Production monitoring in PV: Principles, methodology and deployment

Thibaut Lemoine, STS-Certified, Kunshan, China

ABSTRACT
With lower returns on investment in PV projects, financial institutions have an ever-increasing demand for risk mitigation. Project stakeholders are asked to provide evidence of risk-management actions and have to look for ways to guarantee an adequate level of quality for their systems. Product certification, although necessary to help qualify the design of a product, does not provide a guarantee that mass production will achieve the targeted quality level; it has therefore become necessary to find reliable methods to assess the quality of PV systems on a large scale. Production monitoring, as part of a global quality plan for a PV system, is a cost-effective way to implement real-time checks in the manufacturing facilities, providing reassurance for stakeholders and helping manufacturers to improve their manufacturing processes. This paper details the principles behind production monitoring, the methodology used and how to deploy a production-monitoring project.

Introduction

When asked about his method to improve efficiency in workshops, Toyota Production System guru Taiichi Ohno used to reply that he had two methods: his legs and his eyes. From this concept was derived a principle called *Genchi Genbustsu*, which could be translated as 'go and see'. The principle is based on the fact that to truly understand what happens in workshops, you have to go there, where the work is actually performed. The gemba – 'the real place' – is where you are able to see and understand the problems and, from there, solve them.

This approach also highlights two ideas:

1. No matter how much reporting is fed back to the management or external stakeholders, it is always, by definition, an incomplete and subjective representation of reality, and measurements will only reflect part of what is actually going on in the workshop.

2. By being in the workshop, you increase the chances of your observing problems while they occur and hence of their being dealt with right away.

Production monitoring is just about that: go and see!

The need for production monitoring

Most PV products are nowadays certified by reputable certification organizations; however, end users, EPC and project developers still face quality issues when they receive their products or during the life cycle of their PV systems. The reason is that stakeholders often rely solely on certification of products, which, although necessary, is not sufficient to guarantee the expected performance and reliability of the products and, as a consequence, the return on investment (ROI) of a project.

In order to appreciate the problem, a better understanding of the certification process of products is necessary. Standards are issued by different organizations, whether they be the International Electrotechnical Commission (IEC), Underwriters Laboratories (UL), or independent laboratories developing specific test protocols focusing on long-term reliability. All these standards have the same purpose: the *qualification of a design* by a manufacturer to sustain the conditions described in the standard and to achieve the target performance over time.

The principle behind these standards is to say that once the design of the product (its components and construction) is validated, the factory will manufacture products that are identical to the qualified design, guaranteeing the desired performance and reliability. And this is where the problem lies.

> "The main issue is to know how representative of future production the specimens tested by the laboratory are."

Representative samples and consistency of the quality level

In order to reduce certification time and make certification affordable to the manufacturers, the certification organizations perform tests on only a few samples (8–10 samples per family of products); moreover, for practical reasons, none of the samples will actually go through the whole series of tests described in the standards. The standards imply that if the specimens tested during certification comply with the requirements set in the standard, then all the products made by the manufacturer will also comply with those requirements. This works if all the products made in mass production are actually identical to the specimens tested.

But the main issue is to know how representative of future production the specimens tested by the laboratory are. Although these samples are supposed to be taken randomly from the production line and sent to the laboratory for testing, manufacturers actually select them very carefully in order to avoid rejection during testing. After the samples have been carefully chosen, they undergo a series of additional tests that the 'normal products' will not be subjected to. The specimens are therefore not representative of what will come out of the production line.

The second issue is related to the stability of the manufacturing processes and the consistency of the level of quality of the products. A lot of things can go wrong during mass production, especially with ever-increasingly complex manufacturing processes and extensive manual labour.

