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NATIONAL RENEWABLE ENERGY LABORATORY

Proposal for a Guide for Quality Management Systems for PV Manufacturing: Supplemental Requirements to ISO 9001-2008

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Technical Report
NREL/TP-5200-58940
June 2013

Contract No. DE-AC36-08GO28308

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Executive Summary

The goal of this Technical Specification is to provide a guideline for manufacturers of photovoltaic (PV) modules to produce modules that, once the design is proven to meet the quality and reliability requirements, replicate the design on an industrial scale without compromising its consistency with the requirements.

From 1996 to 2011, the PV industry grew by a factor of almost 400, resulting in annual PV module production greater than 30 gigawatts (GW). With an annual investment in PV around $100 billion, the industry has become highly motivated to ensure quality of that investment, with special emphasis on the quality of the PV modules, as these are the most expensive part of the system to replace and the extent of their power output degradation in the field significantly impacts the return on investment.

The International PV Module Quality Assurance Task Force was formed in 2011 to develop standards that can help customers quickly assess a PV product's ability to withstand regional stresses and to gain confidence that purchased PV products will be of consistent quality.

Reliability is neither defined, nor covered, by the existing International Electrotechnical Commission *(*IEC) standards. Module design qualification to those standards does not imply the PV module's reliability. Therefore, the Task Force set the goal to establish guidelines dealing with all relevant influences on the module such as raw materials and components, process parameter sets and their control, reasonable test sequences, training of the staff, etc.

Task Group #1 of this Task Force has focused on the requirements of a quality program used to guide the manufacture of PV modules in maintaining module consistency. While ISO 9001 is used as an industry standard for documenting quality programs, it addresses generic elements of a quality management system and does not cover specific details of interest to the PV industry. Starting in fall of 2011, Task Group #1 began to write a PV-specific version of ISO 9001 that would strengthen the quality program by incorporating known requirements for PV. This revision of ISO 9001 will be submitted to IEC/ISO for formal adoption and, once revised by the standards process, will become a standard that can be fully used by the community.

In the meantime, this report summarizes the revisions identified by Task Group #1 and provides the community with a way to begin benefitting from the more robust quality programs, even before the standards process is completed. Community experience in implementing this draft standard will also provide essential feedback for the standardization process to help ensure that the adopted standard is optimally useful. In that context, the community is encouraged to use the contents of this report and to provide feedback to the International PV Module QA Task Force and the IEC/ISO standards organizations. We are interested in positive and negative experiences with the application of the recommendations herein.

Key requirements in the proposed standard include:

- Focus on the organization's control of the PV module's design to align the expected lifetime with its relationship to the organization's warranty. Warranty claims must be addressed by product and process design or by financial means.

- Requirement to obtain IEC product certification and implement an ongoing reliability test program that monitors PV modules' performance for compliance with standards and the stated design lifetime.
- Requirement to improve product traceability through the entire supply chain to enact positive control of the product for recalls and warranty claims.
- Design of a manufacturing process that will ensure conformance to the design intent for power, lifetime, and warranty.
- Special processes such as control of solderability, electro-static design (ESD) control, and assignment of PV module power rating.

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Acknowledgements

The international efforts that contributed to this work were primarily provided by volunteers from the companies and national laboratories. This support is deeply appreciated. The portion of this work completed at the National Renewable Energy Laboratory was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308.

Acronyms

AIST	National Institute of Advanced Industrial Science and Technology
ESD	electro-static design
FMEA	failure modes and effects analysis
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
JRC	Joint Research Centre
NREL	National Renewable Energy Laboratory
PFMEA	process failure modes and effects analysis
PV	photovoltaic
QA	quality assurance
STC	standard test conditions

Introduction: Motivation

From 1996 to 2011 the photovoltaic (PV) industry grew by a factor of almost 400, resulting in annual PV module production greater than 30 gigawatts (GW). With an annual investment in PV of about $100 billion, the PV community has become highly motivated to ensure quality of that investment. Because PV module prices fell by a factor of about three between 2009 and 2012, manufacturers have been universally pressured to cut costs. There is some concern within the community that some manufacturers may be reducing costs by paying less attention to quality issues. Even for those who are conscientious, it is difficult to determine whether a PV module will have a lifetime that will meet the warranty (typically 25 years). For those who are less conscientious, the possibility of premature failure can be considered an unacceptable risk.

