Distributed Solar Quality and Safety in India

Key Challenges and Potential Solutions

July 2020

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July 2020

A product of the USAID-NREL Partnership

Contract No. IAG-17-2050

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This work was authored, in part, by the National Renewable Energy Laboratory (NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the United States Agency for International Development (USAID) under Contract No. IAG-17-2050. The views expressed in this report do not necessarily represent the views of the DOE or the U.S. Government, or any agency thereof, including USAID.

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Acknowledgments

The authors thank Anurag Mishra from the U.S. Agency for International Development (USAID)-India and Sarah Lawson from the USAID Office of Energy and Infrastructure for their support of this work. We also wish to thank the following individuals for their detailed review comments, insights, and contributions to this report: Andy Walker, Teresa Barnes, Andrea Watson, Adam Warren (National Renewable Energy Laboratory [NREL]), Prakhar Goel, Rakesh Kumar Goyal, Ujjwal Bhattacharjee (Tetra Tech), Akhilesh Magal (Gujarat Energy Management Institute [GERMI]), Omkar Jani (Kanoda Energy Systems Pvt Ltd), Anjali Garg, and Brendon Mendonca (International Finance Corporation).

The authors would also like to acknowledge and thank Britton Marchese, Isabel McCan, Terri Marshburn, Liz Craig, Judy Powers, Liz Breazeale, Nathan Lee (NREL), Joginder Singh, and Yogeeta Sharma (Tetra Tech) for their editorial and design support.

List of Acronyms

AC	alternating current
BIS	Bureau of Indian Standards
C&I	commercial and industrial
CAPEX	capital expenditure
CEA	Central Electricity Authority of India
CEI	Chief Electrical Inspectorate
CERC	Central Electricity Regulatory Commission
CII	Confederation of Indian Industry
DC	direct current
Discom	distribution company
DPV	distributed photovoltaics
EL	electroluminescence
EPC	engineering, procurement, and construction
GERMI	Gujarat Energy Research and Management Institute
IEC	International Electrotechnical Commission
IECRE	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications
IEEE	Institute of Electrical and Electronic Engineers
IIT	Indian Institute of Technology
IP	Intellectual Property
IP	Ingress Protection
LID	light induced degradation
LPS	lightning protection system
MNRE	Ministry of New and Renewable Energy, Government of India
MPPT	maximum power point tracking
MQT	module quality testing
NABCEP	North American Board of Certified Energy Professionals
NEC	National Electric Code
NGO	nongovernmental organization
NISE	National Institute of Solar Energy (India)
NREL	National Renewable Energy Laboratory (U.S.A.)
NSM	National Solar Mission
OD	operational documents
OPEX	operating expenditure
PID	potential induced degradation
PPA	power purchase agreement
PSU	public sector unit
PV	photovoltaic
QA	quality assurance
QAF	Quality Assurance Framework
R&D	research and development
RESCO	renewable energy service company
RTPV	rooftop photovoltaic
SERC	State Electricity Regulatory Commission
SLD	single line diagram
SNA	State Nodal Agency
SPD	surge-protection device
TERI	The Energy Resources Institute
TÜV	TÜV Rhineland

UL	Underwriters Laboratories
USAID	United States Agency for International Development
VRA	Vendor Rating Agency
VRF	Vendor Rating Framework

Executive Summary

In India, the quality and safety of solar photovoltaic (PV) systems—and their installation—have become a concern for investors, regulators, consumers, and distribution companies (discoms). The lack of quality standards and a push for low prices has led to the installation of poor-quality products and inferior system design and execution on site (Devi et al. 2018). These low-quality systems deliver less energy than expected and have a lower overall lifespan, which are serious issues for developers and investors whose return on investment depends on the amount of power generated from these solar systems for the expected life of the project. Equipment that does not conform to minimum quality standards also creates safety risks for business and homeowners. Overall, both performance and safety concerns lower investor and consumer confidence in solar products, threatening to slow market development, and are likely key contributing factors in slowing rooftop photovoltaic (RTPV) installations in India, particularly small-capacity systems (less than 100kW). Technical issues such as the absence of standards or monitoring systems, and the penetration of inferior-quality products in the market hamper the performance of the solar system and create a poor reputation for PV systems and the technology (Devi et al. 2018).

India is not alone; the solar quality and safety issues it faces mirror global experiences. Worldwide, residential RTPV consumers are typically unable to distinguish between low- and high-quality systems. RTPV system components vary in quality, and inadequate training leads to poor installation practices. Many inspection checklists and certification procedures to rectify these issues are already available in India, however, they are not always used because they are not mandatory, or the workforce is not aware of them, or may not have the technical capacity to comply. Demonstrations of quality products and installation practices are more effective if the information reaches the consumer in a clear way. A successful approach to improving residential RTPV system quality is likely to include an assortment of strategies by different stakeholders, as discussed later in this report.

This report provides solar quality and safety information and best practices that can help increase confidence in RTPV in India, particularly for small-capacity systems, and thus accelerate the growth of that sector. New data stemming from expert interviews and a stakeholder workshop shed light on common quality and safety technical issues at various stages of an RTPV system's life (Figure ES- 1) and potential solutions for addressing them. To achieve the goal of a low-cost system with high energy yield, best practices must be followed at each stage of system life.

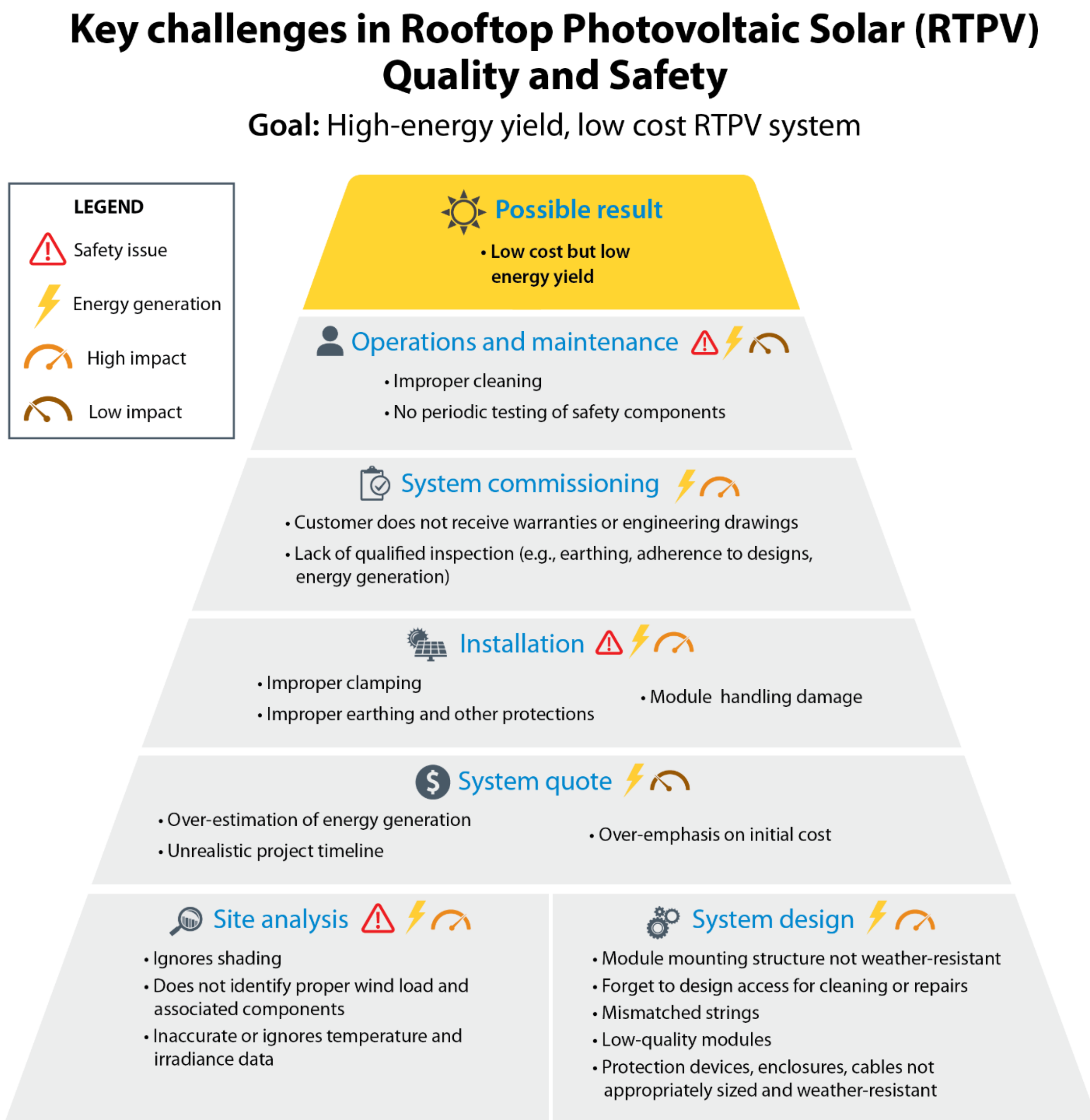

Figure ES- 1. Key RTPV quality and safety issues identified by stakeholders

Note: Common problems occur at all stages of an RTPV system's life, as indicated by the vertical levels of the pyramid. Issues that can result in a safety hazard or severe underproduction of energy are marked with colored icons (see legend)

The new data and analysis are used to identify a prioritized approach to addressing the most common RTPV issues. This approach takes the form of a quality-assurance framework comprising: 1) a Module Quality Assurance program, 2) a Safety Quality Assurance program, and 3) a Vendor Rating Framework (VRF) which are discussed further in Section 5 of the report. We propose that the development of a VRF is likely the next best step to focus initial efforts to improve quality and safety of RTPV installations in India. There are currently no mechanisms in place to monitor, evaluate, and rate vendors (engineering, procurement, and construction contractors or installers) in India. Establishing a VRF would help measure the quality of systems, as well as ensure compliance of those systems to established standards. As vendors and suppliers are held accountable for component and installation quality using this framework, a VRF would also provide an effective mechanism to link quality systems to market share by putting in place a procedure to evaluate, rate, and certify vendors based on their track record of designing, developing, and deploying systems.

