The Manufacturing Execution System (MES) at Conergy

Maiko Kenner, Conergy AG, Frankfurt, Germany

ABSTRACT
In 2006, Conergy AG started construction on one of the most advanced solar factories in the world in Frankfurt (Oder). On 35,000 square metres, a fully integrated and fully-automated wafer, cell and module production facility was created – all under one roof. Since 2008, production has been running at full speed and every day more than 3,000 premium modules roll out of the factory. This paper outlines the Manufacturing Execution System (MES) process put in place by Conergy during the planning phase of the factory, to monitor and control the complex and merging production processes.

Three good reasons for an MES

Interaction of production areas

In the manufacture of solar modules, each area of production has its own optimum. Wafer production, for example, is based on the key performance indications of wafer quantity per kilogram of silicon and throughput per hour which, from a wafer manufacturer's point of view, should be as high as possible. However, what is good in wafer production may be counter-productive for the subsequent cell production. Thinner wafers or wafers that were sawn at high speed can break more easily or have surface damage and therefore could potentially cause problems in subsequent production steps. A perfect interaction of the production areas is therefore of enormous importance. The advantage experienced by Conergy is that all production steps from sawing the wafer to the finished module, take place under one roof in Frankfurt. A process-spanning control system brings all the production areas to an optimum level, thereby supporting the production of good wafers, cells, and durable solar modules.

Process control and traceability

Additional reasons for setting up an MES are the necessary traceability and process control, especially in the area of sensitive chemical processes in solar cell production. Conergy grants a 25-year performance and a five-year product warranty for its PowerPlus modules – a complete and accurate data collection of the history of origins is therefore essential. This was modelled on the experiences of related industries. In the production of control units for airbags, for example, the continuous monitoring and logging of production steps and materials used is required by law. Although there are no rules to this respect in the solar industry, Conergy is still committed to a similar process control.

The control of sensitive processes

Highly automated production steps enable a high degree of repeatable quality with very low fluctuations. This approach to manufacturing allows for fewer interruptions and tighter process limits. The result is a more sensitive process that must be closely controlled. Based on these fundamental ideas, the individual functional groups within the required MES were compiled and prioritised in the early planning phases of the factory. The system should be primarily used for production monitoring. The final decision and control processes, however, should remain in the hands of process managers.

The focus of attention in setting up the MES was the master data and data collections such as production data acquisition (PDA) and machine data acquisition (MDA), which provide the basis for machine monitoring, reporting, analysis, metrics, process visualization and traceability. The system was developed to MES-level according to the original IPO principle (input, processing, output). This initially required the creation of a database through input layers like data interfaces and input terminals. This was followed by the processing of data and ultimately the presentation of the data from different perspectives and levels of abstraction in the output layer. The long-term goal for setting up the MES is the optimization and monitoring of the process windows, production orders, machine utilization and the machine throughput.

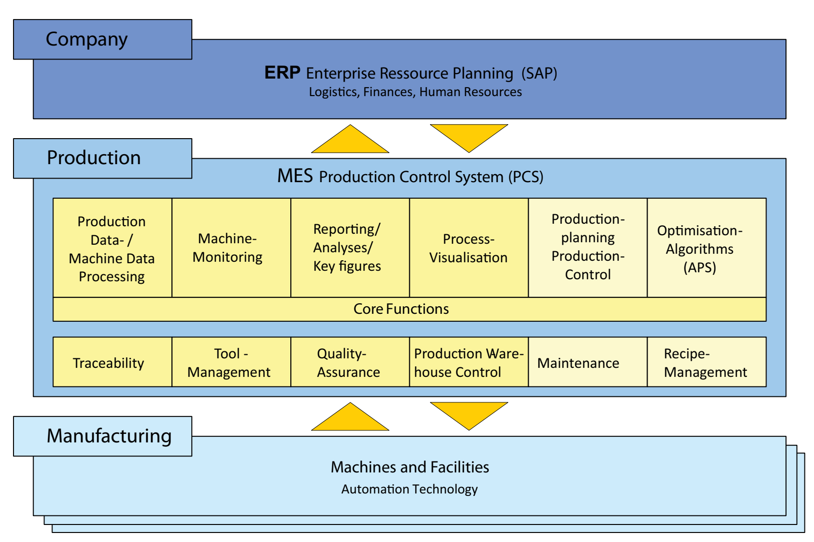


Figure 1. Core functions of an MES.

