Exploring the failure of solar PV assets

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Even a small failure can have serious and wide-ranging consequences for the ongoing operation of a solar project. However, by understanding what caused the failure, steps can be taken to prevent it from happening again. But with the rapid expansion of the solar industry, introduction of new technologies, and projects often deployed in challenging and sometimes extreme conditions, pinning down the cause of a failure can be a major challenge.

Many different materials and parts make up a solar PV farm, including PV modules, mounting parts, solar trackers, inverters, power cables, substations and, increasingly, batteries. They are exposed to varying degrees of solar irradiation, wind, rain, hail, snow, ice, salt and moisture, as well as mechanical factors such as friction, all potentially leading to integrity threats like metal fatigue, corrosion, and cracking.

A failure may be regarded as a loss of material integrity, resulting in the inability of the component or system to perform its normal functions. Even a failure in a small part can have serious consequences.

A typical 100 MWac solar project comprises: 300,000+ PV modules; 3,500+ tracker rows with motors, bearings and dampers; 45,000+ piles; 100+ km of cabling; and 40+ inverters.

The typically high capital and low operating costs of utility scale solar assets require long operational lifetimes of typically 30-plus years to justify both initial investment and later capital expenditure to restore performance, which degrades over time. Understanding why solar systems and solar power plants fail is therefore vital in delivering a secure supply of affordable renewable solar power to help decarbonize the global energy system. The failures challenge will become even greater; our Energy Transition Outlook forecasts a 20-fold expansion in solar generating capacity between 2019 and 2050.

So, if a failure does occur, a thorough investigation and analysis of failures can help pinpoint causes to prevent further incidents, helping to reduce further technical and economic risk in utility-scale solar projects during operations. Learnings can also boost selection of more reliable materials, parts, and systems, to save cost and time on inspection, maintenance, repair and replacement, and avoid underperformance on future projects.

The potential benefits are greatest when such knowledge is applied from early on in designing and constructing utility-scale solar projects. Operators can support this virtuous circle of learning and improvement by being prepared to undertake a thorough investigation, whether it is a formal root cause analysis (RCA) involving all stakeholders, or a more targeted apparent cause analysis (ACA).

What is a root cause?

There are broadly four types of failure and these may be interdependent or occur coincidentally: physical, or technical, human, organisational, or environmental, or external. Therefore, pinning down the cause of a failure in a complex interdependent system like a solar project can therefore be a major challenge likely to require input from multiple specialists.

However, many failure analyses, often through laboratory investigation or engineering analysis, stop after establishing the physical roots within four fundamental categories: design deficiencies, materials defects, manufacturing/installation defects, and/or service life anomalies. For example, corrosion, cracking, and delamination are potential failure risks to the reliability of PV module components.

Human root causes contributing to failure can be obvious but investigating human error can also identify latent causes that are organisational or procedural. Maybe solar PV modules or their components were damaged in shipping, handling, installation, or mounting on a tracker, for example.

Causes may also be environmental and therefore beyond operator control. Solar trackers can be subject to extreme wind loads, for instance, which can be amplified by dynamic amplification.

What are the benefits of root cause analysis?

With sufficient time and investment to undertake a comprehensive RCA the findings can help to design and implement effective mitigation strategies for the remaining plant operating life and to select and/or develop materials and parts more fit for purpose. It can also help in designing improved or new parts requiring less maintenance and to improve procedures and practices, such as better packaging and handling. Additionally, improvements can also be made to design quality assurance and quality control protocols and testing regimes.

The benefits can therefore be realised across the whole lifecycle, from design, through to product selection and procurement, delivery, construction, commissioning. Also during operations and maintenance (O&M), when operators may need to understand underperformance to decide if further capex is needed and justified.

Knowing root causes of common failures helps to develop and improve recommended practices for solar plant design and installation. Aggregating performance and failure data from operating utility-scale solar PV farms is also vital to validating computer models on which the industry will progressively depend for safe, cost-efficient, profitable operation as it embraces digitalisation and connectivity.

