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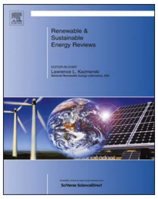

A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols

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ABSTRACT

Data indicate that the inverter is the element of the photovoltaic plant that has the highest number of service calls and the greatest operation and maintenance cost burden. This paper describes the projects and relevant background needed in developing design qualification standards that would serve to establish a minimum level of reliability, along with a review of photovoltaic inverter quality and safety standards, most of which are in their infancy. We compare stresses and levels for accelerated testing of inverters proposed in the standard drafts, and those proposed by manufacturers and purchasers of inverters. We also review bases for the methods, stress types, and stress levels for durability testing of key inverter components. Many of the test protocols appear to need more comprehensive inclusion of stress factors existing in the natural environment such as wind driven rain, dust, and grid disturbances. Further understanding of how temperature, humidity ingress, and voltage bias affect the inverters and their components is also required. We provide data indicating inconsistent quality of the inverters and the durability of components leading to greater cost for the photovoltaic plant operator. Accordingly, the recommendation for data collection within quality standards for obtaining cost of ownership metrics is made. Design validation testing using realistic operation, environmental, and connection conditions, including under end-use field conditions with feedback for continuous improvement is recommended for inclusion within a quality standard.

1. Introduction

1.1. Motivation

Standards for qualification, reliability, and durability of balance-of-systems (BOS) components, such as power conversion equipment (PCE), for photovoltaic (PV) systems have trailed that of the PV modules. The efforts and approach for the qualification standards development have been mostly focused on the PV modules, rather than PCE. This emphasis on the module has been justified because systemic failures of the PV module design affecting a large number of modules can have substantial financial impact to the manufacturer or power plant owner, whereas failures with string-level or larger inverters can usually be addressed by part or equipment changes as required. [1] PV modules are generally not repairable, with replacement being the only viable option. On the other hand, the arrival of module-level power electronic equipment (e.g., one device per module) may conceivably lead to systemic problems at each module in a whole PV field or installation, as well.

We first seek to quantify the extent of the problem. Fig. 1 gives a breakdown of operation and maintenance (O & M) events from three different reports, [2,3,4] provided by PV plant operators. The inverter is seen to be by far the largest percentage of service calls, which leads to higher maintenance costs and lost power production.

It is desirable to understand at the outset the cost of ownership of the inverter, including maintenance, repairs, and downtime costs. To understand the financial impact of these factors, Fig. 2 summarizes an analysis of total cost of ownership (cumulative), not including depreciation, for four types of PCE from three vendors for four years [5]. A total of 400 failure reports were analyzed. Two of the four inverter types (types 2 and 4) show that actual total cost of ownership ran significantly above the vendor-projected costs. Trends in improved

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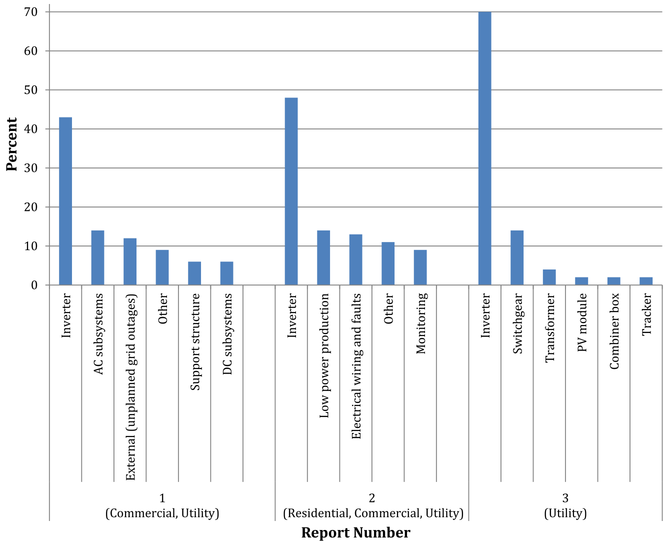

Fig. 1. Three reports ranking the service request of power plants by equipment category. "Other" includes roof leaks/water in conduit/boxes, damaged tiles, dirty array, rattling modules, bird/rodent issues, and other damage. AC subsystem comprises everything between the inverter and the generation meter.

reliability can be seen in some cases. Operating cost vary over the inverters' product lifecycle associated with different challenges that need different approaches.