The International PV Module Quality Assurance Forum was held in July of 2011 in San Francisco, organized and sponsored by the National Institute of Advanced Industrial Science and Technology (AIST), the National Renewable Energy Laboratory (NREL), the European Commission Joint Research Centre (JRC), and the SEMI PV Group. About 160 individuals representing PV manufacturers, PV customers, test laboratories, and government organizations attended the Forum. The participants agreed that improved standards are needed to differentiate PV module durability in different climate zones and in various mounting configurations. In addition to the need for accelerated tests that match the intended use conditions, the participants highlighted the need to be able to communicate the strength of the quality management program used by the factory. Although factories use quality programs, there has been no simple way to differentiate a strong quality program from a weak program. The International PV Module Quality Assurance Task Force was formed at the Forum to develop standards that can help customers quickly assess a PV product's ability to withstand regional stresses and to gain confidence that purchased PV products will be of consistent quality. Five task groups were formed to address the manufacturing consistency (Task Group #1) issues and need for accelerated tests (Task Groups #2–5). Since then, four additional task groups have been formed to help discuss the communication of the testing results, as well as address other issues including those related to thin-film and concentrator PV modules.

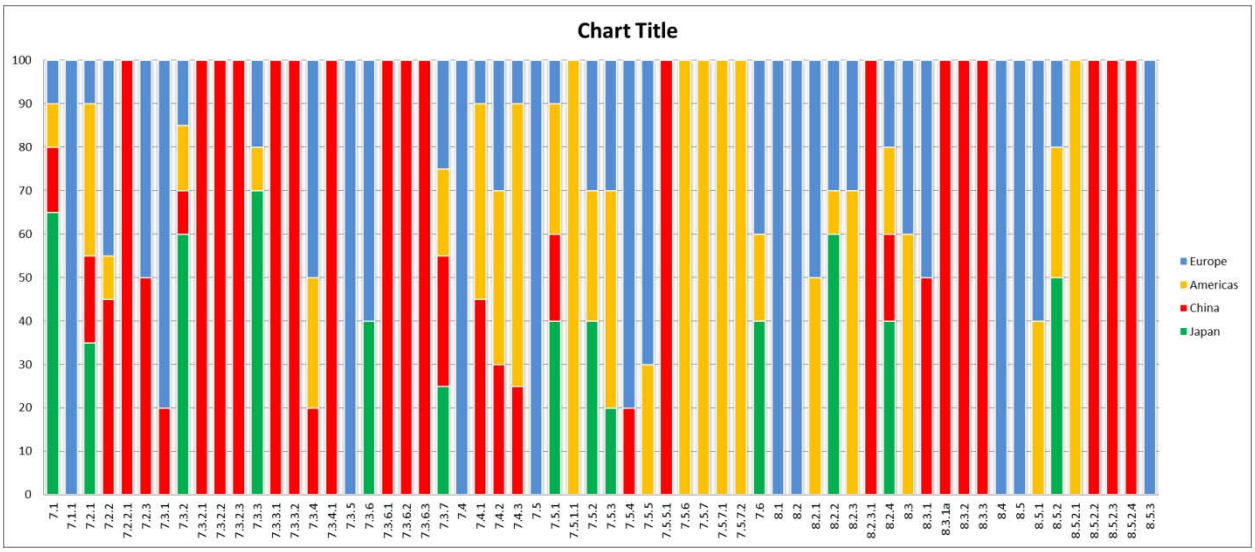
Task Group #1 of this Task Force has focused on the requirements of a quality program used to guide manufacture of PV modules. While ISO 9001 is used as an industry standard for documenting quality programs, it addresses generic elements of a quality management system and does not touch on specific details of interest to the PV industry. Starting in the fall of 2011, Task Group #1 began to write a PV-specific version of ISO 9001 that would strengthen the quality program by incorporating known requirements for PV. This revision of ISO 9001 will be submitted to IEC/ISO for formal adoption and, once revised by the standards process, will become a standard that can be fully used by the community.

In the meantime, this report summarizes the revisions identified by Task Group #1 and provides the community with a mechanism to begin benefitting from the more robust quality programs, even before the standards process is completed. Community experience gained by implementing this draft will also provide essential input into the standards process to help ensure that the adopted standard is optimally useful. In that context, the community is encouraged to use the contents of this report and to provide feedback to the International PV Module QA Task Force

and the IEC/ISO standards organizations. We are interested in the positive and negative experiences with application of the recommendations herein.