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1 Introduction

In India, the quality and safety of solar PV systems—and their installation—have become concerns for investors, regulators, consumers, and distribution companies (discoms). Apart from some existing component-related standards, design and installation standards are either lacking or not adopted by the Indian market. The lack of quality standards and a push for low prices has led to the installation of poor-quality products and inferior system design and execution on site (Devi et al. 2018). Existing literature, reports from field studies that are later referred to in this report, and stakeholder interviews support this claim. These inferior products deliver less energy than expected or have a lower overall lifespan than has been reported in the literature—all of which are serious issues for developers and investors whose return on investment depends on the amount of power generated from these solar systems for the expected life of the project. Equipment that does not conform to minimum quality standards also creates safety risks for the distribution network. Performance and safety concerns lower investor and consumer confidence in solar products, threatening to slow market development. This is apparent in the slow growth of the rooftop photovoltaic (RTPV)[1] segment in India despite being economically viable to many conventional electricity consumers. These concerns are more prevalent with distributed solar systems where developers and consumers have little awareness and technical competence to judge the quality of equipment and installation, let alone the appropriateness of system design. Given the nature of these projects (small capacity and large numbers), Indian states, discoms, and lenders have limited capacity to monitor and enforce existing standards and guidelines for equipment and installation.

Against this backdrop, this report presents a series of best practices and priorities for use by concerned authorities in India to improve the quality and safety of RTPV systems. Prepared under the USAID-NREL Partnership, and in collaboration with USAID-India's Partnership to Advance Clean Energy-Development (PACE-D) 2.0, this report uses primary and secondary resources to help understand the current state of solar quality and safety in India and to provide the basis for future recommendations. An overview of issues and lessons learned about solar quality and safety issues from the United States and other global experiences was also conducted. The report concludes with a series of potential solutions and identify those parties that could most aptly lead change.

This report is organized into six sections:

1. Introduction—solar energy targets, key challenges of RTPV deployment, stakeholders involved, and need for quality and safety standards
2. International Perspective—experiences from the United States and other places globally on solar quality, safety issues, and solutions
3. Research Methodology—how information from key stakeholders was obtained and analyzed
4. Key Findings: Quality and Safety Aspects of RTPV Systems in India—key design, component, and installation challenges, and key drivers of poor quality and safety standards
5. Prioritized Solutions and Implementation Framework—potential solutions for addressing issues
6. Next Steps

[1] Throughout this report, we will use the term rooftop photovoltaic (RTPV) to denote small-scale PV systems adopted primarily by residential and commercial customers and connected to the distribution system (also referred to as distributed solar, or distributed PV in other contexts). RTPV is the term commonly used in India even though these types of systems are not necessarily located on roof tops.

1.1 Solar Energy Targets and Growth in India

The Government of India launched the National Solar Mission (NSM) in January 2010 with the goal of establishing India as a global leader in solar energy deployment. Its ambitious target is to deploy 20 GW of grid-connected solar power by 2022. The NSM aimed to reduce the cost of solar and achieve grid parity by 2022 through:

- Developing a long-term policy
- Deploying solar on a large scale
- Conducting aggressive research and development (R&D)
- Producing critical raw materials, components, and products domestically.

In 2014, India increased the target for the NSM fivefold, from 20 GW to 100 GW of grid-connected solar power by 2022 (Ministry of New and Renewable Energy [MNRE] 2014). The government also segregated this target into ground-mounted and rooftop segments, specifying a 60% versus 40% split for ground-mounted and RTPV systems, respectively (MNRE 2019).

Though the NSM included targets for both ground-mounted MW-level systems and RTPV systems, the initial emphasis from the market was on installations of the former; hence, growth in that sector has been larger and currently exceeds that of RTPV deployment. According to the MNRE, as of May 2020, installed capacity of ground-mounted systems was 32.2 GW[2]; installed capacity of RTPV systems in December 2019 was 5.4 GW (Bridge to India 2019). In 2015, the MNRE developed state-specific targets based on solar resource potential (MNRE 2015). In response, certain states developed road maps outlining a framework for achieving these targets. In addition, many State Electricity Regulatory Commissions (SERCs) announced regulations for net metering of RTPV systems based on technical specifications and guidance provided by the central government. Despite these efforts, RTPV deployment has been slow in India.

1.2 Key Challenges of RTPV Deployment

Several factors have contributed to the slow adoption of RTPV in India, including:

- **Cost of generation:** Solar rooftop deployment is accomplished by thousands of consumers installing these systems on their property. These systems are typically small, with higher deployment costs (compared to ground-mounted systems), and with higher transaction costs for financing and installation. In the current regulatory framework, RTPV is economically viable mostly for high tariff-paying consumer categories such as commercial and industrial (C&I) (Josey et al. 2018; Jaiswal et al. 2017). Residential consumers usually pay much lower tariffs, making RTPV less attractive to them (Patel et al. forthcoming). Higher transaction costs coupled with limited understanding of the technology and quality of the system, further act as deterrents to residential consumers who own a significant portion of rooftop space. In some cases, capital subsidies (central financial assistance) available as an incentive to residential consumers have exacerbated issues due to delayed disbursement, complex procedures, intermittent availability and long pending overdues.
- **Institutional financing:** Most banks either do not want to fund such small transactions or lack familiarity with the technology to feel comfortable financing RTPV systems. These systems are often owned by third-party developers or financed through personal savings, making it challenging to deploy RTPV at scale.

[2] https://mnre.gov.in/the-ministry/physical-progress

- **Utility caution and cumbersome deployment process**: To date, most rooftop systems in India are deployed by C&I consumers (Bridge to India 2019). These consumers also contribute to a high percentage of the margins and revenues of the distribution utilities. Utilities perceive this as a potential revenue loss and are not incentivized to develop a streamlined process (Jaiswal et al. 2017). Utilities would benefit from additional PV technology capacity building and training, especially regarding the safety requirements on the DC side.
- **Complexity and lack of standards:** The complexity of the installation process, the large number of system components, the wide range in quality of available options, and the limitations in defining a single national standard for these systems are barriers to the deployment of high-quality RTPV installations. Most consumers are unable to effectively evaluate the quality of these installations to make informed decisions.
- **Quality and safety:** Stakeholders have limited understanding of the quality and safety requirements associated with RTPV and this further complicates the adoption process. Furthermore, quality and safety considerations are particularly important to facilitate lender confidence in this investment-intensive sector. For example, a significant portion of the overall life cycle costs come as an up-front investment during the deployment of the systems. To recover the investment, it is critical that the systems perform as expected. The success and sustainability of these investments, as well as the achievement of national renewable energy targets, depend to a large extent on the performance of these systems which, in turn, depends upon the quality of the systems, their components, the workmanship during installation, operations and maintenance during the life of the system, and the safety of the financed energy systems.

Over the past few years, the drastic reduction in the cost of solar coupled with a supply glut in the market has led to a suppliers' competition. This has forced engineering, procurement, and construction (EPC) contractors, installers, and suppliers to cut prices to win orders—often sacrificing basic quality and safety requirements. EPC contractors and installers may compromise on the quality of the components, the systems, and the workmanship to keep costs low. This has created a certain amount of scepticism in the market on the long-term performance and sustainability of the systems. To ensure the long-term health of the sector, grow the market, and achieve India's ambitious policy targets, there is a need for a system that facilitates quality in these solar rooftop systems, especially for residential consumers who will make up the bulk of the market in the future and who are most at risk.

1.3 Key Stakeholders and Their Roles in Ensuring RTPV Quality and Safety

Ensuring quality and safety of RTPV systems falls under the domain of several central- and state-level institutions that develop policies, regulations, rules, and guidelines for the power sector in general and for the solar and RTPV sectors specifically. Figure 1 presents the key actors responsible for the development of the RTPV sector in India and highlights some of the major quality and safety initiatives undertaken by each of them.

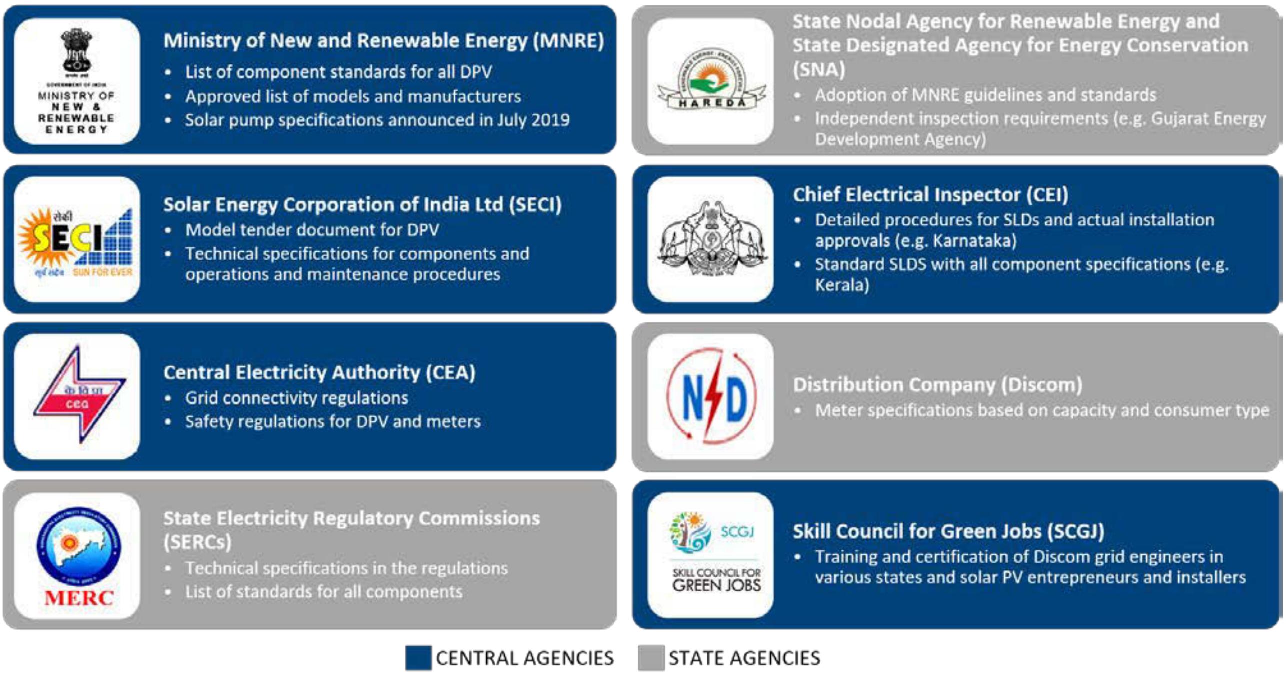

Figure 1. Key institutions and their roles in quality and safety in solar rooftop systems in India.

