PVECI – a new PV standard supporting efficient and effective production

Matthias Meier & **Konstantin Konrad**, Fraunhofer Institut für Produktionstechnik und Automatisierung (IPA), Stuttgart, Germany

This paper first appeared in the fourth print edition of *Photovoltaics International* journal.

ABSTRACT

The European PV committee of EPIA/SEMI released the new PVECI standard that describes a unified IT interface for PV equipment in March 2009. If used properly, it provides the PV industry with a powerful tool for reduction of IT-related issues – especially between the factory planning and the ramp-up phase – and establishes the basis for deploying advanced factory management and control software systems. The first part of this article describes the standard in detail while the second part focuses on the anticipated benefits regarding IT integration and outlines further possibilities of a pervasive production-IT landscape.

Introduction

Falling module prices paired with the oversupply of PV modules worldwide are some of the reasons for rising efforts to optimize production facilities and to generate approaches for differentiation between different manufacturers. A pervasive production-IT environment is considered to be a promising approach to support these efforts as it allows for a better understanding of processes in production and for the implementation of advanced monitoring and control strategies. The new equipment interface standard for the PV industry developed by SEMI's PV Group [1] is intended to support these strategies and is presented in the first part of this article. The second part outlines how the potential of this standard can be fully exploited by the PV industry.

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Part 1: a standardized equipment interface for PV

Read and write access to production equipment from the factory IT environment is an important prerequisite for implementing a pervasive production-IT landscape. This fact has been recognized by the PV industry during its transition to mass production. Baylies et al describe in [2] how the "PV Equipment Interface Specification" (PV-EIS) taskforce has been founded to develop common standards to make this functionality available to the industry in a unified way. The scope of this interface is to provide IT systems on factory management level – represented by the 'Host' in Figure 1, such as Manufacturing Execution Systems (MES) or engineering systems – the ability to monitor and control process equipment. The terms 'monitor and control' comprise tasks such as collecting logistics events, collecting process and measurement data, collecting equipment performance data, adjusting process parameters, etc. The term equipment denotes a – usually modular – mechanical entity that provides defined capabilities to support manufacturing processes, including transport, storage, process and analysis capabilities. Based on this definition, the generic equipment interface can be applied independent of the base technology used, such as crystalline or thin film, and basic operational concepts, such as inline or batch operation.

PVECI – at a glance

The *Guide for PV Equipment Communication Interfaces (PVECI)*, which is currently available in the form of the SEMI draft document #4557 [3], was officially released for publication as a standard by the European PV committee of EPIA/SEMI on March 10th, 2009 in Dresden and is expected to be officially published by the end of June 2009. It defines how to apply a suite of SEMI standards that relate to the PV industry. While PVECI attempts to maintain compatibility to existing interface packages implementing the referenced SEMI standards as far as possible, it was created with the goal of clarifying a number of known issues of these standards, to remove some legacy elements that are not required anymore and thus to simplify the task of equipment integration for the PV industry. Similar to

