Design for fab scalability

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ABSTRACT

Owing to the huge demand for photovoltaic products, the market is still very attractive for investments in production facilities. Nevertheless, the increasing number of competing photovoltaic manufacturers and the decrease in governmental subsidies require substantial and continuous cost reductions. Whilst existing facilities can save costs by enhancing cell efficiency, optimizing production processes or reducing material costs and other resources, for new manufacturing sites there is a great potential in making efficient use of economies of scale. This also holds true - to some extent – for expanding existing fabs. This paper presents the logistics behind and the benefits of implementing economy of scale in a PV manufacturing facility.

A considerable amount of research has been carried out regarding the economy of scale for large-sized manufacturing sites, targeting output values of gigawatt dimensions and above. For all stakeholders, the necessity of a well-planned ramp-up and implementation strategy seems to be obvious for large-scale factories. However, in the case of existing factories and factory layouts, most stakeholders are unaware of the unused potential in their production capabilities.

The extent of the investments needed for such facilities is one of the main reasons for there to be reluctance in this scaling implementation. Therefore, a commonly used approach is to achieve full production capacity step-by-step by using proven standard fabs with lower output capacities. The advantage of replicating these fabs is that lessons learned from one fab can easily be transferred to subsequent projects.

Some useful synergies that can typically be achieved are:

- Large-order quantities and supplier agreements
- Lower personnel costs through reducing the number of specialists and administration staff
- Common supply of materials and other resources, e.g. power or gas supply, and

The limitations of this approach are mainly experienced in the field of inter–fab production optimization. The separation of material flow systems does not allow inter-line balancing, thus resulting in unused potential.

The lack of a higher-level IT system capable of coordinating and gathering data from multiple production lines makes sustainable fab analysis and control impossible (e.g. flexible material routing). Typical IT systems are not designed to be extended to multiple production lines.

Frequent instances of equipment down-time, maintenance as well as qualification and engineering lots can lead to disturbances in production which may result in the starvation of bottleneck equipment. Other equipment invariably has additional capacity available that remains unused, resulting in suboptimal output.

The approach explained detailed in this paper is intended to overcome this obstacle and set up an intelligent and flexible production by:

- optimizing the utilization of bottleneck equipment
- ensuring balanced Work In Progress (WIP)
- minimizing material waiting times
- reducing cycle times, and
- making use of redundancy.

IPA approach – Design for Scalability

In order to achieve optimal throughput, the extension of production capacities must be considered right at the start of the first planning and design phase. Smaller adjustments and improvements can still be made during the implementation phase.

Company	City/Country	MW
Sontor GmbH	Solar Valley Thalheim/Germany	24
Moser Baer	Indien	40
Auria Solar Co.	Taiwan	60
Pramac SpA	Switzerland	30
Sunwell	Taiwan	60
Sontor GmbH	Bitterfeld-Wolfen/Germany	25
Solibro	Solar Valley Thalheim/Germany	30
Würth Solar	CISfab Schwaebisch Hall/Germany	30
CMC Magnetics	Taiwan	46
Wacker Schott	Jena/Germany	50
Odersun AG	Fuerstenwalde/Germany	30
Schott	Jena/Germany	33
SolarWorld	South Korea	150
SolarWorld	Camarillo/USA	100
Signet Solar	Dresden/Germany	120

Figure 1. Breakdown of currently (2008) installed production capacity based on authors' research.

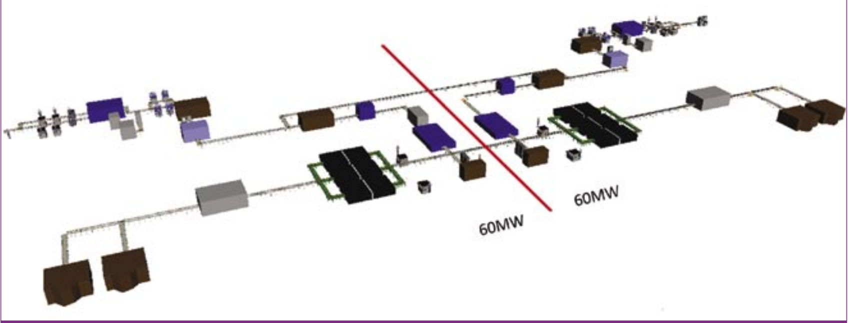

Figure 2. Schematic of IPA's Design for Scalability approach (2 x 60MW > 120MW).