In order to compensate for the lack of

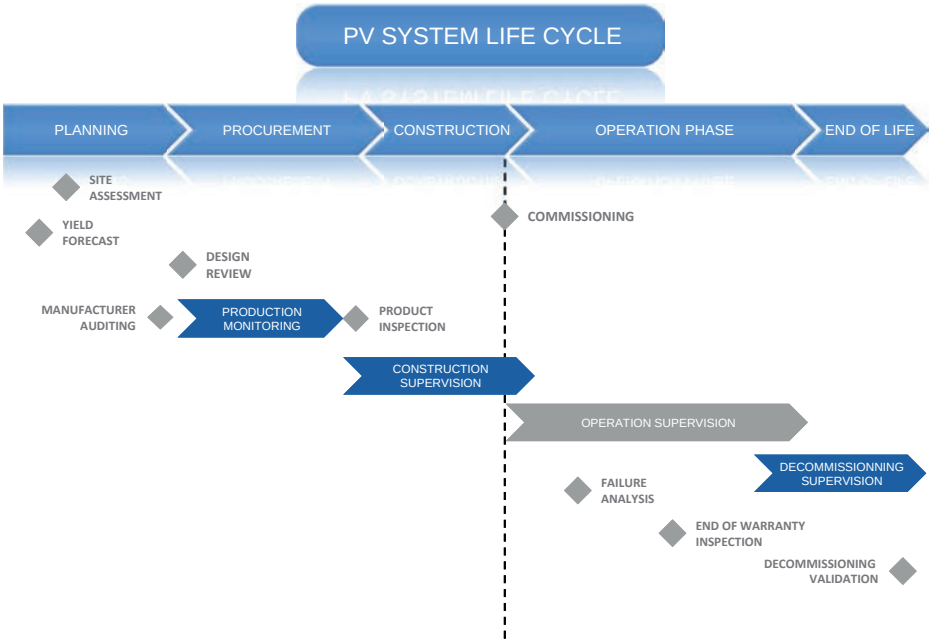

Figure 1. Integration of production monitoring in the PV system life cycle.

requirements set out in the standards regarding factory operations, most of the certification organizations have introduced stricter requirements in their own certification processes, such as an initial audit of the factory and regular visits to the manufacturing sites during the period covered by the certification. However, audits and visits work as a snapshot of the factory on a specific day and do not necessarily represent the 'normal' activity of the factory on any given day, because these audits are planned in advance and the factory will make sure that there are no issues on the day of the audit. It then follows that, in order to ensure the right quality level of a specific order or project, it is of the utmost importance to be onsite when the production will actually run. That said, the question is what to check, how and when.

Production monitoring can be implemented at different stages of the relationship between a manufacturer and its customer. Although considered at the time of production for a specific project, production monitoring can be a very useful tool at the supplier selection stage for manufacturers' clients for assessing the ability of a particular manufacturer to produce quality products on a large scale. Since the monitoring process will run over an extended period of time, it complements the initial audit, which will be limited in terms of gaining an understanding of the production capabilities (Fig. 1). This is particularly adapted to distributors or developers of residential systems who intend to establish a regular cooperation with manufacturers with repeated orders over time. In such cases, production monitoring will first occur during a trial order, allowing the client to make sure that future productions will not be affected by epidemic failures or be delayed at critical stages of the project deployment.

In some cases, third parties are directly required by some proactive manufacturers to either provide reassurances to the manufacturer's clients about the quality level of the products they deliver or provide an external eye on the manufacturing processes with the purpose of continuous improvement and upgrading to world-class manufacturing.

Principles of production monitoring

The first principle of production monitoring is that this activity is related to one specific batch of production, covering either a small order or an entire multi-megawatt project. The activities will be implemented either on the whole quantity or by sampling, but only on the batch(es) of production related to the project.

Although production monitoring usually refers to the production of PV modules, it can actually be deployed under different names in order to cover not only all the components of a PV system, such as inverters, structure and other components, but also the construction of the system itself. In the latter case, production monitoring is often referred to as *construction supervision*, which focuses on all construction activities and processes as well as on the components necessary to obtain a final product, namely the PV system.

Production monitoring can also be performed on subcomponents of the PV modules, such as cells, wafers and ingots. For the purpose of simplification, the focus in this paper will just be on the PV modules, but the deployment of a production-monitoring project can easily be translated to the above-mentioned components and different stages of the system deployment.