The model regulations for net metering developed by the central Forum of Regulators, and informed by guidelines and specifications developed by the Central Electricity Authority (CEA) and the MNRE, are the basis on which SERCs have developed their net metering guidelines. State regulations are key drivers for RTPV deployment, with states dictating technical, quality, and compliance requirements. This includes the technical parameters and specifications for RTPV systems and for grid integration, as well as identifying the various limits, checks, and approval timelines. Some state regulators provide detailed technical specifications while others refer to those specifications published by the central authorities, such as the MNRE and CEA. Ambiguous and loosely defined technical parameters related to design, installation, and safety aspects, and the lack of standardization have an impact on the quality and safety of systems being installed across states. The state-level Chief Electrical Inspectorate (CEI) and the state electricity distribution utility are responsible for the implementation of these technical and safety guidelines and ensuring that all systems conform to the standards laid down by the SERCs, MNRE, and CEA.

1.4 Rooftop Solar Implementation Models and their Impact on Quality and Safety

RTPV systems in India are primarily financed and developed in one of two ways: capital investments by consumers (owners of rooftop) or capital investments by third-party RTPV developers, also known as Renewable Energy Service Companies (RESCOs):

- Capital expenditures (CAPEX) model—the consumer purchases an RTPV system and either consumes electricity through net metering or sells electricity to discoms through gross metering. Most residential RTPV systems and most small-capacity systems (less than 100 kW) are built using this model. Normally, the smaller residential customer hires an EPC agency to manage the project from the beginning to the end, including design, supply, and installation. These systems are susceptible to low quality and safety hazards because of low-level customer awareness coupled with an emphasis on reducing capital costs.

- RESCO or operational expenditures (OPEX) model—the RESCO invests in, operates, and maintains the RTPV system, and the customer provides the rooftop and purchases energy generated from the system. This model is common with C&I customers and public sector systems (for example, government buildings) that have larger loads and rooftop area and higher system capacities (100 kW and more). The quality and safety of such systems are better managed and maintained because the developer is more experienced, has access to quality control and inspections, and directly benefits from the higher revenue from better performing systems.

As of December 2019, total installed RTPV capacity in India was 5,440 MW (1,523 MW OPEX and 3,917 MW CAPEX), of which C&I customers represented 3,964 MW, public sector government buildings represented 728 MW, and residential systems amounted to 750 MW (Bridge to India 2019). Currently, the large C&I and public sector systems are developed under either of these models. These consumer types and agencies have the wherewithal to develop quality systems that are safe and perform per guidelines. However, small CAPEX-based systems and investments are likely to be the most dominant investment model for residential consumers because RESCOs do not find it economical to service this segment, or are prohibited from participating. Owing to improvements in technology, economic incentives, and intermediate subsidies, it is likely that there will be an upward trend in the deployment of RTPVs in the future. Therefore, it is critical to develop a framework and implement solutions that address the quality and safety concerns currently prevalent with these solar PV systems.

Though limited in number, the larger solar developers in India, take measures to ensure that appropriate quality and safety are built into the development of solar PV systems. For example, these developers usually have a well-established team of quality-control personnel who work with component suppliers to ensure the quality of the components. These developers also ensure that downstream work is carried out according to their very strict quality and safety requirements.

These larger developers can implement quality measures because they have the financial resources to buy in bulk (allowing them to dictate quality requirements to component suppliers), employ qualified technical personnel to ensure quality of installations and components, and track quality throughout operations to help them make future development decisions. However, most of these developers work primarily on large grid-connected, ground-mounted systems (larger than 5 MW) and RESCO-based distributed and solar rooftop installations. Acting as RESCOs, these developers assume performance risks associated with their systems; this, in turn, creates an incentive to design and install high-quality systems.

In the RTPV space, these larger developers cater to either large C&I clients or participate in large RESCO bids for institutional players (such as municipal corporations), public sector undertakings, and other similar government establishments with high financial ratings. Small and medium establishments and the residential sector are typically not covered by most developers under the RESCO model because of contract security risks. These electricity consumers rely mostly on self-financed systems or on systems developed through smaller, local RESCOs. This leads to the following issues:

- Consumers developing self-owned systems usually lack an understanding of the quality and safety challenges associated with these systems; they tend to invest in the cheapest system available, resulting in suboptimal performance, potential safety concerns, and impacted investment returns.
- Suboptimal performance of systems has downstream impacts on the industry and results in lower adoption rates by other consumers because of negative word-of-mouth publicity; fewer banks are willing to provide loans.

Price reductions and increased competition in the market will continue to make quality and safety significant challenges for the industry. These challenges can stall the development of the distributed solar and solar rooftop markets, especially for small and medium enterprises, and the residential sector.

1.5 Need for Quality and Safety Standards and Implementation Framework

Implementing quality and safety measures requires adhering to international and national standards for component manufacturing as well as design, installation, and workmanship. It also requires a framework that allows stakeholders to examine whether these standards have been followed, which includes a rigorous system of testing, monitoring, and performance mapping.

Policymakers and regulators in India have developed and prescribed standards for solar PV projects—for both large grid-connected solar projects as well as RTPV projects (Appendix B). However, most of these are component-level standards and do not address workmanship issues. Moreover, the adoptions and enforcement of these standards have been left to stakeholders, such as the distribution utilities, banks, project developers, or consumers. Project developers and EPC companies tend not to enforce these standards under price pressures, while banks and consumers often lack the knowledge to implement these standards. This is especially true for RTPV projects because of their large numbers, high transaction costs, lack of knowledge among consumers and banks, and the small size of individual investments. Therefore, to ensure quality through standards, implementing a framework is critical to enforcing standards and associated services, such as testing, inspection, and calibration.

The key challenge lies in understanding and recognizing where quality compromises occur. For example, during the design phase, it is critical to understand the nuances of designing strings to match the maximum output current of strings, requirements for the design of strings to match inverters, or the use of appropriate fasteners keeping in view the wind profile of the area to name a few. Similarly, compromises may occur when the module manufacturers' bill of material does not conform to prescribed standards, or if specific standards are not adhered to during the manufacturing stage. In addition to prescribing standards, there is also a need for on the ground support through inspections and audits.

Technical issues such as the gaps in standards or monitoring systems and the penetration of inferior quality products in the market hamper the performance of the solar system and create a poor reputation for PV systems and the technology (Devi et al. 2018). Developing a framework that will facilitate developers (RESCOs and EPCs) to buy the right components, as well as ensure that the components have been tested for quality and safety, is an urgent need. A framework will also provide developers standards to conform to, and allow consumers to see that systems are installed in a manner prescribed by standards and best practices.

2 An International Perspective: U.S. and Other Global Experiences With Solar Quality and Safety Issues

India's unique context influences how solar quality and safety issues manifest on the ground in terms of their specific type, frequency, and prevalence. At the same time, India is not alone in facing such challenges. Solar safety and quality issues have persisted worldwide from the technology's early deployment (1980s and earlier) to today. Over time, researchers have cataloged common solar quality and safety issues and developed best practices for overcoming them—a process that is ongoing. Since its inception, the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has focused on PV reliability and system performance research to improve these technologies. NREL's PV Reliability Group, in particular, has been involved in several efforts related to PV system quality; the group's experiences and lessons learned that are relevant to India are summarized below.

2.1 Site Inspections

NREL's PV Reliability Group regularly performs PV site inspections to directly observe possible reliability issues (or lack thereof) and help guide research. NREL also interviews system owners. The majority of site inspections are performed on ground-mounted systems, but some are on residential rooftop systems. Nevertheless, important commonalities have been observed. Major observed trends over the years, and current issues with rooftop installations, are described below.

Failures in early PV systems were dominated by component failures, often in the modules and inverters. Some examples of common failures in older PV systems include browning, cracked wires and connectors, and compromised solder bonds. The incidents of such failures have decreased dramatically because of improved PV component testing and standards. Programs such as the Jet Propulsion Lab block buys between 1975 and 1985 provided guidance on which accelerated tests could reproduce observed failures. Such tests were subsequently incorporated into component standards, such as International Electrotechnical Commission (IEC) 61730 for module safety and IEC 61215 for module design qualification. Qualification to international component standards has become a minimum requirement for many large system procurements. In rare cases where modules are not designed to meet these standards, NREL has observed a recurrence of these early problems. Based on discussions with stakeholders in India (and outlined further in Section 4), a majority of the quality and safety issues was identified to be module related. While standards have been developed and adopted for ensuring module quality, implementation is lacking in India.