Creating the foundations

The goal of building a new MES was an exciting challenge for our IT professionals. The primary reasons for this lay in the still-fledgling PV industry. Standard processes and solutions were or still are a rarity. Production processes, fresh from the lab, were converted into mass production processes in the factory in Frankfurt for the first time.

The production tools were, for the most part, prototypes, which were initially custom manufactured in small numbers. There was no long-term experience with those processes under industrial conditions and standardization was still in its infancy. Data interfaces were not usually available and if so, only in rudimentary ways, quite contrary to the standardized interfaces considered a

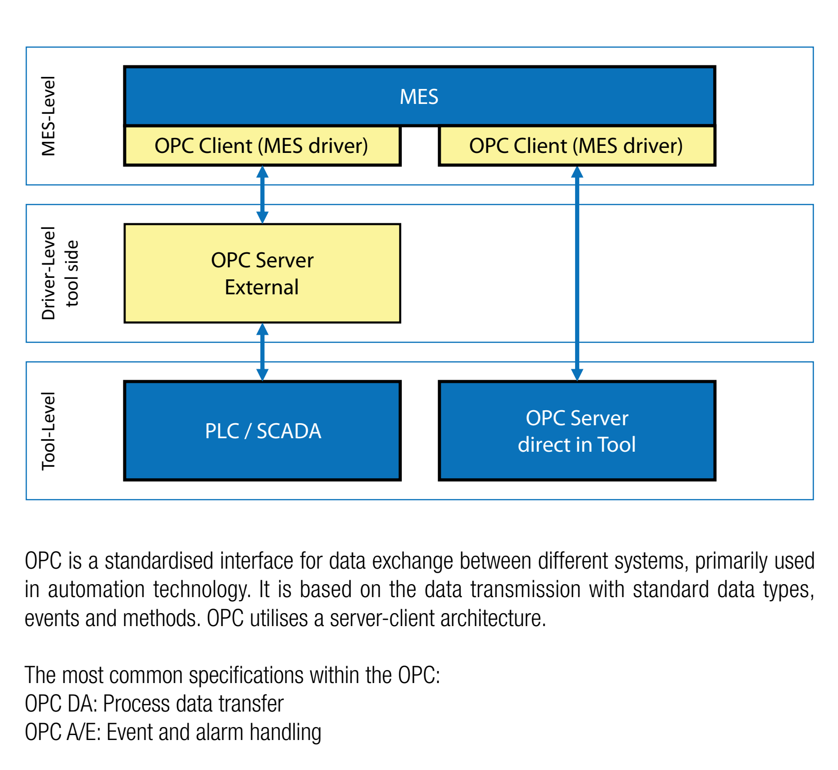


Figure 2. Diagram showing OPC data exchange.

'must-have', such as "SEMI Equipment Communication Standard (SECS)" and "Generic Model for Communications and Control of Manufacturing Equipment" (GEM) (see: http://www.semi.org) in the semiconductor environment.

The technical interface

The primary data source of an MES is the automated data communication with its process tools. The interfaces extend from digital signals on an electrical level and proprietary text files, up to direct access to data blocks PLCs (Programmable Logic Controllers). During the building of the Conergy solar factory, however, the interfaces were for the most part not included in the machine manufacturers' standard package. Interfaces such as PV2 (Communication Equipment Interface Standard for PV production systems, including PVECI) (see SEMI: http://www.semi.org/en/Press/CTR_030751) were not approved until mid-2009 as the industry standard and are only gradually being included in machine technology. The Swiss manufacturer Meyer Burger, whose wafer saws Conergy uses in its factory, was among the first machine suppliers to retrofit the existing tools with the new standards.