Methodology

There have been a large number of participants in Task Group #1 (as of June, 2013 there are more than 190). The participants have represented different continents, requiring optimization of the working method. So, a task leader was set as coordinator, and four regional task groups were formed in Europe, the Americas, Japan, and China. International participation was encouraged, but the formation of regional teams allowed more convenient scheduling of meetings and, in some cases, aided in communication by allowing participants to speak in their native language. The four regional groups separated the various chapters and began to develop a set of suggested revisions. The graph below indicates an example of activities by regional groups when drafting the new proposal (the y-axis represents the percentage while the x-axis represents the paragraph considered).



Example of contribution of regions on chapters of the proposal

The four drafts were then merged to identify and resolve the differences. Each regional group leader was asked to participate, via online teleconference, in an alignment meeting by the coordinator. Moreover, worldwide phone calls and periodic face-to-face meetings facilitated the alignment of the multiple drafts to the draft that is presented here (finalized during the Feb. 26-27, 2013 PV Module Reliability Workshop in Colorado).

The method for implementing the proposed quality program was discussed at length by both Task Group #1 and representatives of ISO and IEC to identify the “smoothest” way to introduce it into the community. According to the authors, the best way will be a joint document (ISO/IEC).

Proposed Additions to ISO 9001-2008

Goal of This Technical Specification

The goal of this Technical Specification is to provide a guideline for manufacturers of PV modules to produce modules that, once the design has proven to meet the quality and reliability requirements, replicate such design in an industrial scale without compromising its consistency with the requirements.

This Technical Specification is meant to be used in assessment audits of the PV module manufacturer's Quality Management System (QMS), and to form a common basis for audits by various certifying bodies.

Such assessments should audit the entire set of materials, components, and processing.

The larger the diversity of products from a manufacturer, the more materials and material combinations must be controlled. All changes in the design and/or materials and processes applied must be considered.

For the convenience of the reader, the relevant paragraph numbers from ISO 9001-2008 are indicated. Note that no changes are proposed for many of the paragraphs.

3 Terms and Definitions

3.1 Terms and Definitions for the PV Industry

For the purposes of this document, the terms and definitions in ISO 9000:2008, IEC/TS 61836, and the following apply.

Control plan

Documented description of the systems and processes required for controlling the product.

Design lifetime

Design target period during which PV modules are expected to satisfy the specified performance under the specified conditions.

> *Note: Specified conditions include application of use, installation environment configurations, and operation conditions of the PV module in use. The design target period is set considering changes in performance of PV modules due to aging degradation of parts and materials used in the stated environment.*

FMEA

Stands for "failure modes and effects analysis." A document that defines the new process or solution with requirements and includes potential causes and effects of failure, along with a prediction of the likelihood of their occurrence and ease of detection. The FMEA provides a mechanism to articulate the risks and take appropriate mitigation steps.

Performance warranty

A warranty provided by the party ensuring product liability to guarantee the specified performance of PV modules over the specified period and under the specified conditions.

6 Resource Management

6.1 Provision of Resources

Provision of resources – supplemental

The organization shall determine and provide the resources needed to maintain the product warranty system through product reliability measurements or provision of after-sales service.

7 Product Realization

7.1 Planning of Product Realization

Planning of product realization – supplemental

In planning product realization, the organization shall also determine the following, as appropriate:

a) Product certification requirements,
b) Design lifetime aligned with the stated warranty under specific conditions and a documented method to ensure compliance to stated warranty by a combination of product reliability and after-sales services,
c) Recycling requirements at the end of the modules' lifetime, and
d) Quality assurance and control measures to be applied to production to meet requirements of the applicable PV standards.

Customer requirements and references to related technical specifications, as applicable, shall be included in the planning of product realization as a component of the quality plan.

> *NOTE 1: "Organization" means an entity that takes primary responsibility for production, quality assurance, and warranty of the PV module.*
>
> *NOTE 2: "Design lifetime" is one of the key design parameters, defined as a period of time throughout which PV modules are expected to generate designed power output under pre-specified conditions.*
>
> *NOTE 3: With changing requirements from the market place and with emerging new technology in the PV Industry, the development and launch of new products should meet requirements of the product warranty as well as customers' needs. Therefore, a completed product life cycle plan is required.*

7.2 Customer-Related Processes

Determination of requirements related to the product – supplemental

The organization shall determine product warranty workmanship and power degradation and its relationship to the expected design lifetime under specified or intended use conditions.

The organization shall incorporate requirements arising from previous failure information, competitive analysis, supplier feedback, and other internal inputs.

