IEC TR 63292

Edition 1.0 2020-06

TECHNICAL REPORT

colour inside

Photovoltaic power systems (PVPSs) – Roadmap for robust reliability

IEC TR 63292:2020-06 (en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-8472-8

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC POWER SYSTEMS (PVPSs) – ROADMAP FOR ROBUST RELIABILITY

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IEC TR 63292 which is a technical report, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
82/1671/DTR	82/1716/RVDTR 82/1716A/RVDTR

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

Mandatory information categories defined in this document are written in capital letters; optional information categories are written in bold letters.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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INTRODUCTION

Reliability of a PVPS or its components is perceived in many ways depending on the perspective of the observer. This document addresses many of these perspectives ranging from component failures to the human factors needed in operations and maintenance (O&M) of a PVPS. Technically, reliability is the probability that a product or a system will perform its intended functions satisfactorily without failure and within specified performance limits for a specified length of time, operating under specified environmental and operational conditions. Stated as such, reliability analysis is a physics problem in that it includes what, how, and why of failure. Reliability is determined by a variety of factors (failure modes) and each failure mode is generally characterized as an average or mean time to or between failure or by failure rates (commonly failures per unit of time) or by failure distributions. Causes include failure mechanisms such as overstress and below specification strength, natural and induced environmental exposures, chemical aging, radiation, and other factors such as weak or intermittent manufacturing quality or shipping and handling induced damage that lead to a component failure. The failed items will need repair or replacement through a function of maintenance actions. Reliability analysis and best practices should be applied throughout the concept and design phases to identify, pre-empt, prevent, forestall, or mitigate such failures during planned operation. Cognizance of reliability factors is important for owners, and others performing project or program financial and technical risk asset management.

Acquiring data to find and understand failure trends, spares forecasting, manpower forecasting, obsolescence planning and repeating component failures requires a management focus to mitigate or eliminate recurring issues and document accurate failure tracking. The ability to estimate the resulting loss of Photovoltaic Power System (PVPS) capability forms the basis for how to allocate time, power, energy and even cost for reporting reliability metrics or, more directly, unreliability due to failure events and/or trends, which in turn, necessitate corrective actions.

Assuring reliability can generally be viewed as two specific and major interrelated efforts:

a) concept and design phase, and

b) the operational and maintenance (O&M) phase.

During concept and design evidence of prior product failures and system history and current testing data are used to estimate the reliability of the system(s). The evidence comes in the form of data from historical operation of existing plants that has sufficient breadth of information to provide the basic reliability information as well as attributes such as the failure distribution (e.g., normal, Weibull, exponential, etc.), failure mechanisms and failure modes, and required corrective actions. With rapidly advancing technologies the concept and design phases also require using engineering judgement, experience, design trade-off assessments, and design/reliability testing of new components for developing failure models. For instance, understanding the physics of failure applies to the design assessment.

During O&M, the owner/operators and the O&M contractor implement a failure detection and data acquisition system that likewise provides data for analysis of the current failures including root cause, failure modes, and failure rates by documenting and tracking the failures and then using the data to develop corrective action plans and when feasible changing the design to accommodate new stresses or to correct a flawed design.

Effective reliability practices will reduce overall system costs through reduction of failures and their consequences. There are initial costs associated with design analyses and reviews, component selection, and analysis of reliability testing. In this context, reliability should be viewed as an investment in the plant or company future. Failure to perform reliability practices results in a low reliability product and its ramification of extended costs for field repairs and replacements, impact to energy generation, problems during warranty, or worse, the loss of business.

This document continues the effort started with the availability technical specification (IEC TS 63019). Availability is closely related to PVPS operational capability, health and condition and to produce energy and is a real-time or historical measure. The availability of a system or component is impacted by contractual and non-contractual reliability specifications, maintenance metrics and a corresponding maintenance and repair strategy, and also external factors such as site environmental and grid conditions. Reliability has a focus more closely aligned on the capability of the components, their health and condition, systems to sustain production, and what manner of operations, maintenance, analysis and actions are effective for economic asset management of the PVPS.