The cost of O & M work necessitated by inverter failures influences the profitability of PV installations. The inverters constitute between 43% and 70% of the PV power plant service requests as seen in Fig. 1. Financial losses additionally accrue due to energy losses. The inverter has been reported to be the greatest factor leading to energy outages, responsible for up to 36% of the energy loss [7]. In view of the high costs associated with inverter failures, understanding the root cause of component failures, methods to access or ensure reliability and forecast lifetime of the PCE and their components through testing and quality standards becomes vital.

While the authors acknowledge it is economically impractical to expect the industry to produce inverters that never fail, never need maintenance, or attain 100% availability, the impact of inverter outages on the revenue streams of PV projects must be dealt with. An impetus for additional testing and quality standards is to minimize unplanned or unexpected outages, and minimize repair/restoration times utilizing quality management principles, design for reliability, and testing approaches as cost effectively as possible while reducing the unpredictability of operating costs for PV power plants.

It is anticipated that this paper will provide the reader an understanding of current industrial practices for testing and ensuring quality of inverters and their components and projecting their service life. In addition, areas that require further work will be discussed, including design, testing, and quality protocols and standards. The efforts recommended in view of the reviews presented in this paper are anticipated to result in increased confidence in the quality of inverters used for PV power plants for the goal of lower O & M costs and risk reduction.

1.2. Scope and organization the review

Giving better visibility to the issues of inverters that power plant operators see as the greatest O & M cost factor is a first step—this was introduced above in Section 1. We follow this in Section 2 by going into the next level of detail—reviewing statistics of the components and factors most responsible for inverter failures so that the reader may gain deeper appreciation for which issues are most responsible for the failures. In Section 3, we give an overview of what has been done and the ongoing work on PV inverter standards for the goal of improving inverter reliability from the perspective of testing and quality. Related standards sometimes relied upon from other industries are also discussed. This section will be useful for those not intimately following the standards development process to gain understanding of where development processes stand. It will be seen that the standardization effort is in its infancy and work remains to be done.

With this background, Section 4 gives a discussion of the application of the tests and methods to improve the design, durability, and consistent quality for key inverter components reported to be responsible for some failures in Section 2. The data and information is from cited literature, including evidence reported by the coauthors based on their experience and equipment, and agreed upon in the form of a failure mode and effects analysis created within PV Quality Assurance Taskforce (PVQAT) Task 11 [6] It should be noted that in many cases, more comprehensive analyses for evaluating component reliability can be found in the scientific literature; however, the purpose of Section 4 is to review the procedures that are currently reported by the industry. Section 5 focuses on the key stress factors of temperature and humidity and how their effects are tested and modeled. Some shortcomings of the traditionally applied damp heat tests and models are also discussed. In Section 6, we discuss how maximizing quality and driving reliability improvement, from the design to the installation process, along with the introduction of design and quality standards, are anticipated to reduce overall technical and financial risks.

Section 7 concludes by summarizing where we are now and where we need to go to achieve higher inverter reliability and reduce the factor that in many studies is highest on the Pareto of O & M costs. It is

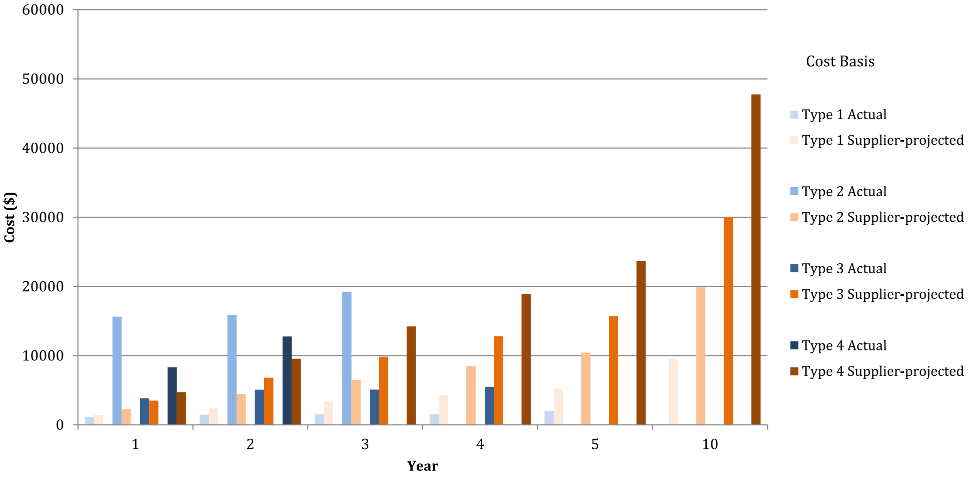

Fig. 2. Actual and supplier-projected cumulative total cost of ownership for four inverter types.