Review of requirements related to the product – supplemental

The organization shall ensure that all modified product, not covered by the retest guidelines, is qualified to all related type designations and that the modified product is evaluated for impact on the warranty.

The organization shall identify and document all limitations on product application.

The organization shall identify critical areas for ESD control.

NOTE: Retest guidelines are being developed.

Organization manufacturing feasibility

The organization shall investigate, confirm, and document the manufacturing feasibility of the proposed products in the contract review process, including risk analysis.

Customer communication – supplemental

The organization shall also determine and implement effective arrangements for communicating with customers in relation to:

a) Safety, workmanship warranty, output power warranty, and installation guidelines including electrical and mechanical installation instruction,
b) Application notes detailing specific attention and/or care needed to secure expected design lifetime of installed modules, and
c) The definition of a warrantable defect or safety-critical defect and the rules and/or process to manage stated defects.

NOTE 1: "Information" includes but is not limited to specifications, drawings, and other material, including "installation" manuals.

NOTE 2: "Suitable Equipment" includes software.

NOTE 3: "Implementation of product post-delivery activities" includes "after-sales service."

7.3 Design and Development

Design and development planning – supplemental

The organization shall include production processes in the design and development planning.

The organization shall also determine:

a) The responsibilities and authorities for a cross-functional project design and development team,
b) the process to conduct design FMEAs or equivalent, reliability verification, expected design lifetime and product specification generation, and
c) The requirements for process FMEAs or equivalent, specifications, layouts, and work instructions.

Design and development inputs – supplemental

The inputs shall also include:

a) Functional, performance, and safety requirements including expected design lifetime, power, maintainability, durability, transportation, timing, and costs,
b) Identification of the product, traceability, and packaging requirements, and
c) Requirements for proper handling of product and components for ESD.

Manufacturing process design input

The organization shall identify, document, and review the manufacturing process design input requirements, including:

a) Product design output data,
b) Targets for productivity, process capability, and cost,
c) Customers' requirements, if any, and
d) Experience from previous developments.

NOTE: The manufacturing process design includes the use of error-proofing methods to a degree appropriate to the magnitude of the problems and commensurate with the risks encountered.

Design and development outputs – supplemental

Design and development outputs shall also:

a) Specify an instruction manual for the end user and an installation manual for proper and safe use,
b) Include design FMEAs, or equivalent, which are to be updated during design reviews, and
c) Define product special characteristics that will require unique controls.

Manufacturing process design output

The manufacturing process design output shall be expressed in terms that can be verified against manufacturing process design input requirements and that can be validated. The manufacturing process design output shall include:

a) Specifications and drawings,
b) Manufacturing process flow chart/layout,
c) Manufacturing process FMEAs or equivalent,
d) Control plan (see Section 7.5.1.1 of ISO 9001-2008),
e) Work instructions,
f) Process approval acceptance criteria,
g) Data for quality, reliability, maintainability and measurability,
h) An ESD protection plan
i) Results of error-proofing activities, as appropriate, and
j) Methods of rapid detection and feedback of product/manufacturing process conformities.

NOTE: PFMEA shall cover the process from material receipt to product delivery, installation and maintenance.

Design and development validation – supplemental

The organization shall include standard requirements from applicable IEC and national standards for validation of the design.

All performance testing activities including durability of first batch modules shall be monitored for timely completion and conformance to requirements. Performance testing shall conform to a product and process approval procedure including a reliability test plan similar to applicable standards. Prototyped PV modules can be tested according to IEC standards.

While services may be outsourced, the organization shall be responsible for the subcontracted services, including technical leadership.

> *Note: Product approval should be subsequent to the verification of the manufacturing process. This product and manufacturing process approval procedure shall also be applied to suppliers.*

Control of design and development changes – supplemental

The organization shall implement a change management system for materials and processes and ensure all changes adhere to product and defined internal/external qualifications and certification requirements.

All design and development changes shall be documented in the appropriate FMEA.

Qualification and reliability tests shall be documented. Changes shall not be released before tests are verified. If the change has impact to form, fit, and performance of the product, notification to the appropriate customer is required.

> *NOTE: All changes should be reviewed and qualified by reference to retest guidelines.*

7.4 Purchasing Process

Purchasing process – supplemental

Materials components and sub-assemblies that have a safety implication on the finished product and that are purchased from or prepared by a supplier require a higher level of control.

The organization shall define a process for the supplier's notification of changes. It is the responsibility of the organization to ensure that subassemblies and assemblies completed by subcontractors meet the quality plans and relevant safety requirements.