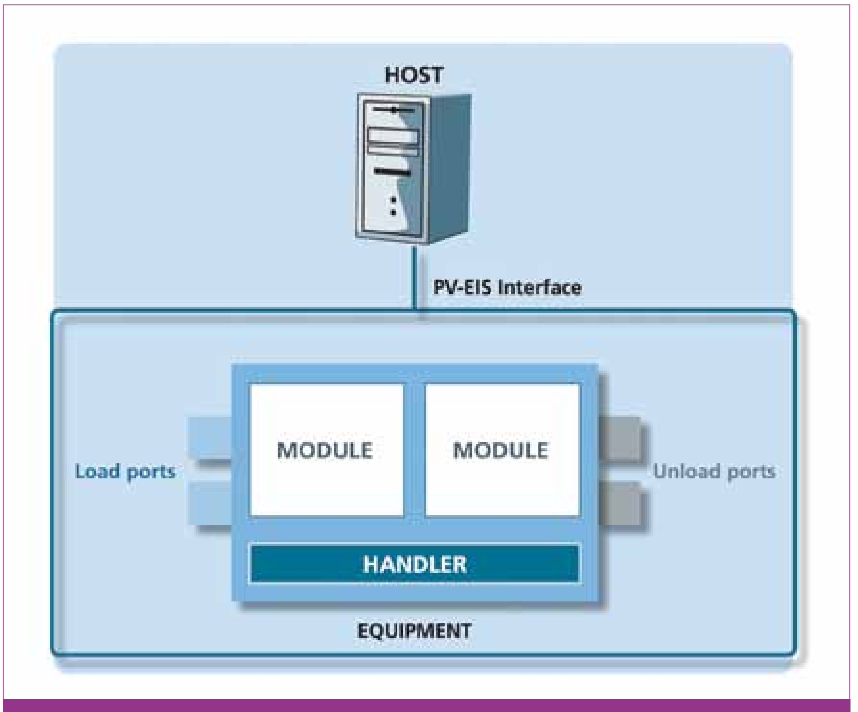

Figure 1. The equipment interface as defined by PVECI.

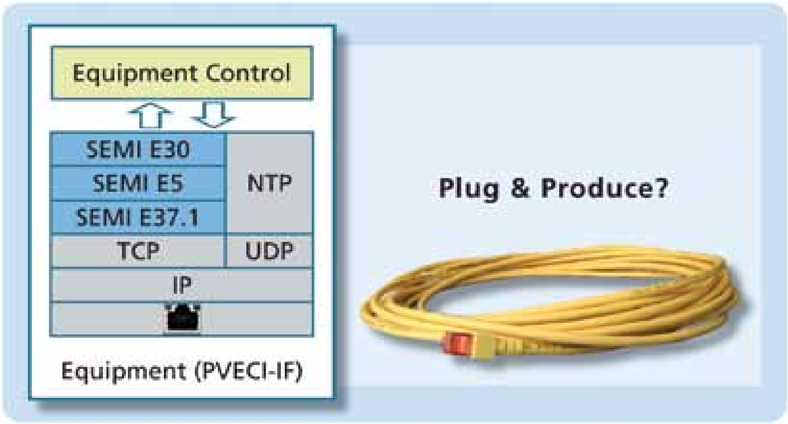

Figure 2. The PVECI protocol stack (equipment side).

```
S5F1 W
<L
     <B 0x57>          /* ALCD */
     <U4 42>           /* ALID */
     <A "Over Temp">       /* ALTX */
     >.
```

Figure 3. SECS-II example message (alarm: consists of alarm severity, alarm ID and alarm text).

other communication standards, PVECI follows a layered architecture approach as conceptually described by the ISO-OSI reference model. On the lowest layers, the physical layer and the data link layer in ISO-OSI terminology, PVECI requests PV equipment to provide an Ethernet interface that supports state-of-the-art communication data rates. The Ethernet interface is used to connect the equipment to the factory network. For the network and the transport layers, PVECI requires PV equipment to provide a standard TCP/IP-stack, which is configured as specified in SEMI E37 – "High-Speed SECS Message Services (HSMS) Generic Services". In conjunction with the subsidiary standard E37.1 – "High-Speed SECS Message Service Single Selected-Session Mode (HSMS-SS or HSMS-SSS)" – a point-to-point message transfer protocol is specified. This messaging service is used by upper layers to exchange self-describing, structured SECS-II messages as specified by SEMI E5 "SEMI Equipment Communication Standard 2 Message Content (SECS-II)". Furthermore, SECS-II defines a set of data formats independent of the CPU architecture (e.g. 4-byte unsigned integer), a dictionary of standard message items (e.g. the process program ID) and a dictionary of standard messages (e.g. alarm report send – S5F1 (see Figure 3)). On top of the E5 layer, any PV equipment generates and understands messages of the same format.

A common message format for all PV equipment worldwide is a good starting point; however, it is not sufficient to efficiently and effectively integrate equipment into PV production lines, as it still leaves multiple degrees of freedom. For this reason, PVECI requires PV equipment to implement SEMI E30 – "Generic Model for Communications and Control of Manufacturing Equipment (GEM)," which resides on top of E5. E30 describes the behaviour of manufacturing equipment as seen through the communication link. The generic behaviour is described in the form of a set of clearly specified automation features ('capabilities' in the GEM terminology) [6].