System downtime because of inverter failures and nuisance trips was also widespread in early systems. Inverter issues have been slower to resolve than the majority of early module failures but are decreasing in frequency with wider applications of revised or new inverter standards, such as IEC 62109 for safety and 62093 for design qualification in natural environments. Benefiting from the newer inverter standards developed and adopted, few survey respondents reported issues with inverters in India (Section 4).

Laws (codes) in the United States cover PV system safety quite thoroughly, but there are few requirements for PV system performance: a system and components must be safe, but system energy generation is not strictly mandated. For example, module certification to IEC 61730/UL 61730 (a safety standard) is required via the national electric code (NEC). The NEC and building codes also govern system wiring and grid connection, fire resistance requirements, and mechanical loads. Only within the last year have governments started to require performance standards, such as the state of California adding a requirement that modules meet IEC 61215/UL 61215 design qualification to receive state incentives.

System energy generation can be compromised by poor choices in any aspect of the system construction. Some system owners have cited an overemphasis on physical system completion rather than quality and energy generation, which they believe was due to developers receiving tax incentives at physical system completion. Thus, despite substantially improving module reliability, other factors may impact system performance severely. An example is a system where the trackers were not certified or tested for PV usage; most became stuck within a year of initial operation.

Some owners of large systems are more focused on return on investment through long-term energy generation. These project owners and designers have become very technically savvy in the areas of component certification, module degradation rates, and system construction requirements. The RTPV consumer unknowingly benefits from this technical know-how because high-quality (certified) PV components have become widely available.

Poor system design and installation are much more common in rooftop systems than in large ground-mounted systems. For example, NREL has seen many rooftop systems inadvertently installed with significant shading. Systems have been installed facing north (in the northern hemisphere) with the designer seeing only that the location is not shaded. In other cases, installers have misinterpreted claims about microinverters to mean that the modules can perform adequately in the shade if microinverters are used. NREL has also seen multiple cases where installers flush-mounted modules to the roof, which decreases performance and longevity because of hot temperatures, without discussing or explaining higher-performance configurations to the homeowner.

These quality-related observations connected to system size are relevant for the Indian context, where business models for RTPV deployment can further amplify these issues as discussed in Section 1.4.

A key stumbling block in U.S. rooftop system quality is that the consumer usually cannot distinguish between a high- and low-quality system. While there are some quality marks that are discernible to a subject-area expert (e.g., IEC component certification and North American Board of Certified Energy Practitioners training of installers), these valid indications of quality are not well known. Instead, cost-per-watt and customer recommendations are often used to select an installer. Even some government websites that purport to compare installers only provide cost-per-watt information. Customer recommendations may be misleading. Such recommendations are more likely to be based on the installer's personality or punctuality because most consumers cannot evaluate PV system quality. NREL inspected a system with significant shading (using a string inverter), code violations, flush-mounted modules, no warranty, and inoperable data transfer from the inverter, where the installer was highly recommended by the homeowner's friend.

When a homeowner suspects a problem with the PV system operation, it may be difficult to obtain warranty benefits. While a part (such as a prematurely failed inverter) may be covered, the homeowner may still be required to pay for shipping and labor. NREL encountered two cases where homeowners were able to detect module performance problems and experienced a great deal of resistance from the manufacturers in obtaining replacement modules (although they did eventually succeed).

Installers cite some challenges unique to rooftop installations. Some believe that they are shipped lower-quality modules than those shipped to large sites because they cannot afford random-sample module testing like the larger users. These installers believe that they may be shipped modules with cell cracks and other flaws that are not visible to the eye. Some installers have also cited unhelpful inspections that can delay the project by days. It is important to remain sensitive to these issues in thinking about quality requirements.

2.2 Standards for Systems—IECRE

To improve system quality and provide solutions to the issues raised in the previous section, NREL worked with teams of international experts to develop the PV portion of the IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE) for PV system certification (https://www.iecre.org/about/what-it-is.htm, https://www.iecre.org/sectors/solarpvenergy/). This effort involved identifying the characteristics and actions associated with high-quality PV systems, coming to international consensus on these items, then updating or creating more than 30 standards, technical specifications, and operational documents to reflect this content.

A general description of requirements for a high-quality system at each stage of its life is included in the IECRE operational documents (ODs). The ODs reference standards for the details of various procedures. For example, the OD describing system commissioning (OD-401) requires that components be of high quality and that appropriate inspection of the installation occur before the system is considered to be complete. The specifics of component testing and site inspection are not described in the ODs. Component testing is accomplished via manufacturer certification of products to standards, such as IEC 61215 and 61730. Operational Document 401 describes which components must be certified to which standards. For the details of system inspection at commissioning time, OD-401 references IEC 62446-1. Where different requirements for different size systems are logical (e.g., onsite irradiance monitoring for large systems versus use of online climate data for residential systems), the standards specify different classes of systems. Table 1 summarizes the ODs used for different stages in PV installation, the desired characteristics ensured by the OD, and the standards referenced to detail the procedures. ODs are available free of charge at https://www.iecre.org/documents/refdocs/. The names of PV ODs begin with OD-4. IEC standards may be purchased from the IEC website or through an institutional library subscription.

The IECRE PV certification system, with certified inspection bodies and all necessary ODs and standards, was first operational in 2017. Some aspects of the system were adopted quickly. In particular, module manufacturers were eager to demonstrate their quality-management systems through certification to IEC 62941. Inspections and quality certificates were issued for some large PV systems. However, the community has not yet begun to include IECRE system certifications regularly in procurement or commissioning requirements.

Table 1. Summary of Stages Relevant to PV System Installation, Desired Characteristics at Each Stage, and Standards that Describe How to Achieve these Characteristics		
Stage in PV System Life (Document #)	**Desired Characteristic**	**Standard Where the Requirements Are Specified in Detail**
Choosing a Module Manufacturer (OD 405-x)	The module manufacturer has a quality-management system in place that covers product design, purchasing, customer relations, monitoring, and measuring.	IEC TS 62941
	Note: This step evaluates the manufacturer, not a specific product.	
Choosing an Installer (OD 410-x)	The installer keeps records of projects and trains employees. Training, continual improvement (including evaluating energy production via 61724).	IEC TS 63049
	The installer follows best practices for array design (including shading, mechanical loads, etc.).	IEC 62548 IEC TS 62738
	The installer follows best practices for commissioning (including system documentation for customer, testing, and inspection).	IEC 62446-1
Commissioning—PV System is Complete (OD 401)	Modules are designed to be safe and durable.	IEC 61730, IEC 61215
	Power electronics are safe.	IEC 62109, IEC 62093
	Commissioning: System documentation is provided to customer. Testing and inspections appropriate for residential systems are performed.	IEC 62446-1
	Performance and capacity are clearly understood.	IEC 61724-2
Checking System Performance (OD 402)	Compare predicted and actual irradiance this year with accuracy appropriate to residential systems.	IEC 61724-1
	Compare predicted versus actual energy production this year.	IEC 61724-3
	Compare predicted versus actual system downtime this year.	IEC 61724-3
	Compare predicted versus actual operations and maintenance costs this year.	

2.3 Education and Developing Best Practices

NREL has worked in industry-wide collaborations to develop best-practices guides for several topics related to photovoltaics. Most relevant to India is a best-practices guide for PV system installation (Doyle et al. 2015), available at https://www.nrel.gov/docs/fy15osti/63234.pdf. This guide includes best practices for several aspects of installation, including requirements for personnel training, company experience and solvency, shading analysis, shading packages, and system production estimates. Requirements are organized into a short checklist in each section of the guide. Some requirements in the guide (e.g., a collection of roof dimensions and type) may be of only minor importance to Indian stakeholders.

NREL has also produced a best practices guide regarding how to plan and deliver effective O&M Best Practices for Operations and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition available at https://www.nrel.gov/docs/fy19osti/73822.pdf.

Also available online are best-practices guides for commercial and industrial PV installations (Doyle et al. 2015), operations and maintenance (Doyle et al. 2015; NREL et al. 2016), solar resource assessment (Sengupta et al. 2015), and development of renewable portfolio standards (Heeter, Speer, and Glick 2019).

NREL promoted an education program for authorities having jurisdiction. These authorities are the state and local officials responsible for inspections and enforcing codes related to PV system installations. The goal of the program was to maintain high system quality but minimize costs to the installer that might be associated with jurisdictional authorities that have not previously specialized in solar, or low-value inspections. Authorities having jurisdiction were educated on important points and common failures and how approvals are typically handled in high-volume solar areas. Installers reported a significant improvement in how efficiently inspections and approvals were executed in areas where jurisdictional authorities participated in an education program.

2.4 Industry-Wide Reports on Rooftop PV Quality

A number of papers and online reports document observations and recommendations for PV system quality internationally (IRENA 2017) or in specific countries such as the United States and India (IRENA 2017; Chattopadhyay et al. 2017; N 2018), Australia (IRENA 2017; Arthur et al. 2017), and Kenya (Jacobson and Kammen 2007; Mills et al. 2014; Duke, Jacobson, and Kammen 2002; Turman-Bryant et al. 2015). These reports contain observations of quality issues (IRENA 2017; Jacobson and Kammen 2007; Mills et al. 2014; Duke, Jacobson, and Kammen 2002), recommendations to solve quality issues (IRENA 2017; Arthur et al. 2017; Duke, Jacobson, and Kammen 2002; Jason S. Trager 2018), instructions and checklists (Turman-Bryant et al. 2015; IBTS 2019.; Stanfield and Hughes 2018; Interstate Renewable Energy Council (IREC) 2010; Brooks and James Dunlop 2016; Energy Market Authority 2011; California Energy Commission 2001) for system design and construction, consumer guides (Energy Market Authority 2011; California Energy Commission 2001; SEIA 2018; Chace and Clay Mitchell 2018), and a study of successful quality improvement (Jacobson and Kammen 2007; Turman-Bryant et al. 2015). The study of PV lighting quality in Kenya is particularly interesting because strategies were effective, and considerable quality improvements were observed (Turman-Bryant et al. 2015).