Production monitoring can thus take different forms and present a scope that can be extended or reduced according to specific needs and agreement between the manufacturer and the client. It is therefore imperative to clearly define the objectives and the scope of the activities, as well as the extent and the boundaries of those activities, such as the physical locations, including the period of time covered by the activities.

In order to obtain a final product with the expected level of quality, there are essentially two aspects in question: use the right components and implement adequate manufacturing processes to combine these components. Production monitoring will focus on these two items to ensure that the targeted quality level is achieved.

Using the right components

The right components can be understood to be the ones approved by the certification body during the

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certification of the product and/or the ones agreed between the manufacturer and the buyer. The list of components used for a specific product is grouped in a bill of materials (BoM) – a document which will be part of the supply agreement between the manufacturer and the customer.

Components can be used either as single-source components – meaning that there is only one model of a specific component and only one manufacturer allowed to build the final product – or as multi-source components. In the latter case, it is imperative to know what combination(s) of components are allowed.

Because of logistic issues, costs, or other supply chain concerns, manufacturers will make use of different combinations of components to build the final products for different orders without always carefully considering the compatibility between these components. As a consequence, in a multi-source components environment, final products can be very different from one production lot to another. One observed relevant example of this is the case of a manufacturer which found out, at its own expense, that a certain EVA material was not compatible with a particular backsheet, which resulted in delamination problems in its modules, amounting to several megawatts of wasted products.

To address the issue, over the past few years certification organizations have developed in their test reports some compatibility tables that specify which combinations of components have been tested and then approved for use.

Figure 2. Incorrect handling during a junction box sealing operation.

Production monitoring will focus on the use of these combinations of products in particular.

Implementing the necessary processes

It has been noted that the choice of components and their combination can have dramatic consequences on the quality of the final product, but the manner of combining these components is no less crucial. In a similar way to that for the components, the first focus of production monitoring in assessing the manufacturing processes is to ensure that the manufacturer uses the approved facilities to perform the manufacturing operations. Once again, 'approved' can be understood to denote either that the facilities have been approved by a certification body, or that a client has specifically requested that, for instance, the products be manufactured on a specific line or in a designated workshop.

With the spectacular development of production capabilities (especially in China), and recent mergers and acquisitions, manufacturers sometimes run several factories and workshops that differ significantly in terms of levels of quality. In the history of the development of their companies, manufacturers have strengthened their processes by investing in newer and better-performing equipment; this is usually done without relinquishing the older production lines, which creates large disparities in terms of processing capabilities, even within a given workshop. It is not unusual to have fully automated production lines populated with robots operating next to production lines supported by an army of workers performing manual soldering operations and transporting semi-finished products in utterly non-recommendable ways (Fig. 2). Some clients are occasionally lured into having so-called 'certified' products made in a factory that was actually never audited by the certification company.

Because products are usually certified with respect to a factory as a whole regardless of the discrepancies in the processing capabilities of different production lines, it is strongly recommended that buyers take into consideration the workshop in which (or even the production line on which) their products will be manufactured.

Quality control plan as the manufacturing processes map

Once the facilities have been identified, the proper assessment can begin. Just as for any type of work, the team in charge of assessing the processes will need a map: this map is called a *quality control plan* or *QCP*.

A QCP is both a document and a strategy, usually presented in the form of a list or table that sets down all the processes and describes the limits within which the processes are to operate. It sets the pre-established disposition (PED) that is necessary in order to master all the manufacturing activities for a product, or a range of products, identifying the parameters impacting the quality of the final products as well as the characteristics of the products under surveillance. The QCP covers all the processes of a manufacturing site, from reception of components to delivery of final products to the customer (Fig. 3).

The QCP itemizes not only the manufacturing processes that add value to the products (manufacturing operations) but also all necessary operations for producing the final product, such as the quality controls performed on the semi-finished products, whether on the production line on all the products or off the production line in laboratories. The plan will also list all operations pertaining to the transportation of components and subassemblies along with the related storage aspects.