GEM provides three groups of capabilities:

- Capabilities for collecting and reporting data, such as Alarm Management, Dynamic Event Report Configuration and State Models
- Capabilities for host control of equipment, such as Equipment Constants, Process Program Management and Remote Control
- Miscellaneous capabilities, such as Documentation and Spooling.

PVECI makes a small set of adjustments to E30 GEM capabilities to simplify the implementation of the standard for the PV industry. As the major adjustment, PVECI clarifies the format of time stamps, requires that equipment use Coordinated Universal Time (UTC) for any time stamps worldwide, and also requires the implementation of a time synchronization mechanism based on the Network Time Protocol (NTP). These definitions provide factory operators the ability to make better use of collected factory data for time-based correlations. In addition to these adjustments, PVECI requires PV equipment suppliers to support the collection of data through the interface that is required to evaluate the equipment utilization based on SEMI E10 – "Specification for Definition and Measurement of Equipment Reliability, Availability and Maintainability (RAM)".

Part 2: making full use of the PVECI standard

Unfortunately, the idea of plug-and produce has not yet been realised, despite the presence of the new PVECI standard. However, if a set of basic rules for the factory planning and integration process is taken into account, PVECI has the potential to generate significant benefit for the PV industry. The phases 'requirement specification' and 'testing' are of particular relevance in this context. Part 2 mentions some examples from the semiconductor industry, as it has been through several learning cycles with the SEMI equipment communication standards.

Requirement specification

In the requirement specification phase, the PV manufacturers describe their requested IT interface capabilities in detail. The general behaviour (functional procedures), which is shared by all equipment types, should be described based on the PVECI standard. Some companies in the semiconductor industry use Tool Operation Procedures where the specification for the IT interface is defined within several modules referencing the SEMI standards [4]. When specifying the particular interface requirements for an equipment type, they just 'pick' the corresponding modules and thus minimize the necessary effort for creating a well-structured and well-defined specification document.

Testing

In the testing phase, the PV manufacturers verify whether the (interface) implementation fulfils the specified requirements. Requirements based on standards significantly simplify this phase, as standard compliance can be tested and verified based on generic tests for the different interface layers. One example with a high penetration of the semiconductor market is the *CCS Product Suite*, which provides a testing framework for SEMI factory automation standards [5].

Additionally, company-specific test sets on top of PVECI should be defined based on the functional procedures described in the requirement specification. This can, again, be realized with a modular solution using corresponding test libraries for each requirement module.

Automation Capability Management Process

Requirements specification and testing efforts unfold their full power if they are strongly integrated into the overall business process. This process is widely known as *Automation Capability Management Process* (ACM) in the semiconductor industry (see Figure 4). It starts with the requirements specification, includes the negotiation phase with diverse suppliers, covers the test procedures and targets to successful integration and further operation

