Line integration of PV module manufacturing technology in the light of a rapidly changing environment

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ABSTRACT

Over the past few decades, the PV equipment manufacturing market has seen a significant change in technologies. Cell sizes are being increased, while cell thickness has decreased at an ever-increasing speed of technological innovation, from 4" 340µm cells in the 1990s to 6"+ 180µm being the current industry standard. Thin-film modules pose completely new challenges to module manufacturing technology with a strong integration of the manufacturing of the active layers into the module production flow. This articles analyses the pros and cons of an increased level of line integration from the viewpoint of an established PV module producer.

Introduction

Suppliers of production equipment have improved the equipment and manufacturing technologies to accommodate changes in product and material technology, often in close cooperation with module producers as their customers. New players have entered the equipment market, often coming from other industries and leveraging their know-how and technologies for application in the PV industry. With an increasing level of professionalism being displayed in production management, what with optimization of production planning, bottleneck considerations, and tools like process control, more and more suppliers are offering highly-integrated turnkey production lines.

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Highly-integrated module production lines

Levels of line integration

Despite the change in materials and production technology, the basic process flow for silicon-based PV modules has not changed in several years (see schematic in Figure 1). Solar cells are joined to form strings, which are interconnected to form a module; the module is then laminated with encapsulation material; electrical connections are formed using junction box (j-box), and a frame is applied. Finally, the modules are flashed and tested.

In the early days of module production, when volumes were low and throughput was not the major focus, the process flow was realized in a job-shop style of production – as shown in Figure 2 – with individual process stations and several customized products. Cell interconnection was divided into two steps whereby cells were tabbed with solder ribbons ('tabbing') and the electrical connection to the next cell was realized in a different machine ('stringing').

With the unprecedented growth seen by the industry in the first few years of this decade, production volumes grew, and as a result capacity and bottleneck planning became pertinent issues. Production flow was organized into line concepts where the individual steps were connected, while cycle times of different pieces of equipment became more and more matched. Many highly optimized production lines run in this manner today, where individual process steps

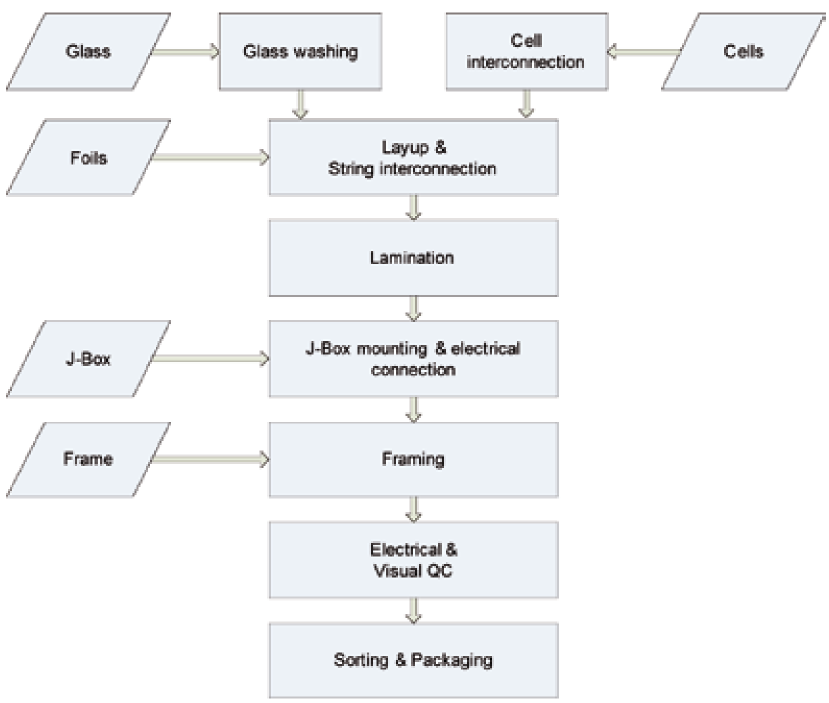

Figure 1. Principle process flow for PV module manufacturing.