2.5 Looking Forward—Important Conclusions and Possible Paths

Experience at NREL, and that described in the literature, is consistent in its recommendations regarding best practices for improving quality and safety of RTPV systems in India and elsewhere. Table 2 shows a brief summary of desired characteristics, observed problems, and possible solutions based on work at NREL and in the literature.

Listed below are five key considerations for improving quality and safety of RTPV systems as identified from the review of this broad collection of studies:

1. Most of the time, residential RTPV consumers are unable to distinguish between low- and high-quality systems. The purchase of a PV system represents a complicated one-time occurrence for many consumers, many of whom have no prior experience with this technology. System quality contains many technical details, any of which can lead to a system failure or underperformance. Even third-party information (including some consumer guides) tends to overemphasize the importance of initial cost per watt, most likely because there is not a readily available quantification of quality. Products change approximately every six months, so a useful guide must be updated frequently. Even after the system is installed, consumers do not know if the system is producing as expected because of the complexities of temperature, irradiance, inverter functions, and data reporting. These situations make warranty claims particularly difficult.
2. Demonstrations of quality (installers or components) are only effective if the information reaches the customer in a clear way.
3. Many inspection checklists and certification procedures are already available. Some checklists focus on different aspects of the PV system (e.g., components, roofing and construction, safety, and energy generation).

4. Residential systems often lack long-term monitoring or effective operational indicators. A homeowner should be able to easily see if their system is operating properly or if it requires attention.
5. A successful approach to improving residential PV system quality is likely to include an assortment of strategies. Up-to-date and accessible communication to customers is very important because customers drive the market. Also important are installer training and certification, use of certified components, inspections, and incentives, warranties, and financing that encourages the purchase of high-quality systems.

<table>
<tr><th colspan="3">Table 2. Desired Characteristics, Observed Problems, and Possible Solutions Based on Work at NREL and in Literature</th></tr>
<tr><th>Desired Characteristic</th><th>Observed Problems</th><th>Possible Solutions</th></tr>
<tr><td rowspan="3">High-quality components</td><td>Early life component failure</td><td>• IEC component certifications—minimal cost to consumer because manufacturer performs test once per product
• Publicize components that meet requirements online to customers</td></tr>
<tr><td>Counterfeit components</td><td>• Import control and random testing of products at market with consumer-accessible online publication of results
• Development of national certification labs when possible</td></tr>
<tr><td>Installers buy poor-quality components because they are most readily available</td><td>• Provide channels of communication between installers and distributors or manufacturers so those up the supply chain know about the problems and buyer preferences.</td></tr>
<tr><td>Competent installation professionals</td><td>Mistakes made because of lack of training or experience</td><td>• Make relevant training programs more accessible
• Publicize system designers and installers who meet training or certification requirements to consumers
• Require training or certification for installers to participate in certain types of financing or incentive programs
• Require system inspections by third parties or government agencies. A large investment is required to make sure all inspectors are expert enough to add value and that a lack of inspectors does not delay projects.</td></tr>
<tr><td>Highest-quality systems are purchased</td><td>Consumers purchase a low-quality system because the initial cost was the lowest</td><td>• Educate consumers that initial cost is not the only important metric. Life-cycle costs are also important
• Publicize from a trusted source, both online and in stores, components and installers that demonstrate exceptional quality—and those that have demonstrated poor quality
• Provide incentives to customers that participate in quality programs
• Make available a good warranty that installers may use and customers may look for online
• Make available financing options (e.g., system lease) that provide incentives for both the customer and the installer to consider quality.</td></tr>
<tr><td>Confident buyers</td><td>Consumers decide not to buy a system because they've heard about some problems</td><td>• A trusted third-party provider continuously updates information online that allows consumers to know they are selecting high-quality components and installers. The information must be publicized so that consumers are aware of the resource
• Make available a good warranty that installers may use and customers may look for online
• Make available financing options (e.g., system lease) that provide incentives for both the customer and the installer to consider quality.</td></tr>
</table>

3 Research Methodology

To gain a better understanding of quality and safety issues in India, this research effort was conducted in three stages, starting with a literature review of solar quality and safety in India, followed by interviews with various stakeholders in the sector, and an in-person workshop.

3.1 Literature Review

Few reports are available from previous studies undertaken to evaluate quality and safety aspects of solar PV deployment in India. Those available are based on actual field visits and tests conducted on installed and commissioned plants in various regions in India. Similar to the global experience described in Section 2, the majority of these studies are based on ground-mounted, MW-scale systems, and only parts of some of these studies include rooftop systems. Nevertheless, important similarities can be observed, and recommendations for MW-scale systems are applicable to RTPV systems as well. Common findings from these reports are corroborated by stakeholder interviews conducted for this research and are presented in Table 3. A list of reports, including those from non-Indian regions studied for this project, is also presented in Appendix A.

The most frequently mentioned issue in these reports is the solar module, which represents the major cost component of the system and most affects system life and performance. These solar modules are reported to be of varying quality from different suppliers.

Table 3. Common Findings at Various Stages of PV System Installation in India

Stage of RTPV Project	Common Findings
Solar module issues	Early degradation, microcracks, potential induced degradation (PID), snail trails
Safety and protections	Incorrect earthing, insufficient lightning protection systems (LPSs), underrated fuses and surge-protection devices (SPDs), disregard for fire-handling systems
Installation methods	Partial shadows on array, long runs of direct current (DC) cables, loose connections and wear and tear of cables, corrosion in structure parts
Commissioning	Absence of independent inspection, lack of commissioning tests
Performance	Lower energy generation, intermittent monitoring of systems, slow or no follow up on corrective actions prompted by monitoring
O&M	Inadequate maintenance, no schedule for preventive maintenance
Documentation	Absence of proper documents with customers, planning and design documents not shared with customers, power purchase agreements (PPAs) or contracts unclear in many aspects.

These findings are attributed to some common probable reasons as presented in these reports and corroborated by stakeholder interviews:

- Lack of awareness of these module problems by all stakeholders involved in PV power projects
- Absence of independent supervision, inspection, and audit framework

- Lack of documentation and reporting framework
- Focus on initial cost of power plant rather than levelized cost of energy
- Cost pressures that result in low-quality and unsafe PV systems.

3.2 Stakeholder Interviews: Methodology

To gain a comprehensive understanding of quality and safety of rooftop PV systems in India and the sector status in general, a series of interviews with different stakeholders was conducted, including EPC companies, installers, developers, component manufacturers, and others. Authorities, financiers, and consultants were also interviewed to provide insights from their experiences in the field. As the agencies actually responsible for onsite quality and safety, the EPC companies and installers were included in larger numbers as compared to others. This particular group of interviewees was selected by categorizing them into large, medium, and small players because the issues, reasons, and possible solutions would likely be different across such segments.

Next, a questionnaire was designed and used to conduct interviews with different stakeholders in person, over the telephone, and via written responses. Questions focused on the role of the interviewee, reasons for poor or high solar quality and safety, impacts of low-quality systems, strategies for improving quality, and insight on specific categories (e.g., components and humanpower).

In-person interviews were conducted with 13 stakeholders and telephone interviews with three stakeholders from June to September 2019. In November 2019, another 8 in-person interviews were conducted. Both of these types of interviews lasted for an average of 1.5 hours each. Several other respondents provided written responses. In keeping with the questions used in the interviews, these stakeholders identified current issues based on their own experiences and provided suggestions for addressing such issues and improving the quality and safety of RTPV systems.

Interview responses were compiled and summarized by categories used in the questionnaires, which included component, manpower, commissioning, inspection, documentation, operations and maintenance, tools, site, installation standards, and safety. Some of these categories, such as tools, humanpower, and site did not receive substantial responses and, hence, were combined into an “other” category for this report. A summary list of issues, along with frequency of occurrence and impact on project development is listed in Appendix D; a complete list of issues and possible corrective actions is listed in Appendix E.

3.3 Stakeholder Workshop

The United States Agency for International Development (USAID) PACE-D 2.0[3] held a solar quality and safety workshop on January 21, 2020, in New Delhi, India, to confirm issues raised by stakeholder interviews and to get feedback on potential solutions. Participants included representatives from key government agencies, technical institutions, quality monitoring centers, multilateral development agencies, utilities and distribution companies, local and regional banks, solar PV vendors and developers, EPC companies, O&M companies, and central- and state-level policymakers. The day-long workshop included panel discussions and breakout sessions to review and discuss three potential solutions to improve quality and safety of RTPV in India

- Module quality certification
- Electrical safety quality assurance

[3] https://www.pace-d.com/

- Vendor rating framework.

Inputs and findings from these discussions were used to further refine the solutions proposed in Section 5 of this report. There was support and general agreement that the development of a vendor rating framework as a mechanism to evaluate, monitor, and rate RTPV vendors based on certain established standards was a timely next step for India.

4 Key Findings: Quality and Safety Aspects of RTPV Systems in India

The stakeholders interviewed in the survey identified major and frequently observed issues related to the quality and safety of grid connected RTPV systems in India, much of which corroborated existing literature and the authors' extensive field experience. Figure ES- 1 captures some of the most severe and frequent solar quality and safety issues organized by category or stages of RTPV system life: site analysis, system design, installation, commissioning, and operations and maintenance. While some issues may have a relatively low impact on energy generation, their impact on safety can be high (denoted by the colored icons).

4.1 RTPV Project Development Cycle

The development of a RTPV project can be divided into three broad stages: design, procurement and installation (including O&M).

