Smart PV inverter benefits for utilities

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Utilities nationwide are currently mandated to install a base of 6.8GW of PV by 2020. However, many utilities are embracing renewable energy portfolios for many reasons beyond the state mandates. As we roll out the supply side of the Smart Grid, utilities are facing unprecedented challenges to each of their business segments (generation, transmission and distribution). Smart PV inverters can make a contribution in all of these areas, by expanding their features with added software functions and without major hardware modifications.

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On the generation side, all of the aging and polluting power plants will have to be phased out or dramatically upgraded over the next forty years to produce clean and reliable power. Utilities cannot count on carbon capture and sequestration technology or cheap nuclear energy to be ready in time. Natural gas combined cycle plants are economical at $0.05/kWhr today, but a steady and cheap supply of natural gas is not certain in the future. Renewable generation sources, including large scale PV deployments, have many benefits, including economic predictability, lower maintenance and downtime expenses, zero refueling costs and faster construction time. Utility-scale PV has been leaping towards grid parity over the last three years, currently sitting about 40% away from this ultimate goal for utility scale plants in the US.

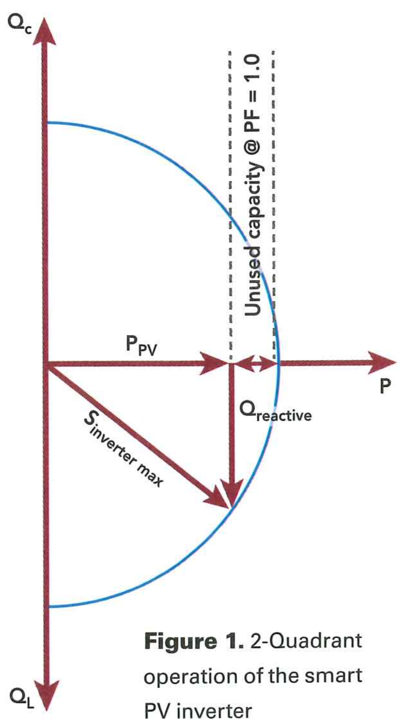

Figure 1. 2-Quadrant operation of the smart PV inverter

PV production prediction systems are being developed that use statistical methods as well as weather forecasts and real time data from a grid of adjacent smaller residential PV sites to allow for the commitment, scheduling and dispatching of traditional generation sources in a more economical way.

Smart PV inverters

Traditionally, PV inverters were intentionally designed to feed as much active power P (kW) as was available from the solar array at unity power factor into the point of common coupling (PCC). More recently, utilities and independent power providers have shown tremendous interest in the three phase inverter's capability to also absorb and provide reactive power Q (kVAR) from and to the grid.

Over 95% of the time a PV inverter is running below its rated output current when converting DC solar power to AC active power. The unused capacity of the inverter can then be put to use to produce reactive power. The output of a smart PV inverter has both reactive and active AC currents that add geometrically to the apparent power S, which will be limited by the current rating of the inverter (Fig. 1).

The flow of active power P and reactive power Q in the grid can be considered as being independent from one another and largely require different control schemes. Active power control is tied to controlling grid frequency, whereas reactive power control is linked with controlling the grid voltage.

Control of active power (kW) and frequency

In a transmission network, it is important to keep the frequency as stable as possible because the biggest generating resources, all of which are synchronous machines, work at their most efficient point at exactly 60Hz. Also, the speed governors on these machines must operate in lock-step to share the generation load between machines to the specified schedule. For the frequency to remain stable the generated active power must match the power demand at all times.

Controlling active power in smart inverters can only help in lowering the frequency, as they cannot absorb energy. Active power curtailment and ramp rates are commonly used in big PV plants to mitigate site-specific concerns and help improve grid stability.

Typical reactive power consuming loads.

Load	Power factor
Fluorescent lighting	0.90
Heat pump and A/C	0.83
Washer	0.65
Industrial motor	0.85

Control of reactive power (kVAR) and AC voltage

Although reactive power can be controlled in large generation stations, it is necessary to control voltage by injecting and absorbing VARs at various points throughout the transmission and distribution network. Excessive voltage can adversely affect equipment and loads. VAR control also greatly enhances grid stability and reduces line transmission losses.

Transmission lines can, depending on load and length, either absorb or provide reactive power. Interestingly enough, the resistive power loss component is often insignificant in comparison to the reactive power component at very high voltage levels.

The reactive power capacity of a smart PV inverter can be used as a fast-acting static VAR (volt-amp-reactive) compensator, controlled either through a supervisory control and data acquisition (SCADA) system or as a stand-alone voltage regulator and acting as either a shunted inductor or capacitor decreasing or increasing the AC voltage along the line. The great benefit of this implementation is that it comes at very little additional component cost. In the US, the first deployments of large PV systems went online alongside transmission lines in 2010, connected through dedicated collector substations and providing static voltage support according to a voltage schedule provided by the utility.

The smart PV inverter's ability to feed reactive power to the line can also be used to help the grid recover from a distant fault that causes the grid voltage to sag momentarily. While riding through a low voltage transient, the smart PV inverter goes into a reactive power overdrive mode to support the grid voltage up until the fault is cleared. Low voltage ride through (LVRT) is a standard feature in wind turbine plants today and will be adopted for large PV sites in the US in 2011.