The PV industry has had a recent period of rapid growth of installations. Existing PV plants are starting to age. Concurrently, new and evolving products are being introduced and a lack of reliability data is a general issue of concern as often there is insufficient testing or test data to properly assign the reliability attributes to these new technologies. This goes to the intended function of the systems, which is a topic for addressing through reliability analyses to determine the impact of known and unknown (postulated) failures and/or the effects of underestimated declining performance. There has been expressed levels of dissatisfaction for many plants not meeting power/energy expectations and, in some cases, this has led to plant shutdowns or expensive upgrades or down rating (derating) of the plant. In some instances, the loss of or the renegotiations of power purchase agreements has also occurred.

Clarity is needed to specifically address issues of the intended function not meeting appropriate specifications, and to numerically assess reliability performance and economic impacts. Throughout, there is competition in the market with cost pressures and without the expectations of continuous process improvement, those pressures will continue to exist.

The motivation for addressing reliability in the implementation and operation of a PVPS is founded in the desire for long lasting energy performance, energy production, secure production and revenue, and safe function. Management of a PVPS may come in many forms, but for reliability to be properly addressed, it is derived from a commitment to establish practices from the beginning development of concept and plans to take necessary actions and financial investment to ensure results and avoid the costs of unreliability. The commitment for reliability must begin at the highest levels of the organization and for those who have financial risks in the project, the course of action must be defined and implemented in a manner similar as that of environmental safety, health and quality. This document is supportive of that approach and defines methodology for accomplishment.

An intention of this document is to be a precursor examination of the reliability issues for further address in a task to produce an IEC Technical Specification on this topic.

While this document identifies reliability tools, topics and procedures, there are commercial products available to perform analyses and there is no assessment of those tools or to provide recommendations for one tool over another in this document.

PHOTOVOLTAIC POWER SYSTEMS (PVPSs) – ROADMAP FOR ROBUST RELIABILITY

1 Scope

PVPS component and system reliability engineering works to define the PVPS probability of making the indicated value such as energy or revenue, also at a given statistical confidence level for an estimate. This needs to be assessed properly as an accurate levelized cost of energy (LCOE) results from identifying and acting on a set of quantifiable metrics based upon real measured data of actual plants under the widest variety of real site conditions. In many instances, the use of P numbers (which stands for "percentile") may not be clearly understood and as a result, inappropriate conclusions drawn which have a financial result. P values are used to establish the confidence that one can require to provide the assurance that the item will meet specification. A P50 value, for example, provides that there is a 50 % confidence in the value used in reliability predictions. This value of confidence translates to the median of the population or in other words, it is equivalent to a coin toss on whether the value is valid. It is better to have a higher confidence that the system will work to specification. For reliability metrics, this is typically defined as being a P90 or P95 values. This level of confidence significantly characterizes financial and technical risk plant availability.

The failure rates and mode become important for predicting future failures. In a worst case, significant wear out failures may be indicative of serial failures and attention is warranted. A needed caution is the components may have multiple failure modes and root cause analyses may be useful discerning the failure modes.

The LCOE calculations may not adequately include all the relevant costs, i.e. all-in costs, and risks which create further uncertainty. That uncertainty has a high probability of coming to inaccurate conclusions and choices.

Ideally, the owners, maintainers and operators should look for reliability issues early in the concept, system, and hardware and software design engineering efforts. Otherwise, the defects in software code and poor design or weak components will manifest themselves in a multitude of unexpected failures resulting in unwanted and unexpected risks and costs.

In addition, there is another issue that is a by-product of unexpected costs. Organizational angst is the result of not addressing issues at specification prior to design that in turn results in organizational effort, time, and expense in the solving of problems (often originally simple) that become quite complicated after the plant has been built. Because this effort may not be adequately budgeted, and places additional stress on the organization, it tends to have a negative impact on the human performance of scope and adds risk to the PVPS performance.