- Design: the design stage includes site assessment activities, system sizing and design, component selection and procurement planning, and scheduling the installation.
- Component procurement: the component procurement process involves contracting for the component, including putting in place performance guarantees, specifications and standards that the components must conform to, specifying the particular tests that the components must go through before being dispatched from the manufacturing facility, and the specific test results that the developer or EPC contractor would like to see before finally receiving the components.
- Installation and O&M: The final installation stage involves receiving components at the site, site preparation, storing material, installing the system, and completing the commissioning. This stage usually lacks standards and is more dependent on the skills and training of the installers.

Figure 2 shows the three stages and the broad set of activities they encompass.

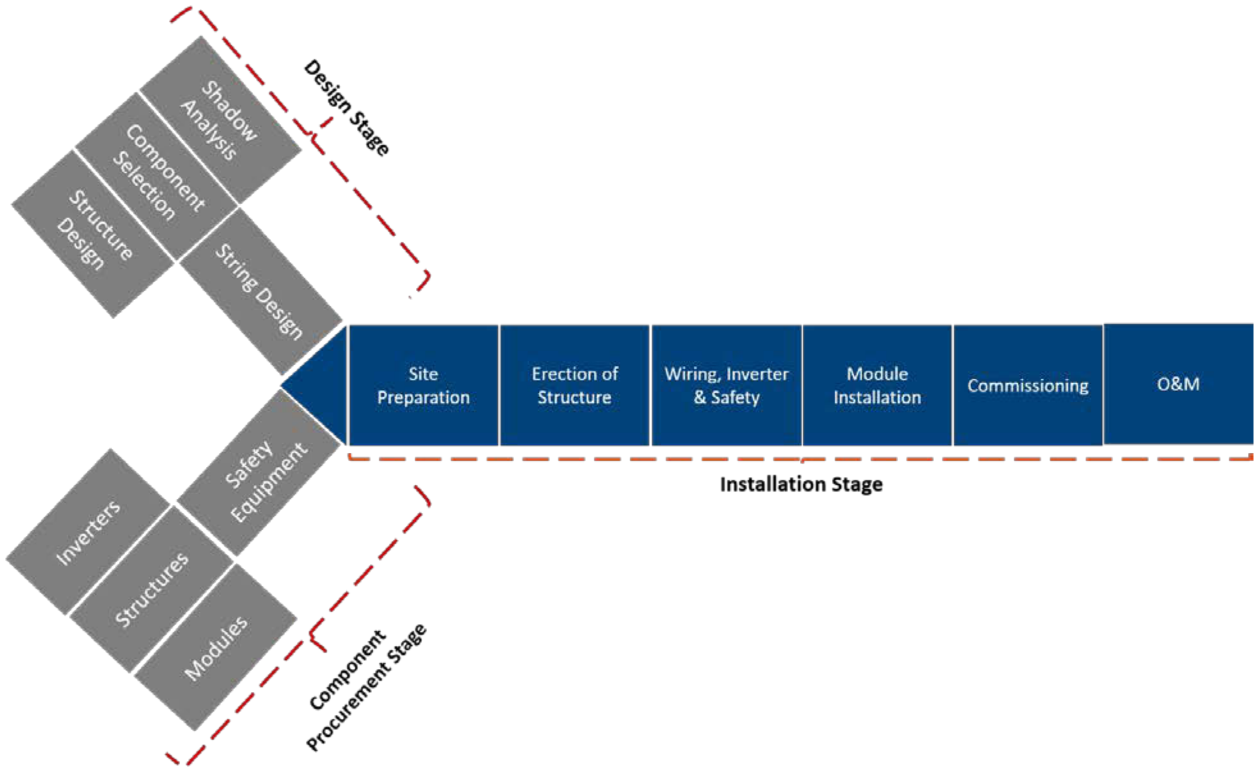

Figure 2. Stages in the development of a RTPV project.

4.2 Key Challenges in RTPV Quality and Safety

Stakeholders raised concerns with component-related quality issues that span several stages of RTPV system life, including the system design and installation phases. Most of the quality and safety issues occurred either at the component procurement stage (about 50% of quality and safety issues experienced) or the installation stage (about 35% of quality and safety issues experienced); the design stage contributed to the balance 15% of quality and safety issues experienced. Within the different stages, some specific areas caused a high proportion of challenges (Figure 3). For example, in the case of system design quality, almost half of the quality challenges stemmed from the wrong array layout, followed by string inverter mismatch and site access. In the case of component quality, the major area of concern was the modules and the module mounting structures, followed by junction boxes; in the installation phase, the main quality issues were related to fasteners, handling of modules, and earthing. Given the emphasis on issues related to system design, component procurement, and installation and O&M, this report expands on those topics in Sections 4.2.1-4.2.3. A summary list of issues, along with frequency of occurrence and impact on project development is listed in Appendix D; a complete list of issues and possible corrective actions is listed in Appendix E.

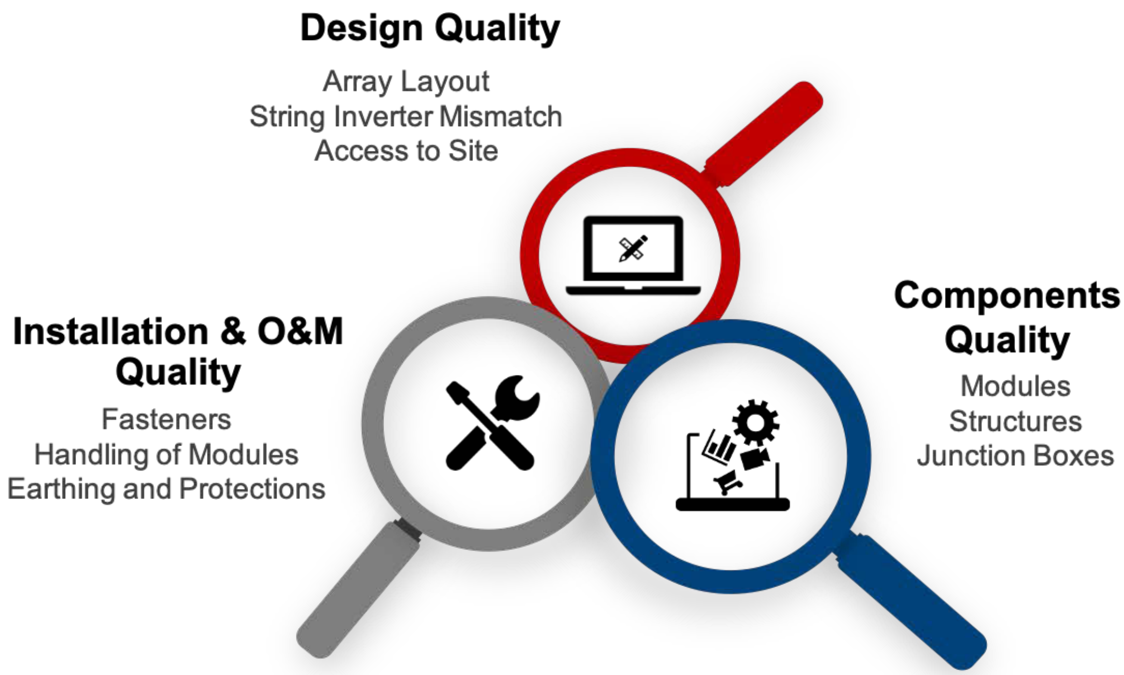

Figure 3. Design, component procurement, and installation related quality challenges based on feedback from stakeholders.

4.2.1 System Design-Related Quality Issues

The biggest challenge identified by respondents in the design phase of RTPV development is the difference in array layout in the installed systems versus the design layout derived after conducting a shadow analysis using software such as PV Syst or PV Sol. For some reason, installers or EPC contractors change the array layout on the ground, resulting in loss of generation and, in some cases, hot spots[4] due to shadows that fall on part of the array. Incorrect array layout is a major error during the design phase and can result in lower performance, which can significantly impact lifetime returns. This issue can either be corrected or can be identified in a post-installation inspection (i.e., by checking if the array layout on the ground conforms to the array layout on the design drawings). Similarly, our analysis found another significant design problem that arose from the designer not matching the string voltage with the maximum power point tracking (MPPT) voltage range of the inverter. Here again this issue can lead to a loss of the returns of the system and can be rectified by checking if the string voltage is beyond the inverter's MPPT voltage range.

Another key issue identified during the design phase was the site access issue, which impacts O&M and the quality of installation. In a number of cases, the site was not easily accessible, and workers had to take unnecessary risks to get to the site for installation, or the site was developed in such a way that although it was aesthetically attractive, the installation experienced generation losses due to alignment issues. Simple precautions, such as ensuring permanent and easy access to equipment, could be incorporated during the design phase. This issue is more apparent with arrays on superstructures where module cleaning may be more challenging, thereby affecting performance adversely. A planned stormwater run-off system

[4] Defects characterized by local overheating of solar cells.

integrated into the surrounding stormwater run-off system is also essential to avoid flooding, erosion of foundations, and muddy ground which can prevent access.

In addition to these key concerns, other design-related issues involved improper cleaning methods for modules, inadequate earthing provisions, and inadequate structural considerations for withstanding weather conditions. These can have a significant impact on the life cycle returns of the project; however, most of these issues can be avoided with good quality control, timely feedback, better training, and awareness. A summary list of issues, along with frequency of occurrence and impact on project development is listed in Appendix D; a complete list of issues and possible corrective actions is listed in Appendix E.

4.2.2 Component-Related Quality Issues

Specifications and standards during the design stage dictate the identification and procurement of components for the RTPV system. Based on discussions with stakeholders, it was found that almost 50% of all quality issues resulted from procuring faulty or substandard components. A majority of the quality and safety issues occurred with the module and the structure, followed by junction boxes.