OPC: the language of automation technology

At Conergy, tools that only give digital signals are usually connected to the MES via PLC. Here, the PLC act merely as data converters of the electrical signals. The communication channels mainly the integrated transport systems that have internal PLC systems, and are connected through them. Conergy was able to retrieve most of the handling steps and simplest plant components via this standardized interface. For communication between these systems and the MES, finished software packages are used to route the data from the controllers via the OPC server to the MES (see Fig. 2). Here, the OPC servers are used as an interface converter between the controllers and the MES. Through the use of standard software packages, the connection of machines can be carried out quickly and easily. The connection between PLC – if they are a common type – and the OPC server, installed for this purpose, usually takes 30 minutes to an hour. The access, created between the OPC server and the PLC in this case, is directly to the data blocks existing in the PLC. Through the use of OPC as a data transport protocol, only "transfer logic" is required. Conergy accommodated this in a MES-oriented driver layer – in so-called MES-drivers who take on these functions centrally (see Fig. 3).

MES drivers: pre-processing and compression of data

The dependencies between the data and the understanding of the data are located within the MES drivers. The benefits for Conergy are, on the one hand, a significant relief to the MES and a clear division of responsibilities, and on the other, the company can limit the amount of data that has to be processed by the MES-core to what is necessary, forwarding the payload directly into the defined internal MES modules. One example is the data gathered regarding wafers and cells at Conergy's Frankfurt (Oder) facility. Within a minute, approximately 120–130 wafers or cells can be processed in a single step. For each process step, the resulting data is transferred to the MES driver, which checks the consistency of the data received with the expected data structure and the allowed value limits.

Upon successful input, verification of the data will be converted into the internal communication structures and transferred to the assigned MES internal modules for processing, such as the online statistical process control (SPC) module. The internal MES modules can process the data directly, without having to check for errors in the structure or values outside the measuring ranges. If the MES drivers recognize incorrect data or data that needs to be filtered out, no load is created inside the MES core.

As described in the OPC sample, the MES driver determines the time of data retrieval, the conversion and classification of data and indicates which MES module within the core must receive which data from the data packet.

Extensible mark-up language (XML): the universal interface

Another interface option in the Conergy solar factory is the data communication via XML files or XML streams (see Fig. 4). This is mainly a way to provide data from measuring systems. The advantage of XML files is the platform-independent data interpretation. In addition, the data processing within the MES drivers takes place asynchronously and thus independently of time; after a successful measurement, the measuring system

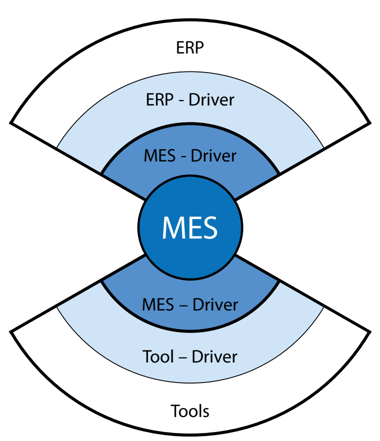
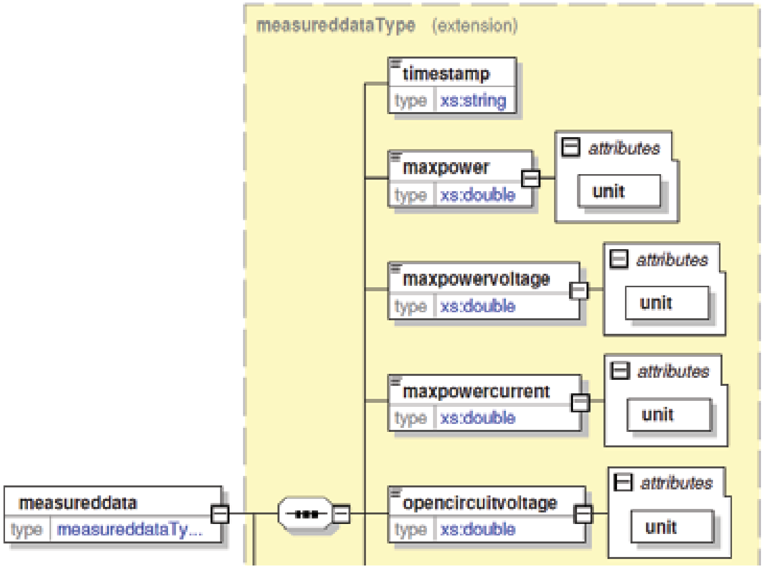