Figure 2. Job-shop module production (SOLON, 1998).

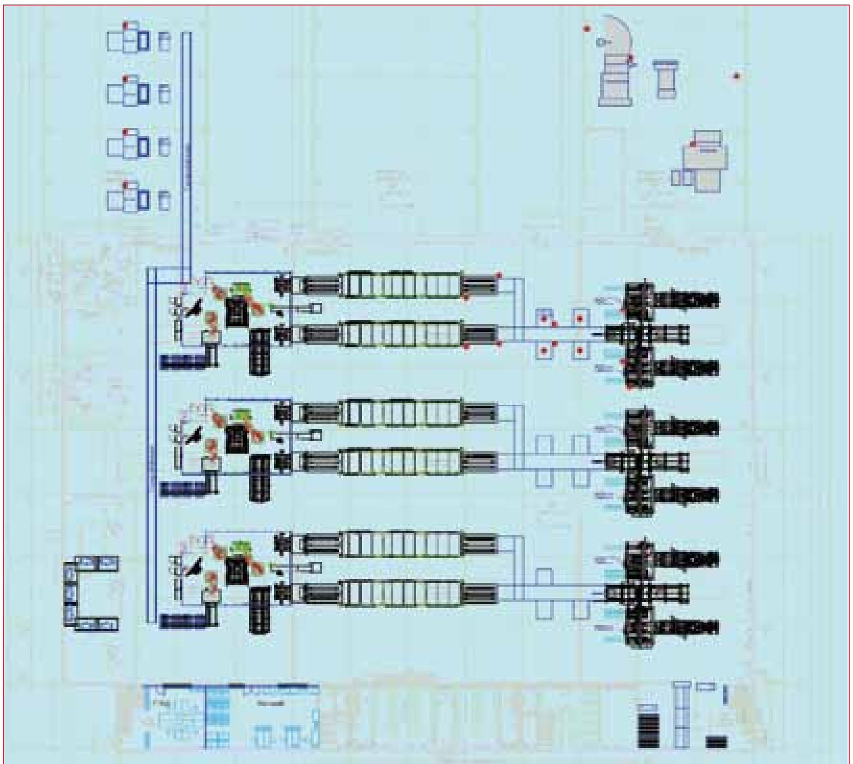

Figure 3. Layout for 120MW production line (SOLON, 2008).

are optimized individually, throughput and capacity planning are considered for the full line, and automation is installed on the level of single process steps or at particular points of interface (see Figure 3).

The evolution of production lines corresponds to the development of product concepts, ranging from low-volume customized solutions in the '90s to high-volume power plant products in the current market, as shown in Figure 4.

A highly integrated line utilizes an increased level of automation. Typically, process steps such as string interconnection, j-box mounting and framing use a higher degree of process automation than they would in conventional lines. Also the material and module handling, with all transportation within the line is carried out by machines as opposed to manual transportation by a human operator. Materials such as glass plates and modules in progress are moved automatically from one process step to another, and are quite often automatically fed into the line, as illustrated by Figure 5.

Highly integrated lines are often equipped with complete interlinked machine and production data collection systems to allow the tracking and documentation of materials and processes used in the manufacture of the products, as well as a central production control system to steer material and product flow through the line.

As matching of all single process steps is not always possible, the direct interconnection between all process steps makes it necessary to implement buffer systems at certain stations, resulting in an optimized output for the entire production line. Due to the reduced amount of operators in the line, highly integrated production requires a significantly higher degree of automated process control, usually in the form of vision systems or measurement tools.

Figure 4. Evolution of product concepts: architectural customized solution (1999, left); power plant product (2006, right).

