These technical requirements governing interconnection were first drafted in the 1980s, when there were only a few megawatts of PV systems connected to the U.S. grid. This was a very small percentage of the total grid-connected generation, which numbered in the hundreds of gigawatts. Therefore, it was decided that if there were a fault on the system, the PV

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Fig. 1. *Remote PV, wind, and battery storage system for a Colorado residence. (Photo by Warren Gretz, NREL 10622.)*

systems should disconnect from the grid as the relatively small PV contribution wasn't worth trying to keep online in the event of a grid fault. This "anti-islanding" requirement keeps PV systems from operating as "islands" in the system.

This approach to grid protection and reliability worked well until recently, when it was realized that PV systems were no longer negligible players in the utility market. In areas of focused PV deployment, utility distribution lines began to experience unusual operating conditions. A distribution line supplying 1.5 MW of load was likely originally designed for that power to come in a single direction from the distant, centralized power plant, perhaps with capacitors installed along the line to maintain voltage. However, if that line had 1.5 MW of load and 1.6 MW of PV, it would actually see power fed back into the substation. And in the case of a three-second outage, all the PV would be required to disconnect from the grid. Within those three seconds, the utility would suddenly have to supply 1.6 MW of additional power back into its system. For utilities with high levels of PV, this local problem becomes a problem across its service territory, as a quick flicker can switch all interconnected PV systems offline right when that generation is needed and expected.

The variable nature of PV power production makes integration of these systems into the grid even more complex. A typical PV system does not have integrated energy storage and will export an amount of power to the grid directly proportional to the amount of sunlight shining on the PV modules at that time. Clouds passing over a small 5 kW system (roughly 400 square feet in area) will cause its power output to fluctuate. Integration of this variability isn't an issue for utilities, any more than it is for them to keep the lights on when an air conditioner or EV charger turns on. For a utility with a service territory spanning a wide expanse of area, managing the variability of several small systems is an easy task, as a passing cloud will not affect multiple systems at the same time.

Energy storage can bring additional functionality to residential PV systems, even though it is often not needed to mitigate the variability at the individual system level. Special bimodal systems can provide power to "protected loads" within the house and keep those loads online even during a power outage. PV system pricing has only recently dropped within the budget of many homeowners, but this bimodal capability can increase the system cost by thousands of dollars. Interest in the bimodal functionality often drops when a customer learns of the extra cost, unless it's immediately following a major utility outage (*e.g.*, the aftermath of Hurricane Sandy in 2012).

Clouds passing over a system of 1 MW or larger, or over many small systems concentrated geographically, can cause issues in some grid scenarios. Many utilities rarely deal with substantial, quick power changes such as those inherent to many PV systems. In Puerto Rico, the utility requires large PV systems to control "ramping" speeds, to ensure that the power output of a system does not vary beyond the utility's ability to manage it. If a system is operating at 500 kW and has the sunlight available to operate at 800 kW, it is relatively straightforward to step up the power output incrementally. However, if a system is operating at 500 kW and then a passing cloud brings the available power production to 200 kW, the system simply has no fuel to do anything but drop down to a 200 kW output as quickly as the sun fades. For these larger commercial-scale systems, some storage device would be required to slowly step down the power output.

The addition of inexpensive storage to PV systems will shape the course of the PV industry over the next 10 years. Storage can offer benefits to all parties involved—residential and commercial customers, as well as the electric utility that serves them. As noted, storage can help mitigate PV system power variability, and in some areas is required explicitly for this reason. Storage can also provide a backup power source for PV systems to supply important loads within a building of any size. Perhaps the idea most interesting for utilities is that PV systems can become reliable, dispatchable power plants. After many years of accepting whatever power the interconnected PV systems could supply the utility at that instant, utilities are already investigating how PV systems—coupled with storage—could produce power even when there is minimal or no sunlight available.

There are some exciting opportunities ahead for PV customers in the residential and commercial sector. The integration of PV, storage, electric vehicles, and various building demand response or load controls can make each customer a much more involved partner with the utility. Customers can become more than just variable loads to the utility—they can become autonomous power plants.

Solar installers are now offering opportunities for solar and storage at the commercial and residential level. SolarCity CEO Lyndon Rive and Chairman Elon Musk announced that SolarCity would be including battery backup systems with every single one of its rooftop solar power systems within 5-10 years.[7] For many customers in the U.S., a solar battery backup system already will be able to produce electricity for less than that from the grid. Sunpower is another large residential unit provider that has also said it will provide storage with solar for residential customers in the next few years.[8] SolarCity is now offering Tesla energy storage to its commercial customers to mitigate demand charges during times of peak demand.