On the distribution side, smart PV inverters are used to correct the power factor by providing VARs close to where they are being used, rather than importing them from far away. Transformers and most electrical loads are inductive in nature and therefore consume reactive power as shown in the table.

Traditionally, power factor correction is done by connecting large, paralleled capacitor banks to many of the voltage levels of the distribution system. These shunt switched capacitors are strategically placed to adjust voltage along the feeder, as the tap-changing voltage regulators only control voltage at the beginning of the branch. Not only can both power factor correction and AC voltage regulation be performed much more economically by distributed three-phase smart PV inverters along the feeder, but they will also do it in

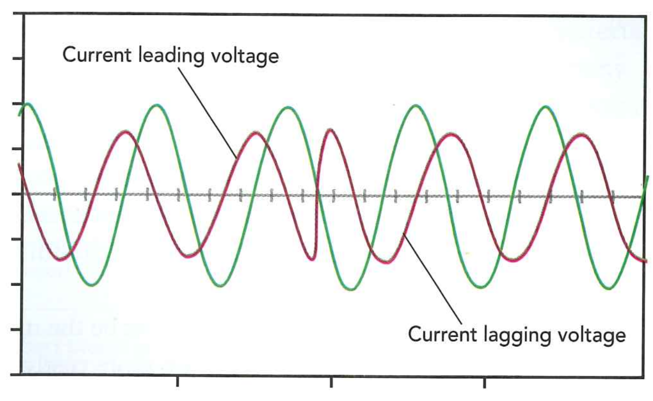

Figure 2. Smart PV inverter's ability to provide inductive current in less than one cycle.

a continuous and smooth fashion, without any step changes or noticeable switching events.

Lastly, as we are waiting for the large-scale deployment of smart meters, smart PV inverters distributed throughout the grid, combined with a smart grid inverter data monitoring system, provide

Continued on page 21

workable thin film technology. It has the lowest efficiency, however, registering between 7% and 10% at best. This material has long been used in consumer products powered by the sun such as calculators and watches. Some manufacturers are pursuing its use in solar cells and striving to improve efficiencies.

Gallium arsenide is a fourth thin film material that has been used to manufacture solar cells used in satellites and space exploration. Currently, GaAs is being tested for use in terrestrial solar concentrator and multijunction cells, which offer several different combinations of materials that will absorb solar rays and convert them to electricity.

Manufacturing advantages

Thin films obviously achieve lower efficiencies than crystalline silicon. Over time, however, the overall efficiencies of thin film materials in solar cells have improved and several major manufacturers are focusing on thin films for their major solar cell product lines. Some advances in the manufacturing process and its equipment have added to the potential benefits of both crystalline silicon and thin-film technologies.

Improvements in capex processes have had a positive impact on both c-Si and thin films. Applied Materials, Santa Clara, California, for example, has introduced several deposition systems that are targeted at a more efficient distribution of c-Si and thin films on various substrates. Their latest system fabricates electrical circuits on both sides of a solar cell. Keys to the performance of this new unit are a higher level of precision and control to the cell manufacturing process.

Oerlikon Solar, located in Trübbach, Switzerland, has lowered production costs for solar cells with the introduction of a new ThinFab line. The company credits its ability to make increasingly thinner films with optimized material usage. Oerlikon has dramatically increased the efficiency of thin-film silicon and enabled turn key systems for fabricating thin-film modules.

Both technologies are beneficiaries of improved and highly specialized solar cell fabrication systems. Thin films were originally adopted to lower the cost of solar cells, but crystalline silicon has also become a cost effective and efficient way of producing them.

A close race

The advantages and characteristics of both materials are similar. C-Si and thin films are light in weight, easy to fabricate, amenable to advances in capex processes and have sufficiently high efficiencies to form reliable solar cells. The problem of efficiencies is a source of constant R&D and we have seen improvements over the years. Applications for both materials are increasing daily.

BCC Research analyzed the markets for both c-Si and thin films and arrived at some interesting data, as outlined in Table 1 [1]. Our research indicates that thin films will adapt to the flexible substrate market, which shows greater potential every year. Thin films were only 16.5% of the market in 2009 and will double their growth by the end of our forecast period in 2015.

In the end, it looks as though both technologies will lead in growth over monocrystalline silicon and emerging technologies. C-Si is being used for rooftop applications, as well as other uses, and thin films are proving themselves in building-integrated PV (BiPV) and other power generating applications. Looking out five years, we see a close race between these two PV material technologies and room for both of them. As in so many other fields of electronics, the application will determine the material.

References

1. "Photovoltaics: Global Markets and Technologies," BCC Research report EY014G, Dec. 2010.

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INVERTER TECHNOLOGY

Continued from page 19

a plethora of new features to progressive customer-oriented utilities today. Real-time data monitoring allows the reporting of voltage quality problems (both magnitude and harmonics) to the utility before equipment is damaged, whereas voltage quality visibility to the utility is usually limited to substations and major distribution feeders.

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