Electric power glitches and PV manufacturing: using SEMI standards to increase yield and reduce costs

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ABSTRACT

PV manufacturers can quickly reduce their costs, and increase their yields, by using SEMI standards that were originally designed to help semiconductor fabs deal with power glitches and power costs. SEMI, the global industry association serving the manufacturing supply chains for the microelectronic, display and photovoltaic industries, has two well-established electric power standards that could prove especially useful for PV manufacturing: SEMI F47, which helps equipment deal with power disturbances, and SEMI E6, which helps users understand how much electric power is used in their recipes. This article provides a method of lowering costs and increasing yield by applying these standards in the PV manufacturing industry.

Power glitches at PV factories

PV manufacturing equipment is sensitive to power disturbances. At a typical PV manufacturing location, equipment can be exposed to about one disruptive disturbance each month. Although these power disturbances can and do occur at every location, there tend to be more disturbances in grids located in developing countries, and more disturbances in locations that have a high isokeraunic level (frequent lightning).

These disturbances come in many forms: voltage sags or dips (a reduction in voltage for one second or less); voltage swells (a brief increase in voltage); high frequency impulses (microsecond-level bursts up to several kilovolts, caused by lightning and inductive loads); frequency variations (caused by generator disruptions), among others. By far the most common power disturbance at PV manufacturing facilities is the voltage sag.

Most voltage sags arrive at the factory from the public grid, but some are created in the factory itself when large motors such as air compressors turn on abruptly, or when an electrical worker accidentally causes a short circuit.

Power companies cannot fix this problem

So why do electric power companies not eliminate these voltage sags? The secondary reason is that the electric power grid is designed for lights, heaters, and motors; sags just do not encroach upon these loads. However, the primary reason is that the power companies are ***unable to*** fix these problems. Sags are caused by short circuits, or 'faults,' on the public distribution grid (see schematic in Fig. 2). These short circuits can be caused by anything from animals, to weather, to workers digging up underground cables. When a short circuit occurs, large currents flow, and the voltage for all users on the nearby grid