This newfound ability of customers to disrupt the traditional utility provider/customer consumer relationship has been noted by many in the utility industry. Given the consistently dropping costs of PV systems and the uncertainty of future utility rates, it's likely that many customers will be technically able to disconnect from the utility grid without sacrificing their way of life. It will certainly be a challenge for utilities, regulators, and the market to derive the best way to reward customer-sited PV and storage, and keep them incentivized to maintain their grid connection. This creates an opportunity for utilities—by absorbing technology risk and becoming

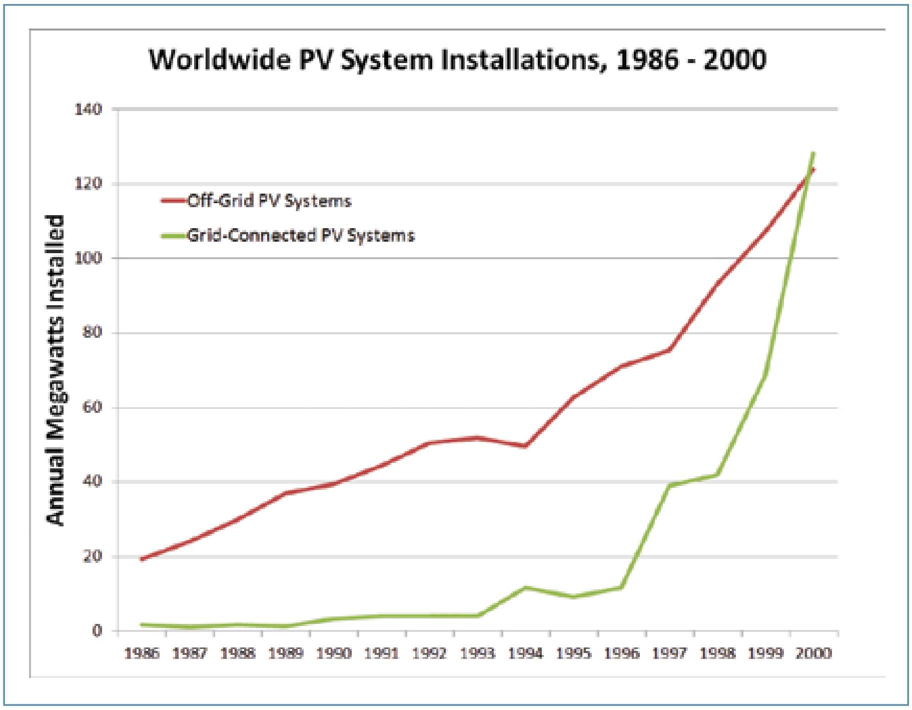


Fig. 2. *Comparison of worldwide off-grid and on-grid PV installations, 1986-2000. (Reproduced from REW.com data.[6])*

more of a services provider to customers. Perhaps utilities could own and operate PV systems and/or storage systems to provide greater reliability to the customers willing to pay a premium.

The PV industry has come a long way over the past few decades, and the installed capacity continues to grow substantially with each year. As noted by the National Renewable Energy Laboratory in a recent quarterly update on PV market trends, more PV had been deployed in the U.S. over the previous 18 months than in the prior 30 years.[9] In the U.S. in 2013, roughly 25% of all new power generation capacity was PV. PV costs have reached grid parity in 10 states that generate the bulk of U.S. solar electricity. Deutsche Bank predicts that when the 30% federal tax credit is eliminated for residential customer-owned systems in 2017, solar electricity costs will still reach parity with traditional electricity sources across 36 states[10]. By the end of 2013, there were over 15 GW of solar electric capacity operating in the U.S.; by 2016 cumulative capacity is expected to exceed 47 GW.[11]

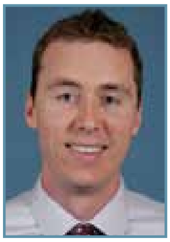
As of November 2014, 174,000 Americans were currently working in the U.S. solar industry,[12] up 20% from 2013, or 10 times the national average growth rate. Over 60,000 new jobs have been added since 2010. All of the growth has exceeded the expectations of many in the industry and in the U.S. Department of Energy. However, even this good news about the decrease in price, and with it the arrival of grid parity, the upfront cost to purchase a 5 kW residential system is on the order of $15,000 to $20,000 before the 30% income tax credit that is in effect through the end of 2016.

Fortunately for the homeowner, businesses have found new ways to finance residential solar. In 2013, over 50% of rooftop solar was installed in a lease or power-purchase arrangement, enabling pay-as-you-go agreements with little down payment, if any. For the first time, annual growth in the residential sector outpaced that of the overall market 60% to 41%, due to widely-available financing.[13] There are many U.S. companies that provide this service to customers, who typically make predictable monthly payments for the output under 15- to 25-year contracts. This makes it easier for homeowners to sign up for rooftop solar and the payback can be immediate. In most rooftop applications of solar, "net-metering" rules allow the excess solar electricity generated to be sent back onto the grid to be used later to offset electric energy provided by the electric utility. The grid in effect provides the storage, because without an energy storage system, PV systems can only provide electricity during daylight hours. Increased deployment of storage could enable PV systems to provide the majority of a region's electrical needs well into the evening hours. As more solar power plants come online at the rooftop (residential and commercial) and the utility scale, the variability and uncertainty of solar generation poses challenges for reliably integrating PV into the electric power systems, both at the distribution and bulk system levels. In the fall 2010 *Interface* issue titled, "Lightning in a Bottle: Storing Energy for the 'Smart Grid,'"[14,15] several articles discussed energy storage using Large Scale Stationary Batteries,[16] Flow Batteries,[17] and Super Capacitors[18] to mitigate variability and provide additional services in ensuring the reliability of the grid.