The QCP is divided into different sections, each identifying various elements of control activities. For each of the processes, a first field will contain a process description, including the type of process and the equipment used. A second field will pinpoint the characteristics of the process (characteristics of the product itself and of the process) which represent the input variables that must be controlled in order to minimize the variations in quality. A third part will identify how, when and to what extent these characteristics will be controlled, as well as the method used to perform the controls, including the related documentation. In the final field, a contingency plan

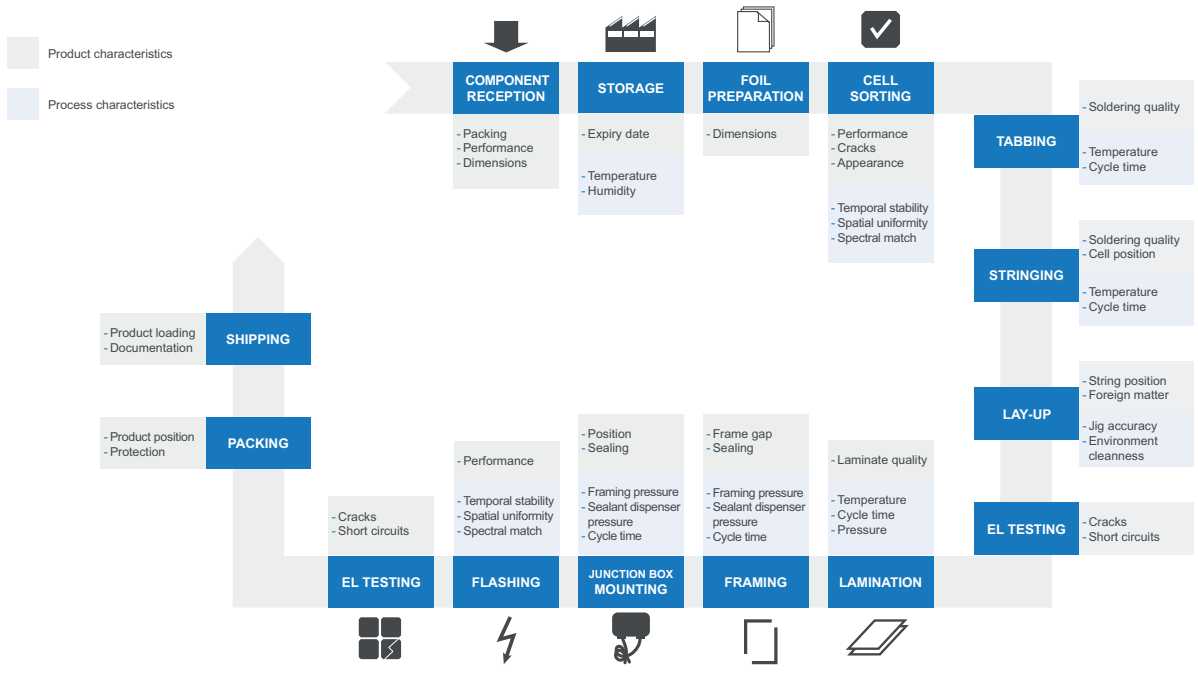

Figure 3. Simplified graphical representation of a quality control plan.

will detail what actions are to be taken if the measured characteristics fall outside the limits set in the control plan.

> "The QCP will be the basis for the team performing the production-monitoring activities."

5M method to cover all aspects of the processes

As explained above, the QCP will be the basis for the team performing the production-monitoring activities. Inspectors will follow the control plan step by step and oversee the correct implementation of the QCP in the factory.

In order to cover all aspects, inspectors will focus on the 5M method, described as follows. For each step of the control plan defined above, inspectors will check that the different points of specification are actually adhered to in accordance with five criteria:

1. **Machine**: check that the proper equipment is used for the process, as well as the general condition of the equipment.
2. **Material**: check that the correct components are used, as well as the general condition of the components, including indirect materials.
3. **Method**: check that the methods defined for implementing the process guarantee that the specified characteristics will be respected.
4. **Manpower**: check that the operators participating in the process are qualified to perform their duties and respect the instructions set for the process.
5. **Milieu**: check that the environment allows a proper implementation of the process (tidiness, cleanness, temperature, humidity, etc.).