In the case of structures, respondents agreed that full energy loss or complete system damage was possible if a faulty structure was not rectified. Respondents felt that structure quality was difficult to map and ensure but was critical for the long-term viability and sustainability of the systems. Some of the specific quality issues highlighted by stakeholders for structures were:

- Material damage and defects (of both galvanized iron and aluminum structures)
- Poorly installed fasteners and mismatched component sizes
- Improper anchoring on sloped roofs
- Poor practices and incorrect equipment used in fixing modules onto a structure
- Design errors that result in an inability to withstand estimated dead load and wind pressure
- Post-construction inadequate finishing/ cleaning-up and waterproofing
- Lack of due diligence to determine base roof strength and quality
- Incomplete, ineffective, or nonexistent certifications.

While several standards have been developed and adopted for ensuring module quality, implementation is lacking. In terms of structures, due to the varied nature of sites, standardization is a major challenge, and this is coupled with the fact that most of the players are small and medium industries with limited design capabilities. This makes ensuring quality of structures a challenge, especially for small RTPV projects installed in small towns and cities. One of the most critical components in solar PV systems is the inverter, but few survey respondents reported issues with inverters. This may be because the market is dominated by a few large manufacturers who may view quality as critical to gaining and maintaining market share.

Procurement of modules and certification of structures is key to addressing these component-related issues. Module certification is an evolving topic, and several banks, developers, and EPC companies have learned how to manage it efficiently. However, small EPC companies and developers often lack the technical and financial strength to undertake this certification. There are existing tests that are critical for certifying these components and for ensuring their high quality. These include acceptance testing at a lab or at the module manufacturer's site (through tests such as Flash, electroluminescence (EL), light induced degradation (LID), and visual inspection and strict monitoring of the bill of materials). Structures have two issues:

- Certifying the manufacturing of structures—this can be done by testing and certifying their structure designs.
- Certifying joints and fasteners—this requires a different type of certification (e.g., finite element analysis or wind tunnel testing) that is only possible for a limited number of standard structures that are used across multiple locations.

In addition to the structures and modules, the junction boxes were identified as a key challenge. When junction boxes don't meet safety criteria, the result could be a total loss of the system from accidents. Stakeholders also identified specific issues related to the structure, modules, and junction boxes, which occur during the development and commissioning of RTPV systems. These issues include nonuniform galvanization of steel, lack of certifications, rusting, no due diligence on roof strength adequacy, and the use of poor-quality module subcomponents during manufacturing. A summary list of issues, along with frequency of occurrence and impact on project development is listed in Appendix D; a complete list of issues and possible corrective actions is listed in Appendix E.

4.2.3 Installation- and O&M-Related Quality Issues

The installation and O&M stages accounted for numerous quality issues identified by the stakeholders across the life cycle of an RTPV system. Most of these quality issues relate to the installation of the systems and their subcomponents, their packaging, transport, storage, onsite handling, and monitoring. A key challenge was the quality of fasteners used in the structure. As discussed earlier, structure designs need to go through a thorough wind tunnel test before being adopted. However, the biggest challenge for the Indian market is that almost all structures are unique to match the site's requirements; therefore, it becomes impossible to test and certify every site for each new system or project.

Two other key issues around installation quality and safety are earthing and lightning (E&L) protection and the handling of the modules. For example, in the case of E&L protection, some of the specific quality issues highlighted by stakeholders were:

- Use of improper cables—wrong size and wrong type of cables are used; mismatch in cable connectors used.
- Use of improper protection devices or no protection devices—lack of fuses and use of wrong surge protectors.
- Inadequate or improper lightning-protection systems—improper selection and installation of lightning arrestors.
- Inadequate earthing provisions—lower-than-necessary earthing pits or rods.

Some of the specific quality issues highlighted by stakeholders for the handling of modules were:

- Material damage and defects (revealed only over the period of installation) in cells, laminates, back sheets, and junction box components.
- Transportation mismanagement (e.g., loosely and/or poorly packed, inappropriately loading and/or unloading of components that causes damage).
- Invalid and mismatching module certificates.

- Poor installation of modules without referring to the manufacturer's instruction manual.
- Ineffective cleaning methods by installers that are harmful to the modules.

Additionally, stakeholders also identified structural hardware issues and lack of inspections by qualified personnel. A summary list of issues, along with frequency of occurrence and impact on project development is listed in Appendix D; a complete list of issues and possible corrective actions is listed in Appendix E.

Table 4 summarizes the key quality and safety issues experienced by most projects between the design and implementation stages, and highlights potential solutions that can be adopted to address these specific issues.

Table 4. Key Quality and Safety Issues, Their Impact on Project Returns, and Potential Solutions

Stage of Project Development	Key Issue	Potential Solutions
Design	Incorrect array layout	• Array layout to conform to shadow analysis drawing (check drawing with actual layout)
	String to inverter voltage mismatch	• PV Syst/ PV Sol reports should be used to verify proper matching of strings to MPPT range of inverter (onsite matching; post installation check)
	Absence of safe structural and site access	• Maintain pathway next to array for O&M • Easy access to modules without the need of specialized equipment • Provision of lifeline for safety for sloping roof installations
Components	Poor design and incorrect selection of structural material	• Structure design certification to match wind zone of the location • Proper material treatment (selection of aluminum alloy or galvanization thickness of galvanized iron)
	Low quality modules	• Confirm that supplied module bill of materials matches the tested and certified IEC 61215 bill of materials • Acceptance testing by buyer at manufacturing facility o Flash test o EL test o LID o Visual inspection
	Improper design of junction boxes	• Integrate with inverter or test all protection devices
Installation and O&M	Incomplete E&L protection	• Lightning arrestors effective radius should cover array • Ensure minimum number of earthing (3 per system) • Soil resistivity in each earth pit (< 5 ohms)
	Improper handling of modules	• Thermal imaging test (post installation to check if micro cracks have developed in handling)
	Incorrect module fixing hardware	• Well defined hardware specifications; fasteners, clamping and hardening requirements

In Section 5, a comprehensive, multipronged quality assurance framework is presented that aims to address the major design, component, installation, and O&M issues identified by stakeholders, and help improve the overall long-term quality and safety of RTPV systems in India.

4.3 Key Drivers of Poor-Quality and Unsafe Systems

Survey respondents offered the following list of possible reasons for poor-quality and unsafe rooftop PV systems in India, which corroborates the authors' extensive expertise, other literature, and experience in the field.

4.3.1 Gaps in Existing Quality Standards

The MNRE has listed various mandatory standards applicable to different components within grid-connected RTPV systems (Appendix B). However, these standards only pertain to components; there are no mandatory standards for workmanship, installation, and grid integration. So, while the components may adhere to the mandatory standards, those standards alone are not sufficient to ensure high-quality and safe RTPV systems.

4.3.2 Focus on Capital Cost Rather Than Cost per Electrical Unit

The most common cause for various issues in RTPV systems is overemphasizing the capital cost rather than the cost of generation or cost per generated unit. In practice, stakeholders involved in any RTPV system installation have a singular focus—that of reducing the capital cost. In doing so, they may compromise on various quality aspects and safety features that are essential for a high-performing system. Because of very low entry barriers into this particular segment, many new entrepreneurs and small agencies enter this business and compete heavily with each other solely on the basis of capital cost rather than long-term system performance and the levelized cost of energy. Unfortunately, customers also tend to focus on low initial cost rather than studying technical features and considering life-cycle costs. Moreover, it is common for customers to demand pricing similar to ground-mounted, megawatt-level projects because they incorrectly interpret the limited information available, and they lack the knowledge to differentiate between ground-mounted and rooftop PV systems.

4.3.3 Competition in Pricing and Speed of Work

Fierce competition in the market compels the system integrator and installer to use low-priced components as well as to cut costs by either omitting completely or undersupplying required features within the system. Because the solar module contributes to more than 50% of the system's cost, the focus is usually on procuring the lowest-priced solar module rather than looking at the quality aspects, such as the bill of material, construction quality, and track record of the module manufacturer. Basic and mandatory standards for solar modules are easily met by all manufacturers present in the market. However, there is also a gap in checking whether such module standard certificates are applicable to the particular module bill of materials that is being purchased, and whether this certificate is valid at the time of procurement. System components, other than the module and inverter, are primarily procured from local suppliers, and may be of low quality and sometimes may not even meet mandatory standards or requirements due to a lack of awareness, knowledge and training.

Cost cutting during system installation also happens in the balance of systems components; these can be missing from the system or the quality may be undesirable. This can have serious impacts on the safety of personnel, on the rooftop and building, as well as on the system and the grid. The components most commonly used to cut costs have to do with protections, such as earthing and lightning protection, as well as disconnect switches, overcurrent protection, and surge-protection devices. Neither grid engineers nor customers are fully able to confirm if the supplied components are essential and/or present in RTPV systems.

4.3.4 Lack of Training for Installers—No Eligibility Criteria

In India, the RTPV sector is at a nascent stage; hence, various stakeholders lack the proper knowledge or experience to achieve quality systems and installations. RTPV systems are quickly becoming a commodity product and, similar to other products purchased by customers for their private use, customers fully depend on the expertise of the system provider, which is the only agency they are in contact with while choosing a system and when the system is being commissioned on their rooftop. Some entrepreneurs are new to the field, are not extensively educated about the technology, and may not appreciate the importance of quality, resulting in higher failure rates of small-capacity systems often executed by these entrepreneurs. Similarly, the grid engineer who inspects the installation, primarily from the point of view of grid safety rather than system performance, may not be well equipped to advise installers and customers on the quality of the system.

Currently, there are few mandatory eligibility criteria for installers and system integrators for commissioning RTPV systems. Also, the states, either through the State Nodal Agency (SNA) or discoms, do not opt for empanelment of system integrators and suppliers because they fear the extra burden in case of a dissatisfied customer.