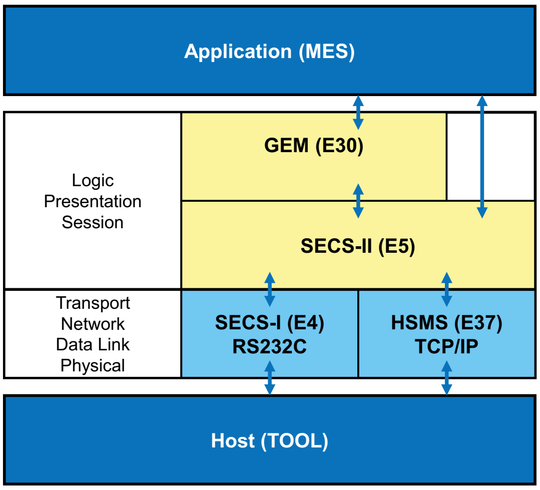
Figure 3. MES data transfer layers.



XML is a structure definition for character-based data files. It is used to exchange structured data, is platform- and implementation-independent, but remains readable for employees. XML was specified by the World Wide Web Consortium (W3C) in the first version in 1998.

By means of XSD files (XML scheme definition), the contents of an XML file can be automatically validated in relation to its structure and data. XML data can be transferred platform-independently as a file or as a stream (e.g. TCP/IP), which makes them flexible.

Figure 4. Schematic showing XML structure breakdown.



SECS / GEM an interface protocol standardized by the SEMI Association (Semiconductor Equipment and Materials International). It unifies and simplifies the communication and the exchange of data between production tools and parent control and monitoring systems. The protocol includes both the cyclic and event-driven process data and status retrieval as well as transmission of control commands and configuration parameters.

Within SECS/GEM Standards SECS-I, SECS-II and HSMS are used as communication protocols.

SECS-I:	SEMI-E4	Protocol for the communication via the serial interface RS232C
HSMS:	SEMI-E37	Protocol for the communication via TCP/IP
SECS-II:	SEMI-E5	Definition of message types and of message structure
GEM:	SEMI-E30	A generic model for defining the behaviour of a tool, its conditions, the business logic and the combined use of the available message types

Figure 5. The SECS/GEM interface protocol.

creates an XML file and stores it in a defined transfer point. The MES driver is now able to retrieve the files at a later date and process them. These XML files also have the advantage that they can be exchanged on different channels, such as FTP, email or other forms of file transfers between different systems, cyclically or event driven. This allows data to be easily inserted at a later point. Conergy uses the data import of information provided by external testing laboratories or materials suppliers; this means that the XML files are easily readable by employees and can be validated by XSD files (XML scheme definition). This strongly supports the fast integration of new data into the MES and a facilitation for the successful exchange of data.

SECS / GEM and PV2: the sophisticated interfaces

In a process that requires real-time monitoring as well as collections of data and information on the condition, XML files are only partially suitable. For data communication close to the process, specialized interfaces such as SECS / GEM or PV2 can be used (see Fig. 5). They are considerably more sophisticated and more standardized. However, due to their complexity, it requires an increased effort to integrate them into the MES. PV2, for the most part, is based on SECS/GEM. Their advantage becomes apparent during the integration of these interfaces. For example, the abstract machine model, standardized through the GEM (SEMI E30), controls the interpretation of the machine condition according to SEMI E10. In terms of material tracking and process data processing, a SECS/GEM interface also offers standardized functions. One major advantage is that events can be stored for so-called message structures. The buffering of events and their associated message packets in terms of data collection is an essential advantage. This way, very short pending messages are not overlooked.

Derived from the SEMI SECS / GEM norm 2009, the interface standard PV2 was adopted for the photovoltaic industry. PV2 comprises the TCP / IP transport layer (SEMI E37 (HSMS)), the data presentation layer SEMI E5 (SECS-II), the abstract machine model SEMI E30 (GEM), the machine condition definition according to SEMI E10 as well as the time synchronization according to SEMI E148 that integrates the known network standard Network Time Protocol (NTP).