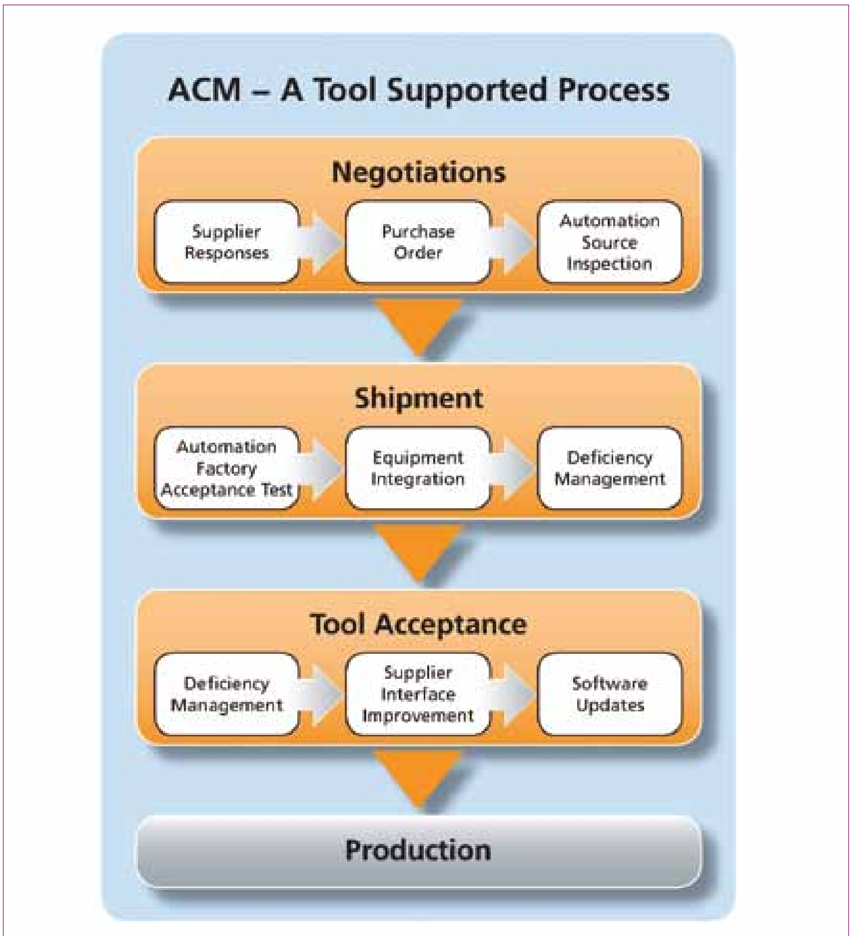

Figure 4. Automation Capability Management [4].

of the equipment in the IT infrastructure at the manufacturer's site.

As an integral part of the negotiation phase, each equipment supplier under consideration has to report the level of compliance to the requirements specification provided by the manufacturer. Judging from the aggregated compliance result of the response, the manufacturer is able to estimate the integration risk and effort more precisely. After the negotiation phase when a supplier for the equipment had been selected, the supplier's response becomes part of the contract – which is a solid basis for later enforcement.

The *Automatic Source Inspection* tests at the suppliers' site include testing of the general communication features and are performed only for a first of a kind EQ. The *Automation Factory Acceptance Tests* are performed for each EQ and include the tool-specific features. Fraunhofer IPA has developed a software tool which supports the whole ACM process starting from the definition of requirement templates and corresponding test sets, through the negotiation and purchasing process and the tracking of test results and deficiencies.

PVECI benefits

The obvious benefits of a unified IT interface specification for PV manufacturers are that they are no longer forced to specify, test, integrate and operate unique interfaces for each equipment supplier and that an enhanced level of IT functionality