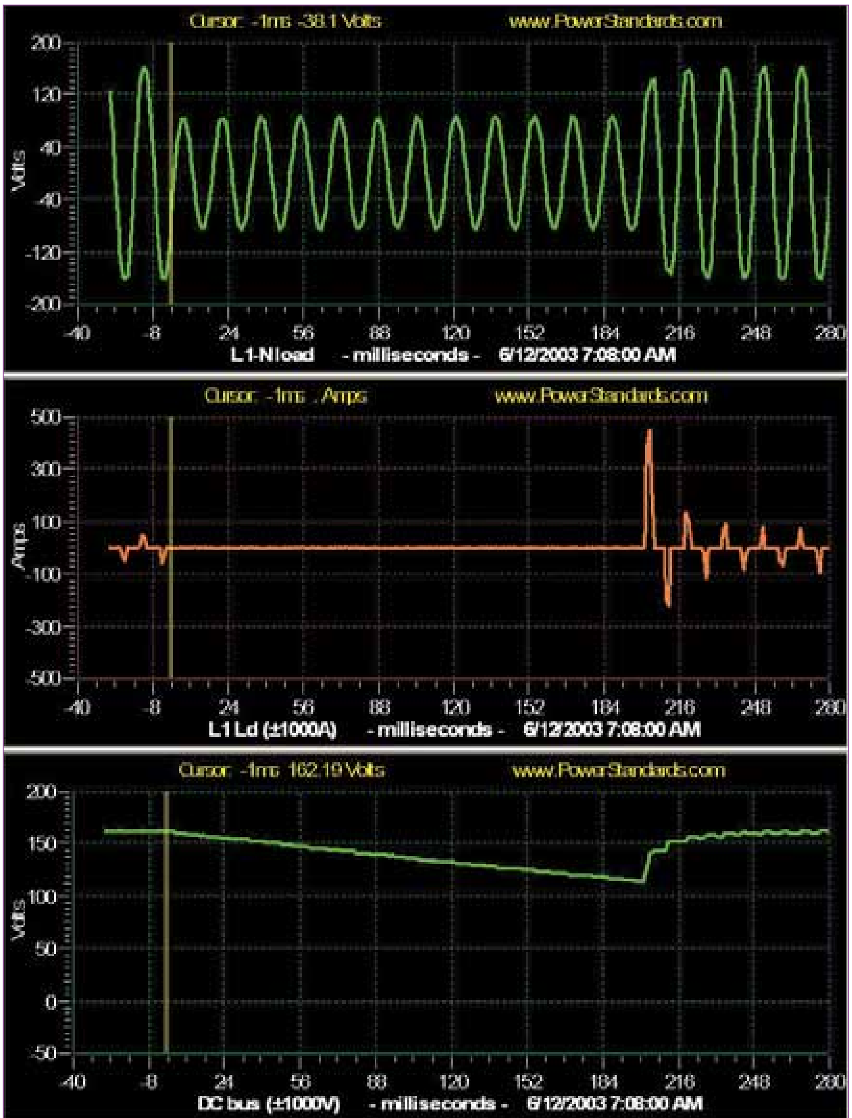

Figure 1. A typical voltage sag (top graph) during SEMI F47 testing. The middle graph shows the equipment current, and the bottom graph shows a DC power supply reacting to the sag. This equipment shows a large increase in current immediately after the sag – one of the most common sag-induced failure mechanisms.

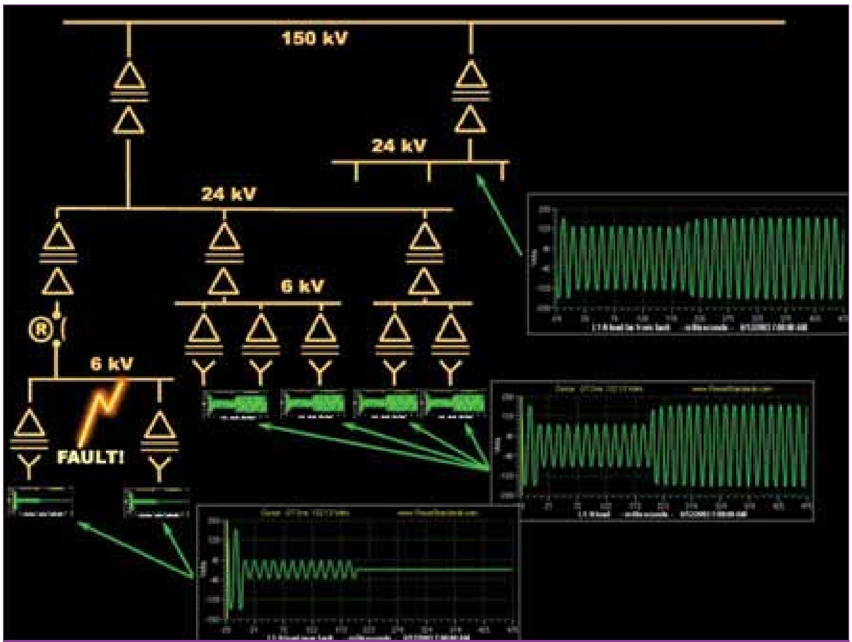

Figure 2. Typical electric power distribution grid showing voltage sag disturbance. A fault, or short circuit (bottom left) causes a power interruption for a few customers in the region, simultaneously causing a voltage sag for many other customers.

Figure 3. Small, low-cost power quality monitors should be installed in every PV factory, such as this PQube monitor that records power disturbances on a digital camera SD memory card.

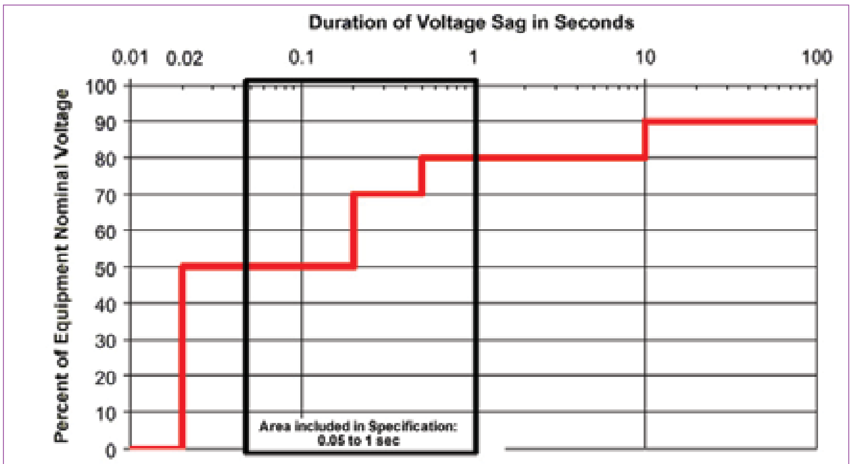

Figure 4. The SEMI F47 curve. PV equipment must tolerate electric power voltage sags that fall above the red line. As a practical matter, about 90 per cent of the sags at PV manufacturing facilities will be above the red line, so SEMI F47 certified equipment will 'ride through' about 90 per cent of the sags.

abruptly decreases, causing a voltage sag. After several cycles of large current, a fuse on the grid opens, or a circuit breaker trips, and the users downstream from the fuse see an interruption or power cut. At this point the other nearby users see the end of their voltage sag as the voltage returns to normal. Given the exposed, public nature of power distribution, it is impossible for power companies to avoid occasional short circuits.