SEMI E10 and E79: machine conditions and efficiencies

For Conergy, the SEMI norms E10 and E79 are a great support in the analysis of machine time and productivity, making

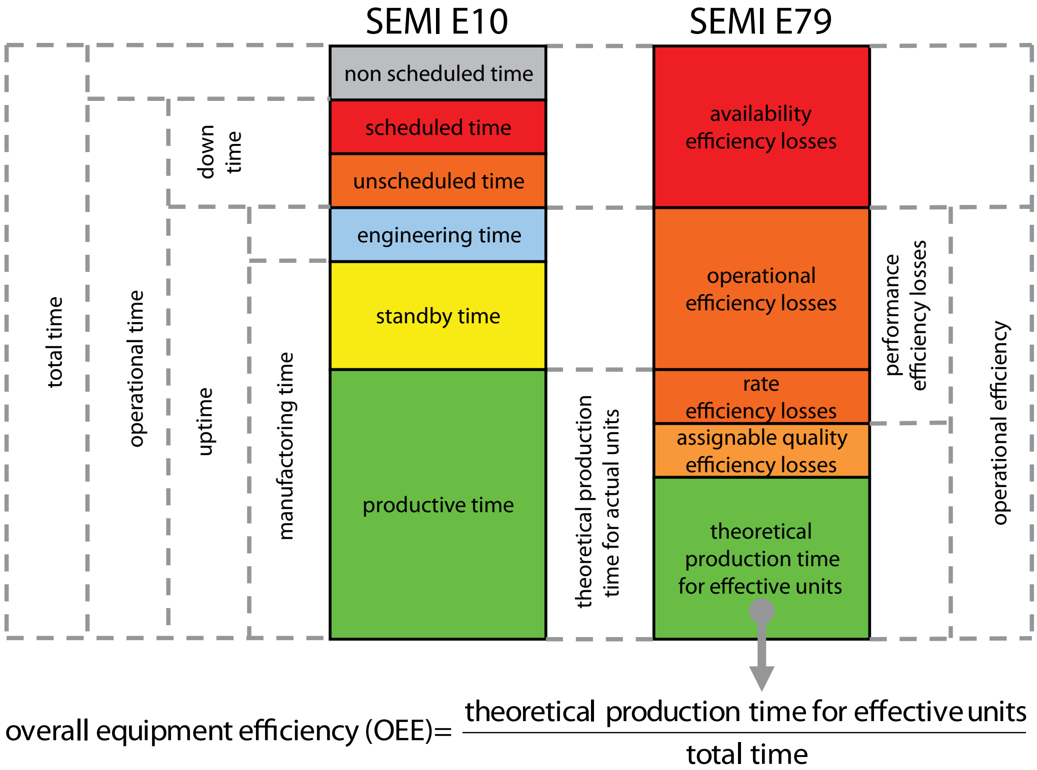


Figure 6. Condition analysis.

the processes and tools comparable to each other and measurable. SEMI E10 defines the machine reliability, availability and serviceability. In contrast, SEMI E79 looks at the productivity and quality yield. Through the norm, the overall machine efficiency was defined as an abstract level for the first overall efficiency equipment (OEE). According to the SEMI E10 norm, six main conditions are permitted. The SEMI E79 norm uses these and combines them from the perspective of efficiency (see Fig. 6).

In the course of continuous improvement processes, necessary in every business, an essential increase in time productivity is derivable from the SEMI E10. The SEMI E79 implies less process delays and an increase in quality. The OEE values describe whether or not a production tool is used optimally. Based on the condition classification and efficiency definitions, standardized through the SEMI norms E10 and E79, key figures needed from a production perspective are easy to calculate. Among these key figures are, for example: mean time between failures, mean time to repair, mean time between assist and mean time between interrupts.

Core function 1: reporting, analyses and key figures

Through the central data collection at Conergy, the automated data interfaces and the user terminals create an internal database, which the core functions of the MES builds on. When the construction of the Conergy solar factory began, the online data analysis, through the use of SPCs, was quickly created, based on the acquired process data. Because of these, raw measurement values can be concentrated, set in correlation and provided with threshold values and control limits.