However, this results in increased expenses and can lead to a limited outcome due to the actual layout restrictions.

Therefore, the basis of an integrated, modular and efficient factory has to be designed and implemented in the first production line. A well-designed logistic and IT approach is fundamental for an efficient production site.

Logistic system

In current extended factories, the logistic connection between different components is either not assured at all or not optimal. Usually there are two almost independent production lines that make very little use of the increased redundancy potential. The factory footprint is not laid out for the additional equipment and materials; even the buffer space or storage locations are often unsuitable for the extended capacity. Therefore, considerable effort is necessary just to ensure efficient production of the two separate lines.

Design for Scalability – logistic approach

The goal of extending the factory needs to be considered in the design phase. Specified transfer stations for extension (extension points) are defined in the first phase. These extension points are used to transfer material smoothly between the different production lines. The specific location of the decoupling points varies from company to company, and depend on facts such as equipment costs (usually the most expensive pieces of equipment are the ones targeted to be improved) and the logistic effort for integration. This ensures improved equipment utilization and enhanced line balancing in the case of tool-downs, maintenance, etc.

At this point, additional space requirements for the extended production capacity are taken into consideration and can be easily adjusted or linked with extra space. By taking these two aspects into account, transfer between separate production lines is ensured efficiently. This guarantees the necessary flexibility regarding changing material flow requirements (qualification lots/research & development lots/process improvements concerning tact times, etc.). The most important benefit is that such a scalable solution makes full use of economies of scale. If this is taken into consideration in the planning phase, there should be no problem in connecting the production lines even if they are housed in different buildings. Transport systems (e.g. conveyors) transporting batches or single-wafer substrates can easily be installed in tunnels or housings.

IT infrastructure

There seems to be a lack of comprehension of the level of IT integration needed for PV factories. More often than not, the IT system is not efficient enough for the extended capacity and unable to make full use of the increased redundancy. It can have trouble efficiently integrating and operating additional components that are required when production capacity is extended.

Design for Scalability – IT approach

The IT roll-out/implementation takes place in two steps.

In the first step, an efficient scalable backbone for the IT system is implemented. Important features at this point in time include:

- Rapid and uncomplicated integration of equipment. Where several equipment types with highly varying interfaces are implemented, an equipment integration layer is generally used. Now that the first standard for IT interfaces in the PV industry is under way, interoperability will be significantly facilitated and integration effort considerably reduced.
- Component tracking to trace materials.
- Rapid integration of external software.
- Resource management.
- Collection of process data, reporting, analysis and more.

Special care is taken regarding the later addition of supplementary components, which are necessary to manage larger production sites efficiently. Components that are not necessary for the operation of one manageable production line can easily be added and integrated at a later stage. Some may be more useful in cases where processes have reached a higher level of maturity (fault detection and classification, statistical and advanced process control, etc.); others are directly

related to the extended capacity (scheduling and dispatching, material management, maintenance management, etc.).

This approach minimizes the effort required to extend capacity as all of the business logic and features (e.g. reports or master data management) keep working in the same way as before. By combining the Logistic and IT approach, a flexible system is realized for production capacity, equipment requirements and changing logistic demands where new software and hardware components can easily be integrated.

Procedure

The Design for Scalability procedure consists of five phases in which the factory concept is developed. In the preliminary survey, a *feasibility study* is carried out where the potential risks are evaluated, and the scope, deployment of resources and the timeframe for realization are all outlined. Additionally, an adapted *cost-benefit analysis* is performed where the monetary aspects are reviewed. In this phase, the project potential is estimated and a decision made by the project managers as to whether further investigations are justified. .

Requirements are then gathered in a structured way and aligned with the business strategy. The production processes are initially described with the aid of *business process modelling*. Based on the process sequence, a *use case analysis* is carried out in which the core use cases are described and examined. Subsequently, the *technical requirements/restrictions* for each process step are considered and listed in a document. Again, special emphasis is placed on the extension phase during the factory lifecycle.

Armed with the familiarity of the use cases and requirements, the factory layout can then be designed. Starting with an idealistic layout, the gathered knowledge is considered and the layout gradually redesigned. This is achieved using a top-down approach, which takes the most important requirements into account (extension points, transfer routes, footprint for additional equipment, etc.), resulting initially in major layout changes and in optimization (short routes, etc.) at a later stage. This phase realizes a flexible, adaptable material flow and an optimized footprint for further factory improvements.