Illustrating how Root Cause Analyses can be extended to provide insight and support both the operating project and the broader solar industry when issues arise, DNV uses advanced analysis tools simulating solar trackers to investigate how a tracker subject to a failure, flexes in reaction to

wind loads. An example of this is the development of advanced non-linear finite element (FE) models for realistic simulation of these structures. Properly implemented, these models can provide better understanding of structural behaviour given product-specific characteristics.

What does RCA involve?

RCAs generally involve a detailed, systematic process to identify the cause contributing to a failure event. Drawing on our own experience for illustrative purposes, the OEM/manufacturer ideally is part of the RCA team coordinated by a specialist like DNV.

After the customer or operator takes steps to preserve the evidence, failure investigation follows a structured process of collecting and analysing data to determine the immediate, basic, and root causes. The process aims to identify ways to prevent similar failures (or failure events) reoccurring. Figure 1 illustrates a typical five-step approach to RCA, though we tailor it to the failure event and a customer's objectives. As shown, some steps are iterative as they may need repeating as new evidence emerges.

To determine the most probable root cause, the ideal RCA, unlike an ACA, incorporates validation testing of the hypothesis of failure, which takes time and likely involves support from the original equipment manufacturer. The RCA's advantage is that it provides the most comprehensive possible approach to determining root cause.

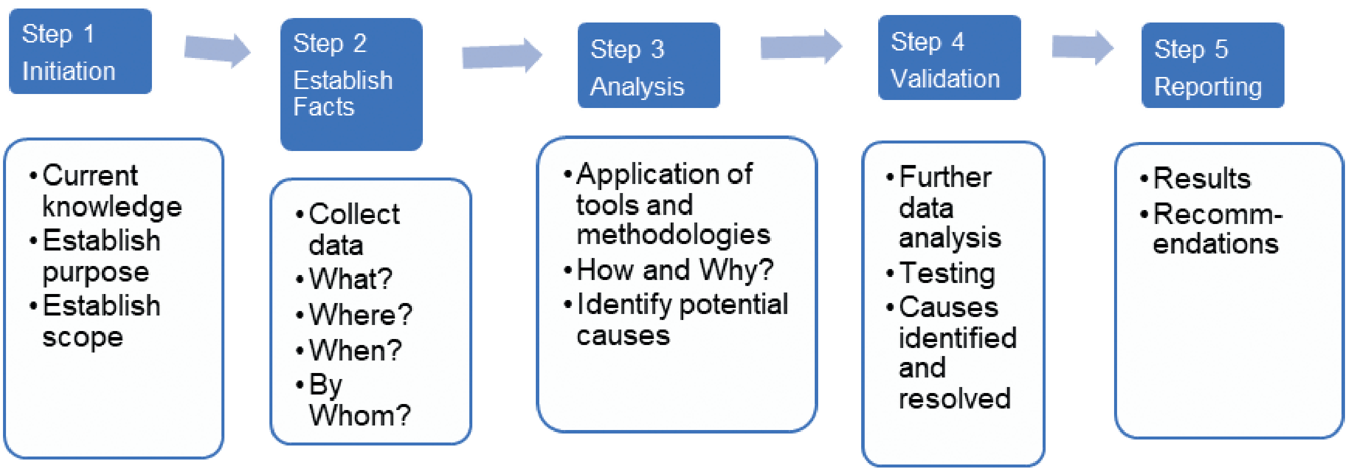

Figure 1: DNV typical RCA failure investigation process (Adapted from IEC 62740:2015 Root Cause Analysis)

However, in practice a full formal Root Cause Analysis is often complicated to implement and undertake given the number of stakeholders who need to be involved, contractual complexities and the economic imperative to return to full operation as soon as possible.

Therefore, a more pragmatic approach is often required.

Apparent cause analysis a pragmatic approach to failure investigations

In practice, a full formal root cause analysis is often complicated to implement and undertake. The RCA process sits within a range of failure investigation services that customers can select from. Others include apparent cause analysis (ACA), and more limited scope options such as independent inspections, and laboratory testing.