The organization should ensure that the supplier can meet product requirements by doing the following:

a) Evaluate the quality performance of key materials and audit the supplier of key materials on a regular basis
b) Ensure that materials used in the product conform with related regulations in the PV industry
c) Optionally, carry out onsite audits to check that:
   - The material produced is conformal with PV industry regulations;
   - The supplier has the capability to deliver the goods on time;
   - The supplier has the capability to maintain product quality consistently, and will notify customers when there is any change of products or interruption of production,
d) Urge the supplier to improve its quality performance, and
e) Apply methods for incoming inspections and preparation of raw materials.

Purchasing information – supplemental

Purchasing information shall also describe the requirements for materials/component traceability.

Verification of purchased process – supplemental

The organization shall have a process to ensure the quality of the purchased product by utilizing one or more of the following methods:

a) Receipt of certificate of conformance or analysis,
b) Evaluation of statistical data by the organization,
c) Conducting a receiving inspection and/or testing such as sampling based on performance,
d) Have product evaluation or material analysis performed by an independent laboratory or testing facility, and/or
e) Require evidence of supplier inspections when the supplier has been delegated the inspection authority based on the supplier's history of product conformance to requirements.

7.5 Production and Service Provision

Control of production and service provision – supplemental

The organization shall devise methods to monitor the performance and accuracy of the equipment utilized in the product realization process.

The organization shall create definitions of serious product problems and determine rules and/or processes to minimize the impact of the problem.

The organization shall provide technical support to help customers use the product properly, help customers in trouble-shooting, and help prevent any safety risks.

Control plan

The organization shall establish control plans for all appropriate processes, subassemblies, components, and materials for the final product. Control plans shall:

a) Be based on a risk analysis such as design or process FMEA outputs, or equivalent,
b) List the controls used for the manufacturing process control,
c) Include methods for monitoring of control exercised over special characteristics (see Section 7.5.2 of ISO 9001-2008) defined by the organization,
d) Include customer required information, if any, and
e) Initiate a specific out-of-control action plan when a process becomes unstable or not statistically capable.

The organization shall review and update control plans when any change occurs that affects the product manufacturing process.

The organization shall define and manage a process to disposition the affected product impacted by an out-of-specification process.

The organization shall maintain data records in a manner that allows detection of possible tendencies.

Validation of processes for production and services provisions – supplemental

The organization shall also validate all software utilized in the production and services provision.

The organization shall define a recertification process for qualified personnel.

The organization shall determine parameter sets for the acceptance tolerance for the module.

The organization shall validate the effectiveness of its ESD program, as required.

NOTE: Use of statistical process control is recommended for these processes.

Identification and traceability – supplemental

The organization shall document traceability of changes to the product and the impact from those changes for previous and future product deliveries.

The organization shall ensure traceability of the product by:

a) Tracking product construction to the constituent raw materials and the components used to the lot/batch level that are traceable back to suppliers, dates and locations of manufacture,
b) Tracking the product through each process step to the specific machine and time of processing.

The organization shall inspect the product in process and at the final inspection to ensure that the requirements of the product specification are met. Repaired/reworked products must be subject to and meet all in-process and final inspection requirements.

The processing, storing, and back tracing of test and process data must be documented in an adequate way. The recording of the data should allow a monitoring that shows possible tendencies.

Customer property – supplemental

NOTE: If required, the control methods of customer property shall be approved by the customer.

Preservation of product – supplemental

The packaging method of the PV module needs to be tested and validated to meet customer requirements and ensure that the product can be transported to customer sites properly. Product traceability information should be easily identified from outside packaging.

The organization shall use an inventory management system to optimize inventory turns over time and ensure stock rotation, such as "first-in-first-out." Obsolete product shall be controlled in a similar manner to that for nonconforming product.

Ongoing product monitoring

The organization shall define an ongoing/periodic reliability-monitoring/production-monitoring program that uses accelerated stresses for the known failure mechanisms of the product. The tests shall be conducted on random samples from normal production.

Discovery of failures from these activities shall follow Sections 8.5.2 and 8.5.3 of ISO 9001-2008. Corrective, root cause action shall be taken and documented for any failures.

Records of the results of any ongoing/periodic reliability testing/production monitoring program activities and any necessary actions arising from such activities shall be maintained (see Section 4.2.4 of ISO 9001-2008).

7.6 Control of Monitoring and Measuring Equipment

Control of monitoring and measuring equipment – supplemental

Monitoring and measurement equipment shall be characterized by measurement system analysis to understand gauge capabilities (tolerance and precision).