Material flow simulation studies are carried out with the aid of discrete event simulation software to verify and further enhance the layouts. This enables the dynamic behaviour of the production system to be modelled and different layout versions to be evaluated. Aspects such as buffer capacity, optimal throughput, improved equipment utilization and enhanced line balancing (in case of down events) are considered. Different scenarios with research & development lots, re-qualification lots or dummy substrates can be examined and evaluated without difficulty. The whole structure of the simulation model is based on a modular approach. Building the simulation model in this way reduces the effort involved in modifications that are essential in order to test different scenarios and finally enhance overall factory performance. For example, the position of extension points can be changed without difficulty.

At the end, a final report and implementation plan are prepared. A total cost of ownership is drawn up in which all costs for the initial investment and later operation of the PV factory are listed and considered.

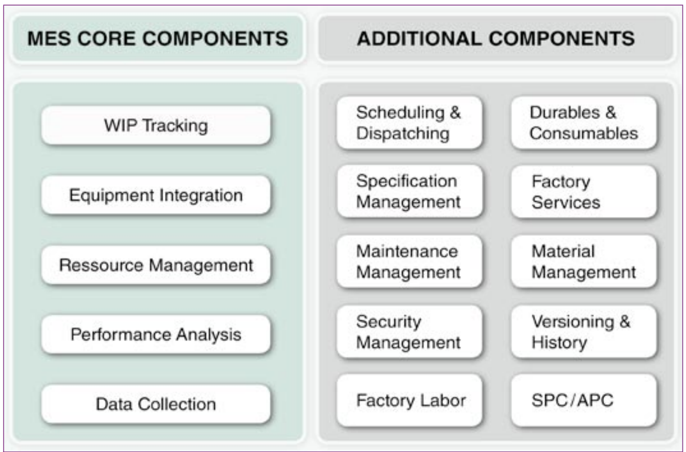

Figure 3. Suggested MES core components for the first stage and additional components that can be integrated in a second step.

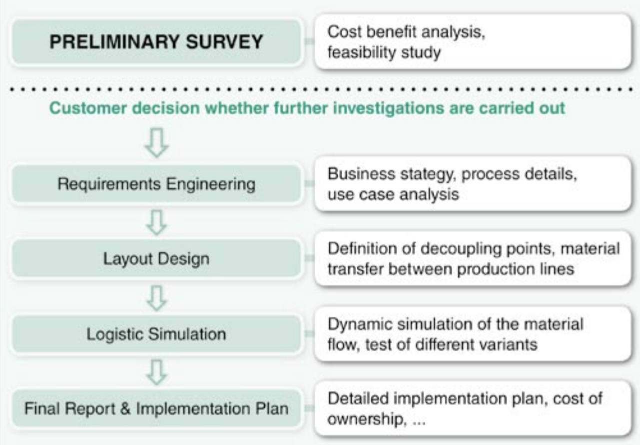

Figure 4. The five phases of the Design for Scalability procedure.

Limits and summary of the approach

As the state-of-the-art extension approach for PV production lines lacks both efficiency and effectiveness, this new scalability approach has been introduced. It considers the logistic and IT requirements and optimizes overall factory performance and effectiveness when extending production capacities.

One limitation of the approach is obvious for all stakeholders. The initial investment for the first production line fulfilling the requirements for an easy and efficient extension at a later stage is bigger compared to that of a standard production line. Another important obstacle for the Design for Scalability approach is the turnkey business in the thin-film photovoltaics market. Turnkey suppliers can often be reluctant to adapt their standard fab concept to specific customer requirements. In the event that they are willing to customize their automation and IT system according to the client's needs, they tend to charge high amounts for specifications and limit their warranty for the production system.

Nevertheless, the extension concept of PV factories will become more important and consequently more enhanced in time.

About the Authors

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. He has sound knowledge in the field of factory logistics and manufacturing IT, as well as experience in software and hardware projects.

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Joachim Seidelmann has been working in the Cleanroom Manufacturing department of Fraunhofer IPA since 1997. As group manager, he is responsible for the 'Shopfloor IT' domain of highly-automated cleanroom manufacturing for the semiconductor and photovoltaic industries. He received his Master's degree in mechanical engineering from Stuttgart University, Germany.

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