The main difference between RCA and ACA is that an ACA aims to establish why the problem happened in so far as reasonably practicable based on available information, reasonable effort, and the analyst's experience and specialist engineering judgement.

In contrast, a formal RCA would typically include all site-specific or equipment-specific design, manufacturing, and operational subject-matter experts. It would also involve a much deeper and more granular investigation. RCA requires a level of cooperation from the OEM and third parties that they may be, and are typically, unwilling to provide. Such unwillingness realistically limits a RCA's achievability and, therefore, the degree of success it might achieve above and beyond an ACA.

An ACA extends the more basic failure investigation approach by including a review of potential causal factors by specialists and developing hypotheses of what caused the failure. The ACA approach typically relies more on support from the solar farm owner and readily available information obtained during construction and operation of the project, and less on the OEM.

In an ACA, subject matter experts review potential causal factors and develop hypotheses of what caused the failure. This usually generates recommended corrective actions that the customer or owner can take to limit their exposure to certain causes of the failure mechanisms discovered. For operating assets, corrective actions typically require further discussions with the O&M contractors, and maybe the OEM.

The advantages of an ACA are reduced cost and time compared with a full RCA. But due to the reduced involvement of other stakeholders, the ACA may not address the root cause of the failure mechanism. Though for the owner of a solar project determining the root cause in extreme detail may not be as critical having sufficient understanding in order to implement the necessary mitigation strategy. In other words, an Apparent Cause Analysis is a pragmatic approach to failure investigation that arguably provides better value whilst not diminishing the owner's option for contractual remedies through the EPC or O&M agreements or product warranties.

The importance of impartiality and expertise

Root cause analysis and apparent cause analysis are among a range of DNV services that can support owners, operators, and investors through failure investigations in the utility-scale solar PV industry. Our experts also draw on deep and long experience globally in other types of renewable energy projects and technology. Other relevant services include site, plant, and factory inspections; field testing and measurement services; comprehensive data analysis; laboratory testing, in some global locations; and computer-aided design / computer-aided engineering simulation (CAD/CAE) simulation.

Our investment in accumulating these competences and capacity underlines the fact that properly performing failure investigation and analysis requires an unbiased perspective of the failure from multi-disciplinary experts, who have experience in a range of failure analysis tools and access to well-established and experienced laboratories.

Whether the approach involves a full RCA, or more targeted ACA, it is important that they are, and can be seen to be, fully impartial. Because such independence is often essential to finding the actual root cause of a failure, we always treat all failure-related or incident-related information with the utmost confidentiality. That way, customers can be assured that their information is safe.

Independence and confidentiality help to surmount limitations that proprietary models and design codes can impose on sharing know-how across the industry. It also means other parties are confident revealing to us essential information that would otherwise never be released.

Be prepared, just in case

With lifecycle cost growing in importance to investors in utility-scale solar PV, it is essential in equipment selection, design and construction phases to choose solutions that will perform optimally and profitably for decades.

However, when a failure does arise it is important to have adequate contractual provisions that allow for owner-led failure investigation and warranties that adequately cover the risks of underperformance and the costs of remediation. Contractual aspects are often overlooked during the contract negotiation phase.

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Ways to be ready for a failure investigation should the need arise include:

- Ensure access to product and construction documentation

  Do you have access to detailed equipment and plant drawings and design documentation?

  Are there installation and commissioning records?

- Have relevant Engineering Procurement and Construction (EPC) and Operations and O&M contract clauses

  Can you undertake an independent analysis and review?

  Can you direct the operator to provide necessary support?

- Have access to your SCADA data

  Can you access all the SCADA data?

  What data is it collecting?

  Is it online and working?

- Have good product warranties

  Are you undertaking comprehensive inspections at the end-of-warranty?

Biography

Richard Gledhill joined DNV in 2010 and is currently Head of Section, Project Engineering and Due Diligence, Australia, in the company's Energy Systems business. His primary role is supporting customers to develop, finance, and construct utility-scale renewable energy projects.

Richard has over 20 years' professional experience working in multiple countries, including Australia, the UK and USA, and has expertise in team leadership, business development, renewable energy, product design and project management.