An example of this is the monitoring of the measured cell efficiencies of the individual production lines. A machine-induced change in the cell efficiencies can be monitored per line – in case of deviations, the MES automatically send notification. This direct online monitoring provides a prompt statement about the current situation of the production for a variety of data measurements and process steps. A central reporting system, which is a type of intranet for production data, allows a view into the development of process values. Through this tool, any authorized employee, from any workstation within the production, can access all historical and current data of the production and have it presented in various graphical and tabular reports with selectable filters and groupings. Shortly after the introduction of this central access to the data analysis, it became one of the most widely used systems in the solar factory and an integral part of the everyday working life.

Core function 2: machine monitoring

Machine monitoring is one of the most common methods for monitoring a factory. The usual standards in the semiconductor industry, according to the norms SEMI E10 and E79, also allow a comprehensive and comparative analysis of machine conditions in the related solar manufacturing industry.

Conergy has more than 300 production machines. Analyzing them is part of daily business for the employees and individual reporting of the base systems is possible through only a few clicks of the mouse. For example, the operational time in use of individual tools within one line can be compared with each other but also with tools of several lines. This allows Conergy the rapid ability to identifiy critical tools, which would reduce the throughput per line for an extended period of time.

To obtain a finer breakdown and representation of the individual condition details, next to the abstract machine conditions according to SEMI E10, the main conditions are broken up further. The analysis of the machine conditions allows production managers a permanent view of the capacity utilization of the tools, one can also keep an eye on any failure vulnerabilities or maintenance efforts.

Core function 3: quality assurance

Quality assurance is one of the most important criteria in a facility. Because the MES is primarily installed in many parts of the production, it accompanies all work processes of employees. MES supports quality assurance as early as from the receipt of goods. Through an integrated assurance system, all bought-in goods must pass a quality verification. A material subject to an audit requirement will be actively suspended from the MES until the final outcome of the investigation and not available for use within the production. All data collected during the quality inspection will be logged. Based on defined limits, the system will decide independently whether or not the relevant batch or pallet can be released for production. These MES functions exist throughout the factory, from the value-adding steps, to the final quality verification of finished products.

The semi-finished wafers and cells are monitored meticulously. This is mainly done through automated processes. They detect the slightest deviation from the desired parameters, monitor them and incorporate them into the quality grading. This ensures that only efficient and visually flawless cells are installed in the Conergy PowerPlus module. In the final inspection of the photovoltaic modules, the optical inspection is also carried out by specially trained employees who report even the smallest abnormality of a module to the MES. Based on the collected data from visual inspections, product master data and electrical measuring data, the MES determines the class of quality assigned to the product and which sales order number it will receive.

Core function 4: tracking

To meet stringent quality requirements, all process data, process steps and detailed classifications are recorded for each individual and centrally provided on the reporting system. Using the example of module production, each working step up to the customer delivery can be tracked. Conergy maintains this traceability through permanent monitoring and continuous identification of each individual for each step of the process flow.

Conclusion

The development of an MES is extrremely complex. Therefore, Conergy decided in the very beginning to establish the MES in such a manner that each step of the process – from the silicon block to the finished module – can be recorded in detail. The basic considerations of which functions the MES should have were already of crucial importance during the planning phase of the factory. Thus, the individual core modules within the system were selected in such a way that despite the wide range of functions, clear distribution of tasks and responsibilities were created, yet the system still offered enough flexibility for changes and additions. These benefits can be seen in everyday business operations; Conergy is able to analyze its production data from several years in seconds and run comparisons. This is based on the extensive data structure that over time formed a comprehensive database.

An advantage for process technologists at the site is that within a short time, they can examine historical mass data for potential improvements, test new ideas and provide effective process developments with fast successes. In addition, Conergy can comprehend the history of origins for each individual module and thus, even with a module that is already installed on a roof, can trace its history, up to the respective silicon block.

About the Author

Maiko Kenner has been Head of IT in Frankfurt (Oder) since 2006. The graduate IT business engineer has been responsible for the development of the MES since construction began. Prior to joining Conergy, Kenner worked as an independent IT consultant for several companies.

Enquiries

Conergy SolarModule GmbH & Co. KG
Conergy-Strasse 8
15236 Frankfurt (Oder)
Germany
Tel: + 49 335 521130
Email: m.kenner@conergy.de