There's a long road ahead for the industry, as PV will still produce less than 1% of the electric energy required in the U.S. in 2015. The industry has many more gigawatts of installations ahead of it, with low-cost energy storage enabling a transformation of our power generation system. Inspired by the efforts of Charles Fritts to commercialize the first solar cell, R. Appleyard dreamed of a future where "the blessed vision of the Sun, no longer pouring his energies unrequited into space, but by means of photo-electric cells…, these powers gathered into electrical storehouses to the total extinction of steam engines, and the utter repression of smoke."[19] A dream when written in 1891, but decades of technological advancement have started to make it a real, achievable goal.

 DOI: 10.1149/2.F03151IF

About the Author



David K. Click, is a Program Director in the Solar Systems Research Division at the University of Central Florida's Florida Solar Energy Center. Mr. Click holds BS and MS degrees in Electrical Engineering from the University of Virginia and has been working in PV system installation, training, and research for fifteen years. He may be reached at daveclick@fsec.ucf.edu.

http://orcid.org/0000-0003-3991-120X

References

1. "Electricity," http://www.eia.gov/electricity/data/eia923/index.html (accessed Jan. 22, 2015).
2. "United States Department of Agriculture: Rural Development," http://www.rurdev.usda.gov/rd/70th/rea-history.pdf (accessed Jan. 22, 2015).
3. "This Month in Physics History," http://www.aps.org/publications/apsnews/200904/physicshistory.cfm (accessed Jan. 22, 2015).
4. "Carlisle House," http://www.solardesign.com/SDA_Today/carlisle-house/ (accessed Jan. 22, 2015).
5. "Sunshot Vision Study," http://www1.eere.energy.gov/solar/pdfs/47927_chapter4.pdf (Figure 4-3) (accessed Jan. 22, 2015).
6. "Off-grid Solar Applications, Where Grid Parity is Truly Meaningless," http://www.renewableenergyworld.com/rea/news/article/2013/08/off-grid-solar-applications-where-grid-parity-is-truly-meaningless (accessed Jan. 22, 2015).
7. "Every Solar Customer Will Get Battery Back-up Within 5-10 Years," http://cleantechnica.com/2014/09/22/every-solarcity-customer-will-get-battery-backup-within-5-10-years/ (accessed Jan. 22, 2015).
8. "Sunpower to Bundle Solar with Storage," http://www.utilitydive.com/news/sunpower-to-bundle-solar-with-storage/206491/ (accessed Jan. 22, 2015).
9. "U.S. PV Market Trends Update," http://solaroregon.org/solar-now/snu-2014-presentations/kristen-ardani-us-pv-market-trends-update (accessed Jan. 22, 2015).
10. "2014 Outlook: Let the Second Gold Rush Begin," https://www.deutschebank.nl/nl/docs/Solar_-_2014_Outlook_Let_the_Second_Gold_Rush_Begin.pdf (accessed Feb. 25, 2015).
11. "GTM Research/SEIA: U.S. Solar Market Insight, Q2 2014 Executive Summary," http://www.seia.org/research-resources/solar-market-insight-report-2014-q2 (accessed Jan. 22, 2015).
12. "National Solar Jobs Census 2014," http://www.thesolarfoundation.org/research/national-solar-jobs-census (accessed Jan. 22, 2015).
13. "U.S. Residential Solar Financing 2014-2018," http://www.greentechmedia.com/research/report/u.s.-residential-solar-financing-2014-2018 (accessed Jan. 22, 2015).
14. J. P. Meyers, "Lightning in a Bottle: Storing Energy for the 'Smart Grid'," *Electrochem. Soc. Interface,* **19** (3), 44 (2010).
15. C. Harris and J. P. Meyers, "Working Smarter, Not Harder: An Introduction to the 'Smart Grid'," *Electrochem. Soc. Interface*, **19** (3), 45 (2010).
16. D. H. Doughty, P. C. Butler, A. A. Akhil, N. H. Clark and J. D. Boyes, "Batteries for Large-Scale Stationary Electrical Energy Storage," *Electrochem. Soc. Interface,* **19** (3), 49 (2010).
17. T. Nguyen and R. F. Savinell, "Flow Batteries," *Electrochem. Soc. Interface,* **19** (3), 54 (2010).
18. P. Jampani, A. Manivannan, and P. Kumta, "Advancing the Supercapacitor Materials and Technology Frontier for Improving Power Quality," *Electrochem. Soc. Interface,* **19** (3), 57 (2010).
19. R. Appleyard, *Telegraph. J. Electr. Rev.,* **28**, 124 (1891).