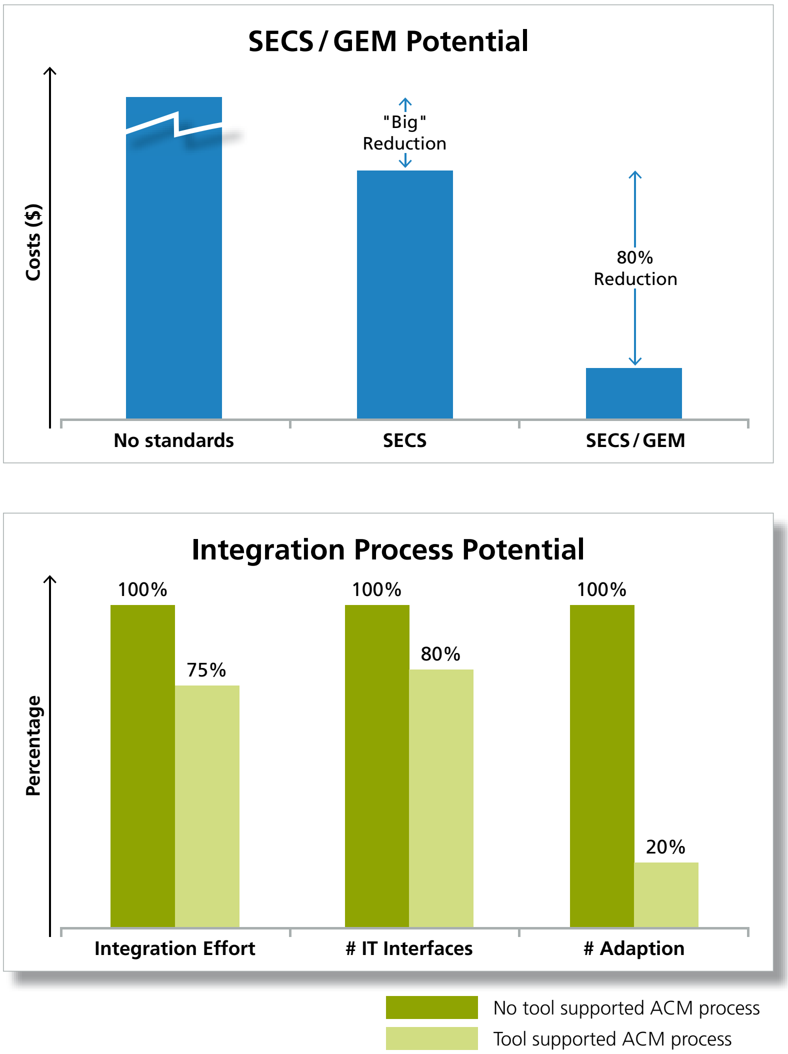

Figure 5. Benefits from IT standardization achieved in semiconductor industry.

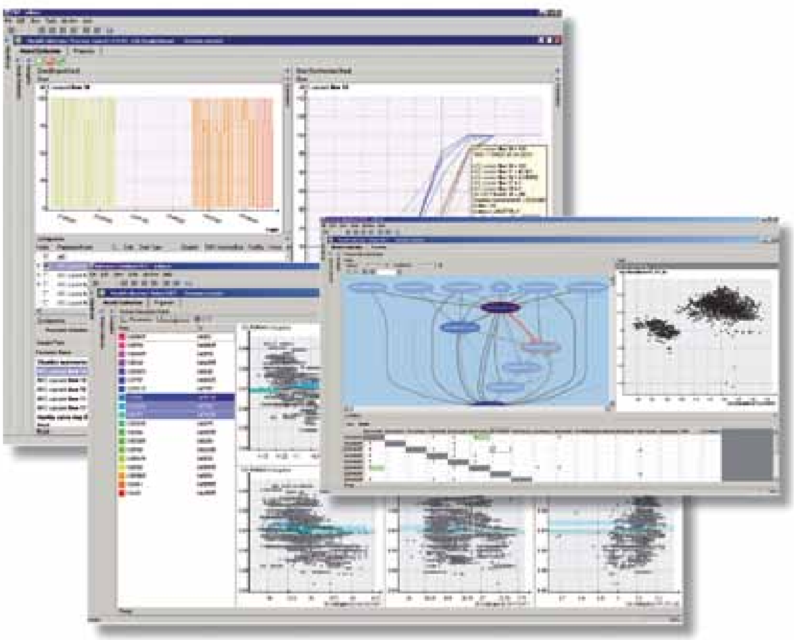

Figure 6. Example of an APC tool illustrating graphical impact analysis of equipment parameters on process or product results [7].

is assured for all equipment. Moreover, equipment suppliers are no longer forced to implement and maintain specific interfaces for each customer. 'Hard facts' – for example in terms of monetary benefits – are more difficult to gather. We will take a closer look at the benefits reported in the semiconductor industry below.

Although most semiconductor companies did not publish exact numbers for their savings achieved with the introduction of SECS-II in 1982, there are at least some numbers for the introduction of GEM in 1992. It enabled a cost reduction of approximately 80% for host-side software compared to the previous attempt (see Figure 5, top) [6]. Additional savings are reported after an effective, tool-supported ACM process, as mentioned above, had been put into place [4] (see Figure 5, bottom). Compared to a former factory setup of the same type, the number of required interface implementations was reduced by 20% and the number of adjustments required for these implementations was reduced by 80%. Thus, the total effort for the IT equipment integration was reduced by 25%. Although the benefits reported from the semiconductor industry are not immediately transferrable to the PV industry, they give valuable hints as to how to make the best use of the PVECI standard in the PV industry.