Deployment of a production-monitoring project

In the case where the main activities of production monitoring occur during actual production in the factory, specific steps have to be followed before and after these activities in order to successfully deploy a production-monitoring project.

Preparation

As with any project, the first task is to prepare the production monitoring. This part will be done in cooperation with the project client, be they a buyer, a manufacturer or a third party. At this stage, the objectives, scope and criteria for the project will be defined. The objectives will specify what is to be accomplished during production monitoring and may include the release of a production batch, the beginning or resumption of production activities, or the identification of areas for potential improvements in product manufacturing.

Typical information will include the quantity of products that will be subject to monitoring, and the sampling plan clarifying whether all the production or only a certain percentage is to be monitored, along with the rules for increasing or decreasing this percentage. Another point to be agreed upon will be the authority provided to the monitoring team allowing them to halt or continue production according to their findings during monitoring activities, as well as under what circumstances they are permitted to act.

Technical information is collected in order to plan the monitoring duration, assign the resources needed for the project and prepare the working documents. Typical technical information includes product specifications, BoMs, factory information, equipment lists, production information, production plans and quality control plans. In some cases, not all of the documentation may be available prior to the audit activities: part of the preparation activities will therefore be performed onsite, which can impact the duration of the onsite activities.

A review of all the information is performed to analyse the needs, and the onsite inspection team is appointed to assess compliance with the scope, objectives and criteria of the project. The resources will be allocated with regard to workforce size and technical knowledge necessary to perform the job. Once the preparation task has been completed, an announcement is made to the different parties in order to clarify the work to be done and to facilitate the onsite activities.

Onsite activities

The first task of the workforce conducting the onsite activities is to hold an initial meeting with the manufacturer's management team, as well as with those responsible for the processes that will be monitored. The purpose of this meeting is to confirm the scope of the production-monitoring project, to present a short summary of how the activities will be undertaken, to verify the communication channels and to provide an opportunity for the manufacturer to ask questions. In effect, the opening meeting will introduce the participants, confirm the timetable, ensure that the resources needed by the inspection team are available, and provide clarification on factory safety rules and the methods used as well as on confidentiality issues.

Depending on the complexity of the project, intermediate formal meetings may be arranged on a regular basis with the manufacturer either with or without the organization in charge of the project. In a general manner, the team leader will communicate how the work is progressing, and any evidence of an immediate and significant risk will be reported immediately to the project client.

As discussed earlier, the team will then move onsite and act in accordance with the 5M work methods by collecting information, including records, interviews with personnel, observations and the results of witnessing the work performed in the facilities. The information is then verified and evaluated against the agreed criteria in order to report and, if necessary, to take immediate action. The easiest way to perform the activities is to follow the control plan from reception of components to shipping of final products to customers.

Project conclusions

Prior to a closing meeting, the team confers in order to review the findings of the onsite activities, to agree on the conclusions and to prepare recommendations, if specified by the project objectives.

A closing meeting is then held by the inspection team to present the findings, so that they are understood and acknowledged by the manufacturer, and to agree, if relevant, on the presentation of a corrective and preventive action plan.

Reporting

The audit report provides, as far as possible, a complete, accurate and concise record of the activities performed, including or referring to the project objective, scope and criteria, the period covered, the findings and the conclusions. The report, in the case of complex or numerous processes, details the observations and findings for each of the different processes within the scope of the work. It also lists the areas that were not covered by the activities of the team. If it is specified within the scope of the project, the

report also includes recommendations for improvements as well as a relevant action plan related to the findings.

The report is reviewed and approved and then distributed within a previously arranged time frame to the agreed recipients. In certain cases, the activities may be complemented by a follow-up in order to verify that some agreed actions have been implemented and are effective.

In-house or third-party production monitoring

When faced with the need for production monitoring, project stakeholders are confronted with the decision whether to perform these activities in-house or to entrust them to third-party organizations to perform on their behalf. Different factors may influence this decision.

Depending on whether the need is an external or internal choice, the decision may be restricted. Some project stakeholders, especially financial institutions, sometimes require that approved organizations be called in to perform the work. This provides the guarantee to these stakeholders that the work will be performed by an impartial and skilled workforce using indisputable methods. Manufacturers too may require that work be performed by these organizations for reasons of impartiality.