Software shall be considered an integral part of monitoring and measuring equipment, and shall be appropriately controlled and validated.

For monitoring and measurement equipment found to be out of tolerance at the time of calibration, corrective actions must be taken to determine the impact to the product and documented per Section 4.2.4 of ISO 9001-2008.

Performance rating (IV) measurement equipment

The accuracy of measurement should be shown on the label and this should be verified (ISO/IEC Guide 98-3:2008: Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement) during factory inspection regardless of simulator class.

The organization shall include a statement on the accuracy of power measurement on the label of the produced module and, if applicable, refer to the name of the PV institute that issued the reference device calibration certificate.

8 Measurement, Analysis, and Improvement

8.2 Monitoring and Measurement

Customer complaints

The organization shall manage customer complaints in a controlled fashion and log the issues and the corrective and preventive actions taken to satisfy the complaint.

Complaints must be dealt with in a timely and effective manner.

Monitoring and measurement of a manufacturing process

The organization shall perform process studies on all new manufacturing processes (including assembly or sequencing) to verify process capability and to provide additional input for process control. The results of process studies shall be documented with specifications, as applicable, for means of production, measurement and test, and maintenance instructions. These documents shall include objectives for manufacturing process capability, reliability, maintainability and availability, as well as acceptance criteria.

The organization shall maintain manufacturing process capability or performance as specified by the customer part approval process requirements or organization-targeted level. The organization shall ensure that the control plan and process flow diagram are implemented, including adherence to the specified:

a) Measurement techniques,
b) Sampling plans,
c) Acceptance criteria, and
d) Reaction plans when acceptance criteria are not met.

Significant process events, such as a tool change or machine repair, shall be recorded.

The organization shall initiate a reaction plan from the control plan for characteristics that are either not statistically capable or are unstable. These reaction plans shall include the containment of product and 100% inspection as appropriate. A corrective action plan shall then be completed by the organization, indicating specific timing and assigned responsibilities to ensure that the process becomes stable and capable. The plans shall be reviewed with and approved by the customer when so required.

The organization shall maintain records of effective dates of process changes.

Monitoring and measurement of product – supplemental

Monitoring and measurement of product shall include studies of the performance during the expected design lifetime of the product.

8.3 Control of Nonconforming Product

Control of nonconforming product – supplemental

Product with unidentified or suspect status shall be classified as nonconforming product (see Section 7.5.3 of ISO 9001-2008).

Customers shall be informed promptly in the event that nonconforming product has been shipped.

The organization shall obtain a customer concession or a deviation permit prior to further processing whenever the product or manufacturing process is different from that which is currently approved.

Instructions for rework, including re-inspection requirements shall be defined and validated to the same requirements as new product.

8.5 Improvement

Continual improvement – supplemental

> *Note: The organization should identify measure and report quality metrics to drive continuous improvement.*

Corrective action – supplemental

Records of customer notifications, where appropriate, shall be maintained (see Section 4.2.4 of ISO 9001-2008).

Proposed Implementation

For an interim period of time until this proposed program is standardized to IEC/ISO, the program can be used in internal audits of the PV manufacturer to assess robustness of its quality management system. The program may also be used in factory inspections by test labs for IEC 61215/61646 certification of the modules as an alternative to ISO 9001-2008. We encourage organizations to provide feedback to the IEC standards process to reflect their experiences.

When this program is published as an IEC/ISO standard, it will substitute for ISO 9001-2008 in factory inspections by test labs for IEC 61215/61646 certification of the modules, to provide better assurance of quality management for the clients. Test labs are requested to prepare their factory inspection guide for this program and release it to the customers so that module manufacturers may be well prepared for the inspection. We anticipate that this will be issued by the IEC/ISO as a Technical Specification some time in 2015.

These criteria may be implemented in a pass-fail evaluation, or it may be beneficial to differentiate excellent quality programs from inferior programs, as judged by how well they address all aspects of these criteria.

References

IEC 61215 Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval

IEC 61646 Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval

ISO 9001-2008 Quality management systems – Requirements

JIS Q8901-2012 Terrestrial photovoltaic (PV) modules – Requirement for reliability assurance system (design, production, and product warranty)

ISO/TS16949 Quality management systems – Particular requirements for the application of ISO 9001:2008 for automotive production and relevant service part organizations

IEC/TS 61836 ed.2 Solar photovoltaic energy systems – Terms, definitions and symbols

ISO/IEC Guide 98-3:2008: Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement

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