Without analysis of accurate field data and metrics, there are a series of negative results that include unidentified or unexpected levels of plant failures and degradation. Lack of ongoing (from concept to end-of-life project phases) reliability analyses, the results of inaction raise unaddressed costs, risks, reduced plant capacity and capability, and potential for plant derating. All these issues could potentially result in substantial negative financial impacts to the owners, insurers, users and/or operators.

Reliability of a PVPS requires a comprehensive approach to identify, maintain, correct, and understand costs. Some critically necessary specific gaps for the PV industry need advancement:

a) A standard way to define failure statistics for PV, for PV components and specifically PV modules where failure can be either catastrophic- or degradation-driven. This can be accomplished by a bottoms-up fault tree nodal model with further guidance on how each of the nodal distributions can be derived qualitatively.

b) Defining a common nomenclature of describing failures in the field so that failure statistics can be gathered and analysed (i.e., failure coded or word search capability). Further there needs to be coordination between the various stakeholders to standardize data capture in a format that allows for meta-analysis. Different levels of data can be used for different or enhanced understanding of reliability issues depending on available technology and installed capability. Improvement in monitoring is assumed but there is a need to create standardization criteria, and details on data capture.

c) Defining a standard for how operational failure data is classified, root cause identified, and reported to aid objective b) with guidance or criteria established or cited.

Reliable systems, processes, and procedures produce energy more safely at a consistently lower cost while reducing waste, unnecessary labour, unplanned O&M, and unnecessary organizational angst while providing additional actionable information to continually build and operate better, higher producing and safer plants.

An obvious concern is that the system appears imposing at first sight. It is not the intention that the effort be a greater cost than its benefits. The resultant specifications and design shall fit the business /financial needs of the project. The cost of ensuring reliability needs to be weighed against the costs of not ensuring reliability at achievable levels. The types of data and commitment to data collection, however, should be tempered while addressing the initial and future data requirements. The Pareto techniques allow insights to be gained on the vital few as per the 80/20 % rule (see 7.11). However, much data needs to be collected and this provides references to other documents that address data.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-192, *International Electrotechnical Vocabulary (IEV) – Part 192: Dependability*

IEC 60300-1:2014, *Dependability management – Part 1: Guidance for management and application*

IEC 60300-3-3:2017, *Dependability management – Part 3-3: Application guide – Life cycle costing*

IEC 60812:2018*, Failure modes and effects analysis (FMEA and FMECA)*

IEC 61078:2016*, Reliability block diagrams*

IEC 61215 (all parts), *Terrestrial photovoltaic (PV) modules - Design qualification and type approval*

IEC 61649:2008, *Weibull analysis*

IEC 61703:2016*, Mathematical expressions for reliability, availability, maintainability and maintenance support terms*

IEC 62740:2015*, Root cause analysis (RCA)*

IEC TS 63019:2019, *Photovoltaic power systems (PVPS) – Information model for* availability

ISO 9001: 2015, *Quality management systems – Requirements*

ISO 55000:2014, *Asset management – Overview, principles and terminology*

IEEE 493, *DoD Failure Modes and Distributions, Gold Book*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

The International Organization for Standardization (ISO) and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
availability
ability of an item—under combined aspects of its reliability,maintainability, and maintenance support—to perform its required function at a stated instant of time or over a stated period of time

3.1.2
available state
where the PVPS, a subsystem, or a component is capable of providing service, regardless of whether it is actually in service and regardless of the capacity level that can be provided

3.1.3
confidence level
probability that the value of a parameter falls within a specified range of values

3.1.4
derating
a) using an item in such a way that applied stresses are below rated values
b) lowering of the rating of an item in one stress field to allow an increase in another stress field

3.1.5
failure
event or inoperable condition in which a PVPS, a subsystem, or a component did not, or could not, perform as intended when required

3.1.6
forced outage
damage, fault, failure or alarm that has disabled a system or component

3.1.7
inherent availability
steady state availability considering only corrective downtime and no other causes

3.1.8
lowest level of repair
lowest level of item (component, assembly, module, card, box, or subsystem) that is replaced as the result of failure of the end item