Another factor influencing the decision is cost. Where organizations might think that it would be more cost competitive to perform such work in-house, they are usually faced with unplanned costs which, ultimately, make it much more expensive than if they contracted specialized firms to perform the job. Indeed, if a project grows in size, the need for resources within the inspection team can rapidly expand, and with them the related cost. Manufacturers are not necessarily located close to the buyers, and the transportation and accommodation costs alone can make it already a burden for the stakeholders if they decide to perform the job themselves.

Another economic concern relates to making the best use of the resources needed to perform the work. As discussed above, production-monitoring activities are extremely technical activities and require both excellent general knowledge and process expertise. This means that the organizations intending to perform production monitoring in-house will have to recruit skilled labour, but with a workload factor that can be dramatically low, which increases costs even more.

If an organization decides to contract a third-party partner to perform the job, the next decision will be choosing the right one. Even if there seem to be many companies providing this kind of function, only a few of them will be able to guarantee the professional level of service required to ensure the requisite level of quality of the products delivered. Some companies providing this type of service cover a wide range of products and are not specialized in the PV industry. Although these companies have usually developed solid methodology for performing the activities, most of the time they lack the technical expertise in manufacturing processes that is necessary for identifying the risks to the products; moreover, they may not have the ability to judge if the PEDs are exhaustive and relevant to manage the risk. Even within the PV industry, some companies will focus primarily on the production of PV modules, while others will focus on the downstream part of the project, mainly on construction supervision and commissioning. Depending on the size of the project under consideration, other companies might have trouble providing enough resources to cover the whole production, with a consequent decrease in the level of service provided.

It is therefore important to be able to assess the capabilities of these third-party companies in terms of technical capabilities (by understanding the level of skill of the team assigned to perform the work) as well as in terms of availability of resources allocated to a project. Previous-project references/endorsements, inspector profiles and accreditation by a recognized accreditation body can provide a good indication of these factors.

> "Monitoring activities have to be performed in a professional way with a high degree of expertise to guarantee the outcome of the work."

Conclusions

While production monitoring provides a cost-effective way to mitigate quality-related risks for a project, the monitoring activities have to be performed in a professional manner with a high degree of expertise to guarantee the outcome of the work. The results achieved will largely depend on the resources allocated to the project and on how rigorous the monitoring methods used will be. It is therefore essential to assign the work to the right team either internally or externally.

The principle of production monitoring is not the replacement of the controls performed by the manufacturers but rather ensuring that these controls are performed correctly. Production monitoring does not relieve the manufacturers of their responsibilities, and the ultimate success of a project will still be closely related to the choice of the right partner.

Despite paying the most careful attention during production monitoring at the different critical steps of the production, an inspection team cannot be everywhere at the same time, and it is possible for the team to miss some issues. The teams do their utmost in performing the job to the best of their ability; however, as for any onsite activity, they are very reliant on the cooperation of the manufacturers and on the availability of equipment onsite. It is therefore recommended to include other means of control – such as off-site inspections and tests by sampling – in order to minimize the uncertainty related to the quality risk. In any case, production monitoring remains one of the most efficient ways to increase the overall quality levels of products installed worldwide and is a useful tool in the great adventure of making PV one of the major sources of energy for the future.

About the Author

Thibaut Lemoine is a co-founder and the general manager of Senergy Testing Solutions Ltd (STS), a company that is involved in the creation and implementation of individual product certification in the PV industry. He has an extensive knowledge of PV manufacturing in China, where he has been working for almost 15 years in various industries, including PV. Thibault received a master's degree in mechanical engineering from the National Engineering University of Belfort, France, and a master's degree in international industrial business management from the Technical University of Belfort-Montbéliard.

Enquiries

STS-Certified
777 Yuyang Road
Gaoxin District, Kunshan
Jiangsu Province
215300 China

Tel: +86-21 63816578
Email:
alexander.minuzzo@sts-certified.com
Website: www.sts-certified.com