Without instrumentation, it can be very difficult to find the root cause of intermittent equipment failures. Indeed, there is often a temptation to blame intermittent failures on electric power problems when no other explanation is available. But other causes are equally likely: operator errors, software bugs, loose cables, feedstock flaws, bubbles in process cooling water, pressure drops in CDA, ambient temperature or humidity variations, and so forth.

The best way to fix voltage sag problems

So what should a PV factory do? The most expensive and wasteful approach would be to install power conditioning devices to eliminate the sags. While this is a technically feasible approach, it does not make economic sense (except in the most extreme cases, such as ultra-reliable data centres) as the cost per kilowatt is just too high. A far better approach is to purchase PV manufacturing equipment that is certified to tolerate 'normal' voltage sags, as defined by the SEMI F47 standard: equipment should tolerate 50 per cent of nominal voltage for 200 milliseconds, tolerate 70 per cent of nominal voltage for 500 milliseconds, and tolerate 80 per cent of nominal voltage for one second.

Any equipment that can tolerate these three sags will typically tolerate nine out of 10 sags that actually occur at a PV factory. Furthermore, it is quite straightforward and inexpensive to tweak equipment design so that it tolerates sags of these depths and durations because most of the power going into the equipment goes to insensitive loads. Taking a process oven as an example, only the controller is typically sensitive to sags, while the electric heater elements are insensitive. However, the heater elements use roughly 98 per cent of the power. This means that only about 2 per cent of the total power going into the oven needs to be conditioned, which is why it is so much less expensive to adjust the equipment design than it is to clean up the power. Tiny power conditioners can be built in specifically for the most sensitive portions.

Note that equipment that meets the SEMI F47 requirements can tolerate about 90 per cent of real-world sags, not 100 per cent. This is an economic tradeoff. While it is cheap to adjust equipment to handle most of the sags, making the necessary adjustments to handle all of the sags, no matter how deep or how long, is much more expensive. After years of experience and revision, the SEMI F47 Working Group selected this reasonable tradeoff.

Figure 5. Engineers use an Industrial Power Corruptor (centre) to create calibrated voltage sags. Using these sags and the SEMI F47 standard, specialists from the Power Standards Lab can increase the immunity of almost any equipment to voltage sags, increasing yields and reliability.

Interestingly, two related IEC standards, IEC 61000-4-11 and IEC 61000-4-34, reached almost the same conclusion as SEMI F47 regarding this tradeoff. In general, manufacturing equipment that is specified to meet any of these standards will be far more reliable during voltage sags.

Voltage sag-sensitive equipment

The best time to specify SEMI F47 voltage sag immunity is before the equipment is purchased – an approach taken by all major semiconductor companies. Thankfully, it is perfectly possible to test and retrofit equipment that is already installed at a PV factory (see Fig. 5). In cooperation with field engineers from PV equipment manufacturers, specialist engineers from Power Standards Lab regularly carry out this kind of work in North America, Europe, and Asia. Using a large device called an 'Industrial Power Corruptor', they intentionally create programmed voltage sags and observe exactly how the equipment fails. When a failure is identified, a small low-cost solution – typically a capacitor on a DC supply, or even a tiny UPS – is installed at the appropriate location inside the equipment, and the PV equipment is retested. Another failure mode may occur; that failure is addressed, and the process is repeated until the PV equipment fully meets the sag immunity requirements. This process makes sense if there are several identical pieces of equipment because the same solution(s) can be applied to all. However, if a single piece of equipment is in question, it is generally cheaper to avoid the engineering cost and just install a voltage sag correcting device in front of that equipment.

Equipment energy consumption: a huge zero-cost opportunity

In the semiconductor industry, reducing process energy is just one of many potential cost reductions. But in the PV industry, reducing process energy is vital: ultimately, before any PV device can benefit the environment, it must first pay back the energy that went into its manufacture. Finding zero-cost opportunities to speed up this payback requirement is critical.