Two approaches to highly integrated lines

There are some established players in the equipment market among the suppliers of highly integrated manufacturing lines, usually those that already have the major production equipment in their portfolio, like stringers and laminators. Additional automation and interconnection into an integrated line is often realized in-house or under contract and only less critical building blocks are realized through cooperation partners.

On the other hand, there are new suppliers entering the market that quite often have accumulated the knowledge of the potential benefits of line integration from other industries or have a particular manufacturing know-how that they wish to leverage into the PV industry. Robot technology has found its way into PV module manufacturing through this strategy. These suppliers usually offer an individual process step, like framing, plus an integration service, and tend to form alliances to supply fully integrated lines. Several of such alliances have been seen in the market over the last years. Only in a few of such concepts can individual building blocks be exchanged upon customer demand.

Shorter time-to-market for new players

Highly integrated production lines use standardized building blocks, standardized interfaces, and processes known and established by the supplier of the line. Building up a production from scratch to a level provided by a turnkey supplier requires:

1. Selection of equipment vendors for each step
2. Definition of interfaces between process steps
3. Development and implementation of production and control processes
4. Implementation of a quality management system
5. Training of engineers and operators.

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A new player in the field of module manufacturing can easily source points 1 to 3 from a one-stop shop, and can typically get support on 4 and 5, giving the manufacturer at least a six- to twelve-month head start over taking the route of building up all necessary know-how in-house. This approach can also save the module manufacturer from making expensive mistakes during the learning curve. In using the integrated line, it can be possible to source the product design at a certain quality level. The resulting shortening of time-to-market can easily pay off the higher investment required to implement an integrated line.

Advantages for established module manufacturers

Established manufacturers will already have process know-how in-house, as well as an existing supplier base and production equipment. For this group in particular, it is much harder to justify the investment required of a highly integrated line. However, there are contractual advantages or project management competencies that can prove beneficial for these companies, as the manufacturer in question can make the decision to have just one contract partner who is responsible for guarantees, installation, and service.

With particular focus on those coming from industries that also use automation, line integrators can tend to have a strong focus on project management. Although this does not necessarily mean that timescales are

Figure 5. Principle process flow of a highly integrated line.

kept to the satisfaction of the module manufacturer, the integrator can cover resources that the manufacturer does not necessarily want to build up beyond the ramp-up project. As some of the integrators are experienced in worldwide operations, line integrators can bring significant benefits to line installations in remote sites where intercultural communication, travel, time shifts, and delegation of workforce raises additional challenges to the project.

Capacity variations and cost considerations

The current slowdown of the industry shows how important flexibility in production output can be. Naturally, the higher the investment, the higher the financial impact is of changing a production output. In contrast, the financial impact of output changes is reduced for a line with a limited depreciation but larger workforce. Though this is a platitude, it is often neglected at the time of line-concept planning.

Further cost drivers in this regard – besides depreciation and labour cost – are yield and uptime. Yield can be increased by introduction of individual automation of critical processes, which are hard to control in manual operation. Line integration does not necessarily improve the yield. However, any initial line ramp-up coupled with a changeover of production generates additional yield losses. An integrated line will fundamentally have a downtime that is worse than the downtime of the bottleneck equipment, which can be easily overcome by making the right choice of buffer steps and buffer positions, in turn increasing the investment needed for such a line.

> "With the increasing speed of technological innovation in materials, process know-how requirements are being shifted more often from customers to equipment suppliers."

Moving process know-how

With the pervasive technology change occurring mainly in the materials sector, equipment suppliers are building more and more of the required process know-how in-house. New cell generations are usually tested at the sites of the lead customers among the module manufacturers and the stringer manufacturers in parallel. The reason for this method is that such a major change in the materials technology directly impacts the technology of processes such as soldering technology or cell handling.

A general trend is forming. With the increasing speed of technological innovation in materials, process know-how requirements are being shifted more often from customers (i.e. module manufacturers) to equipment suppliers, a trend that is being driven further by additional line integration.