Using a pervasive production-IT landscape

Besides the support for widely applied features such as tracking and tracing, equipment performance tracking or maintenance management, PVECI simplifies the deployment of additional software systems such as state-of-the-art *Advanced Process Control* (APC) software. These tools allow for detailed examination of PV manufacturing processes – e.g. correlation analysis of settings and parameters – and may even trigger corrective actions.

Figure 6 gives some insight into a case study wherein process parameters collected from several process steps have been correlated with a performance indicator at the quality gate (Wp at the flasher). The APC software was used to calculate and predict the impact of single parameters (or combinations) on the target value, allowing the system to detect issues in processes or process chambers that were not evident by merely looking at the raw data. Furthermore, the system has been used to analyze correlations between process parameters and measurement results. In this context, the system evaluates the impact of process parameters on these measurement values and visualizes findings. This knowledge is useful to predict measurement results in order to optimize the sampling frequency.

These kinds of analysis and control capabilities are expected to be of increasing importance with the growing size of PV factories, increasing cost pressure and quality requirements.

Next steps

In order to complete PVECI in a timely fashion and thereby to provide added value to the PV industry as soon as possible, the PV-EIS taskforce decided to strictly follow a stepwise approach for creating the communication standards framework for PV. As the basic automation and communication capabilities are now available in a unified way based on PVECI, the PV-EIS taskforce is currently moving on to complement the guide with specifications supporting single-substrate tracking. Support for single-substrate tracking has been identified by the PV industry as a major issue to be tackled to improve traceability on the one hand, and to enable more sophisticated process monitoring and control capabilities on the other. These capabilities are expected to generate significant competitive advantages in the future. Therefore, the PV-EIS taskforce has initiated activities to make use of the extensibility mechanisms of PVECI to incorporate single-substrate tracking features into the interface, and to specify an additional interface for horizontal communication that supports propagation of substrate information within inline equipment without having the need to read an ID from the substrate.

Conclusion

It is now up to the PV industry to exploit the potential of the new PVECI standard. Creating a standard document is only the first step; bringing it to life in the industry is the difficult second step. The field is prepared – implementation packages are ready for use, the first equipment suppliers offer PVECI interfaces out of the box and the first factories utilizing the standard (or at least large parts thereof) went live or are in the process of going live. From today's perspective, PVECI is on a good way to being successful.

References

[1] PV Group [available online at http://www.pvgroup.org].

[2] Baylies, W. et al 2008, 'Structuring standards for the photovoltaic manufacturing industry,' *Photovoltaics International*, 2nd Edition, pp. 151-155.

[3] *SEMI Draft Document #4557: Guide for PV Equipment Communication Interfaces (PVECI).*

[4] Dreiss P. 2007, 'System für die modellbasierte Integration von Anlagen in die Halbleiterfertigung,' *Jost Jetter Verlag, Heimsheim.*

[5] The PEER Group, Inc. [available online at http://www.peergroup.com/CCSProducts.aspx].

[6] Ghiselli J. 2008, ´SEMI GEM / SECS Training for Photovoltaic Industries,' Fraunhofer IPA.

[7] acp-Information Technology GmbH (acp-IT) [available online at http://pcs.acp-it.com].

About the Authors

Matthias Meier is Project Manager and researcher at the Fraunhofer Institute for Manufacturing Engineering and Automation (Fraunhofer IPA) in Stuttgart, Germany. His main area of research targets issues in the Production-IT environment. Furthermore, he is actively contributing to the emerging PV-related standardization activities within SEMI as a coach of the PV-EIS task force. Mr. Meier holds an M.Sc. in information technologies from the University of Stuttgart, Germany.

Konstantin Konrad is Project Manager and senior scientist at Fraunhofer IPA, which he joined in 2007. He has a Master's degree in Cybernetics Engineering from the University of Stuttgart and has sound knowledge in the field of factory logistics and Production-IT. Mr. Konrad has experience in software and hardware projects including design, analysis and optimization of automation systems.

Enquiries

Fraunhofer Institut für Produktionstechnik und Automatisierung
Nobelstrasse 12, 70569 Stuttgart, Germany
Tel: +49-7119701217 Fax: +49-7119701010
Email: matthias.meier@ipa.fraunhofer.de
konstantin.konrad@ipa.fraunhofer.de
Website: www.ipa.fhg.de