In the semiconductor industry, it has become apparent that opportunities for reducing energy consumption are driven almost entirely by recipe design, not – in the short term – by manufacturing equipment design. The same is most likely true in the PV industry. Although recipe design is critical, recipe designers are rarely given information about how their process choices affect energy consumption.

SEMI developed a standard that helps fix this problem, SEMI E6 (see Fig. 6). The electrical energy section of SEMI E6 sets out a standard way of presenting the energy consumption during a recipe or process. Several years of experience with this standard have shown that recipe designers, if they are simply given information about the energy costs of each step of their process, can easily reduce the energy costs by 10 per cent or more – sometimes by shortening a recipe step, or by performing two processes in parallel, or simply doing a process at a lower temperature or pressure.

The good news is that whenever an Industrial Power Corruptor is connected to equipment for performing voltage sag immunity tests, it records all of the energy consumed by the equipment, and generates the graphs for recipe designers. SEMI E6 energy reduction strategies are an almost free side-effect of SEMI F47 voltage sag immunity testing.

If the PV industry makes use of the knowledge base incorporated in SEMI E6, there is every reason to believe that 10 per cent or more can be removed from the process energy simply by making the process designers aware of the energy costs of each step.

Recommendations:

- Specify SEMI F47 (or IEC 61000-4-34) voltage sag immunity whenever you purchase equipment for your PV factory.
- Install power quality monitors near the sensitive equipment, so you know exactly what power disturbances occur at your PV factory.
- If you are having problems with voltage sags with specific equipment, and you have several identical pieces of equipment, consider having a specialist engineer test, modify, and certify the equipment for SEMI F47 voltage sag immunity.
- Use SEMI E6 energy recording to find opportunities to reduce recipe energy consumption.

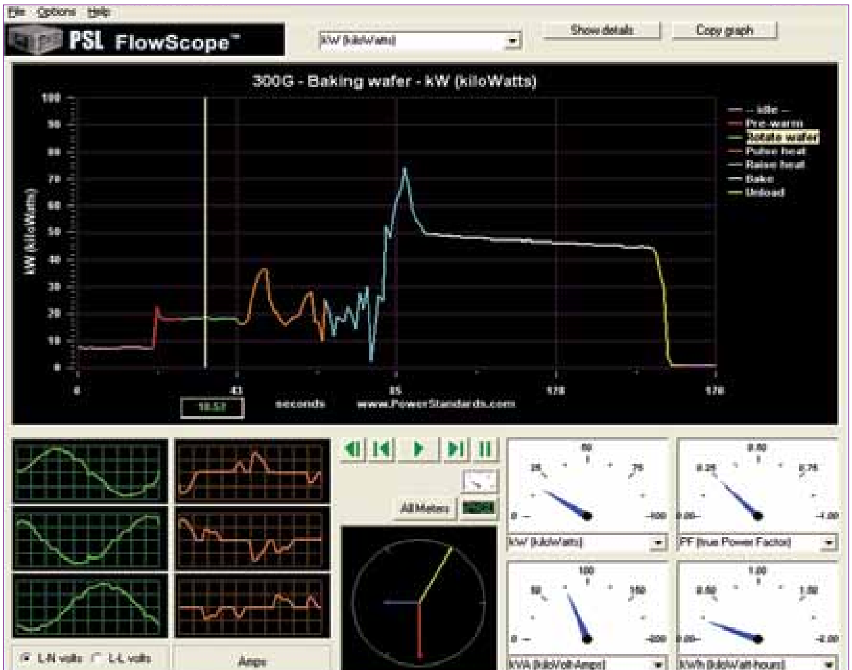

Figure 6. Zero-cost reduction of process energy consumption using the SEMI E6 standard. If process designers are given all information about the energy used during every step of a recipe, they can make adjustments. This graph can be automatically produced by Industrial Power Corruptor during SEMI F47 testing.

About the Author

Alex McEachern is President of Power Standards Lab and is an expert on electric power problems at sensitive locations, including semiconductor fabs, hospitals, automobile factories, and data centres. He is based in Alameda, California, but visits an average of 19 countries per year to solve difficult and interesting power problems. He is the principal author of SEMI F47-0706, and the Task Force Lead on IEC 61000-4-11 and IEC 61000-4-34, and has been awarded 29 U.S. patents on power-related topics.

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