Limiting the growth of the PV industry?

Are today's modules ready for grid parity?

Looking at the performance of the PV industry over the past few years, it has shown tremendous improvements in production quality, process stability and product costs. Still further innovation is required to reach grid parity for larger parts of the worldwide electricity market. In the early years of PV module manufacturing, automation was driven by the requirements of process quality, like automated stringing and lamination. For the past few years, however, automation has started to increase efficiency of production flow, cycle time and labour resources; to date, none of these approaches has led to significant innovations in the design of the product. The logical step of designing a module suited for automation still has to take place.

Future innovation requires flexibility

The main driver for innovation over the past few years has been in material changes - mainly cell sizes and thicknesses, though not limited to cells. This has led to a technological lifetime of down to two years for some major equipment. With the current slowdown in industry growth, the areas of innovation will be widened ever further to new products, new applications, and additional customer benefit, in addition to all ongoing efforts at reduction of product and production costs.

It is the nature of innovation that the exact path of improvement is not predictable. It certainly requires in-depth know-how in the fields of materials, products and processes, as well as crucial changes to production flows and processes. Extrapolating the past into the future shows that the product of tomorrow – and thus the production lines to build those products – will look different from today's most efficient lines.

In highly integrated lines, even minor changes in mechanical dimensions or the usage of second-source material with only slight variations in process parameters can require hours of changeover. A major change in the product usually cannot be covered by an existing line, but will require either major re-design efforts or a lot of expensive variability in the automation.

Highly-integrated lines form a de-facto standard for production processes (and thus for products)

Highly integrated, highly automated production lines always refer to comparably high investments. Such lines need to run at high workloads for the longest possible lifetime to amortize the additional invest. During the technological lifetime of the investment, only minor product changes can be allowed from a financial perspective. Increasing the technological lifetime of equipment corresponds to discussions about standardization of products. It is the obvious interest of line integrators that the innovation frequency of the *product* will be decreased.

Highly-integrated lines limit flexibility for production processes (and thus for product design)

A longer innovation cycle driven by actual or de-facto standardization is in contrast to the increasing speed of product innovation needed. A module manufacturer, having invested heavily in a fixed line concept, will meet with the major hurdle of having to adapt to new developments, problematic because of the associated fixed investment, as well as the investment needed to change the lines. Installed lines need to be filled with the products for which they were designed.

The efforts of equipment vendors are focussed on improvements in line integration, in individual processes, and sometimes in product modifications to enhance automation possibilities. The efforts of module manufacturers operating integrated lines are, conversely, focussed on total line management than on understanding and improving individual process steps. Module manufacturers having such process know-how in-house can more quickly and efficiently adapt to any material or process changes.

> "Flexibility – needed for product innovation over the next few years – can be only accomplished with more individual building blocks instead of a fixed fully integrated line concept."

As a result, a higher share of integrated lines will reduce the effort spent on product innovation and increase the innovation time cycle. In today's market, when growth needs innovation, longer innovation cycles put growth rates at risk. The need for competitive differentiation and the availability of technological know-how also foster innovation. Flexibility – needed for product innovation over the next few years – can be only accomplished with more individual building blocks instead of a fixed fully integrated line concept.

Outlook

In the long run, more standardization in the PV industry can be expected. Once module prices approach grid parity, innovation will move into process improvement rather than new product technologies. Standardization makes sense when the growth driven by increasing demand is larger than the growth brought about through new applications and products. Nevertheless, the market is not yet ready for such a move. We need further product innovation to grow implementation of PV in order for it to be classed as a major source of renewable energy. Time will tell: when the industry is mature enough for standardization, it will then be possible to source more standardized lines at a higher level of integration.

In the meantime, we expect the supplier market to split between companies focussing on mass manufacturing of standardized products on the one hand – although these products may vary between companies, and companies with a strong knowledge base of products and processes, where the latter will drive the technological innovation.

About the Authors

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