4.3.5 Lack of Customer Awareness

Rooftop systems can be broadly categorized into large-capacity systems for C&I customers and small-capacity systems for residential customers. Currently, C&I consumers primarily opt for using the OPEX model wherein the system is designed, installed, owned, and maintained by the developer or RESCO, and the customer is happy to pay for the energy generated from the system. Such systems typically perform better compared to residential RTPV systems because the revenue for the developers depends on energy generation. In small-capacity residential systems, customers may not have experience or knowledge about system performance or expected energy generation. Most customers are happy about savings achieved in their electricity bills even when these savings are far below the potential savings that could be achieved by their system.

4.3.6 Lack of Proper Inspection During and After Installation

Another missing activity in the overall framework of grid connected RTPV systems is the lack of inspections by an independent agency that is experienced, professional, and capable of identifying issues as well as recommending corrective actions. Often, it is left to the system integrator—or sometimes only to the installer—to commission the system. Many times, the only inspection carried out on site is by the grid engineer, who primarily inspects the grid-integration aspect of the system, not the direct-current side that can have a larger impact on system performance. When systems are financed by a bank or third-party investor, these agencies have some checks and balances in place if the investor is an experienced, serious player in the RTPV sector; currently, such investors are few in number. Bankers may depend on the lenders' engineers whom they would appoint only for systems above a certain capacity. Many small-capacity systems may be inspected only by the bank officer who is generally unaware of the technical aspects because this sector is completely new for financing professionals.

4.3.7 Absence of Mandatory Requirements for Supervision and Audit

Systems installed under a RESCO model (primarily C&I customers), may get an inhouse inspection as well as commissioning tests conducted by an experienced engineer. There are no standards for these tests to be conducted before declaring the system commissioned and before synchronizing the system with the grid—either by the company engineer or by a utility-grid engineer.

5 Prioritized Solutions and Implementation Framework for Quality and Safety Issues in RTPV

Possible government-led efforts to improve RTPV quality and safety can be as simple as providing good quality metrics to consumers, or as complex as detailed mandatory inspections, required by law, on each system. To evaluate which measure to implement, one must weigh the expected impact against the expense, resources and efforts. A progressive approach from the simplest, least-expensive solutions, toward the more complex ones, can maximize benefits per investment, allow gradual development of infrastructure and workforce, and provide time and experience to tailor policies before implementing the most expensive steps. As discussed earlier in this report, in addition to adhering to prescribed standards during the design, manufacturing, and installation of RTPV systems, there is a need for a framework that allows stakeholders to examine whether these standards have been followed, which includes a rigorous system of testing, monitoring, and performance mapping.

With these principles in mind, given the issues identified in this report and international best practices reviewed, a multipronged approach to address long-term quality and safety through the implementation of a Quality Assurance Framework (QAF) is suggested. The QAF aims to:

- Ensure market focus on developing quality systems and not solely on low upfront cost systems
- Enhance and improve customer understanding of the need for quality and safety in RTPV
- Facilitate the design, development, and deployment of standardized systems and products in the Indian RTPV market
- Facilitate the development and adoption of industry-wide best practices for the design, procurement, installation, and maintenance of RTPV systems
- Provide resources (information, tools) to help system owners and asset managers plan an effective O&M program, estimate a budget for on-going O&M requirements, and effectively monitor performance and take action based on monitoring results.

The QAF focuses on three main components (Figure 4):

- **Module Quality Assurance Program:** This process would focus on the components and help ensure module quality. It would also help small-capacity and dispersed systems to adhere to certain standards. It could be implemented by a Module Quality Certification Agency (to be established).
- **Electrical Safety Quality Assurance Program:** This process would certify for safety during the design phase by ensuring adequate site access, provide design certification during the component stage, and help ensure adequate electrical and lightning protection during the installation phase. Distribution utilities and Electrical Inspectors could play a role in ensuring that all safety standards for the RTPV system were followed.
- **Vendor Rating Framework:** Implementing a VRF may help evaluate the quality of work undertaken by EPC companies and installers. The ratings from this framework would allow the consumer, investor, or developer to identify the best providers and their capacity to install quality RTPV systems. This would require establishing a Vendor Rating Agency (VRA) to oversee the implementation of this process.

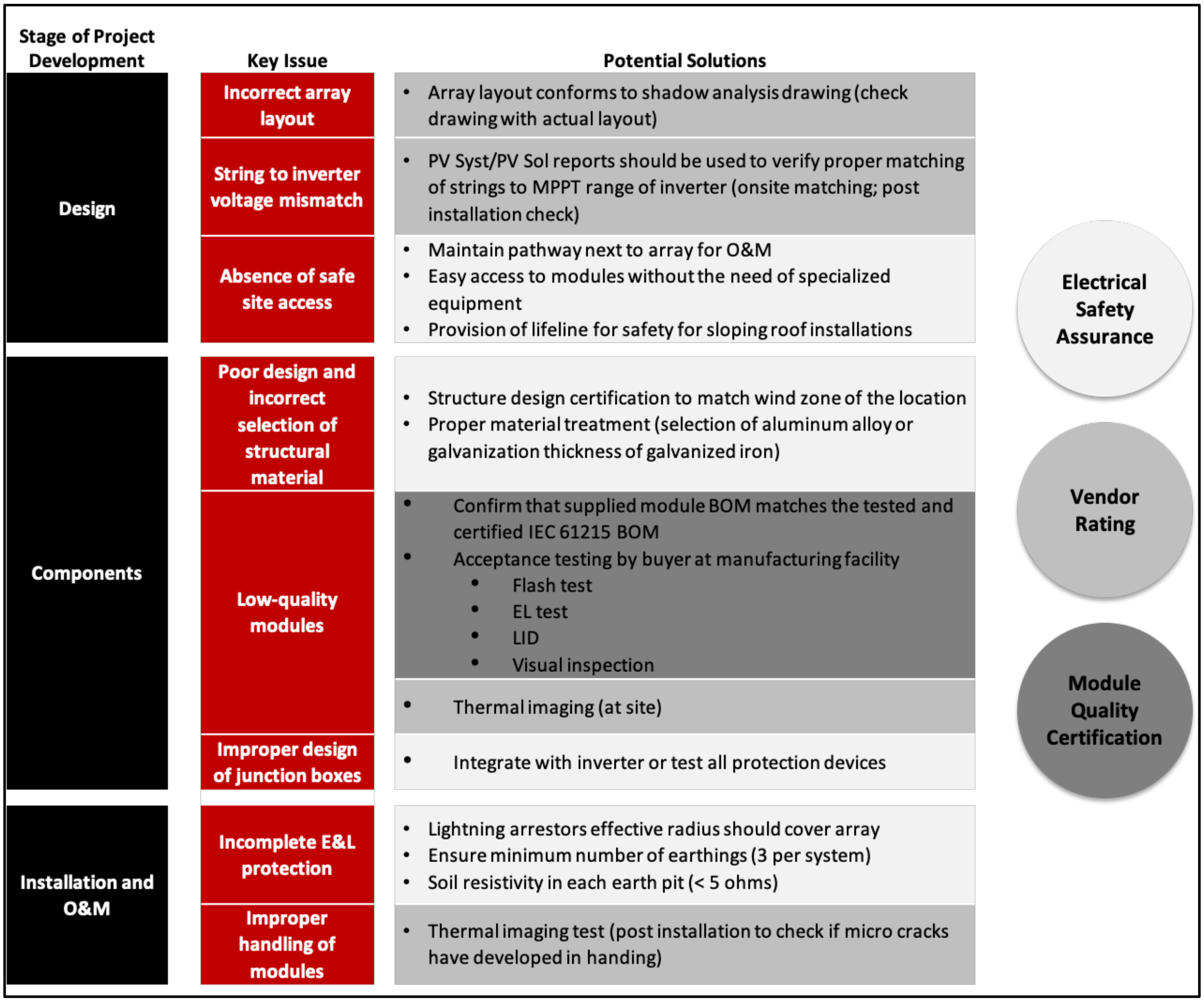

Figure 4. Key quality and safety issues, and potential solutions.

Each component is described in the following sections, with particular emphasis on the VRF because stakeholders identified this concept as useful and easier to implement in the short term. At this initial stage, it is proposed that separate agencies manage each of these components until a VRF has been established and attained scale. Once established, and as the market matures, all three components could be implemented by a single agency—the VRA—which could act as a central authority addressing quality-related issues in the long term.

There are unique opportunities and constraints related to the design and implementation of the three components discussed below (Figure 5).

	Vendor Rating System	Quality/Safety Assurance through Discom	Module Quality Assurance
Opportunities	▪ Ability to rate components, design, and workmanship ▪ Comprehensive assessment ▪ Trained manpower ▪ Appropriate instruments ▪ Detailed analysis of each site	▪ Comprehensive coverage as all sites visited ▪ Deep understanding and concern about safety issues ▪ Lowest transaction cost ▪ Concurrent monitoring	▪ Brings economies of scale ▪ Lower transaction costs and low cost of quality assurance ▪ Specialized agency for purchasing key components
Challenges	▪ Can be undertaken on sample basis ▪ Will be costly–need a business model ▪ Ex-post and not ex-ante ▪ Need to simplify rating system for consumers	▪ System quality of limited interest for utility ▪ Limited capacity of utility personnel ▪ High bandwidth requirements from utility personnel	▪ Limited to components (and only to modules) ▪ No input on system design and installation ▪ No mandate and no institution currently working on this aspect

Figure 5. Opportunities and constraints for recommended solutions to quality and safety issues in India's RTPV systems.

5.1.1 Module Quality Assurance

Modules, which still make up almost half of the total cost of the project in India, need to meet basic quality standards for each project. Although several global standards and design qualification tests (e.g., IEC 61215, IEC 61730, and IEC 62804) have been developed to ensure the safe operation, service life, reliability, and durability of PV modules, these standards alone have not been adequate in ensuring that modules conform to these standards in India. Most manufacturers get a few of their modules tested for these design standard certifications. However, modules being produced on each run do not necessarily conform to the same requirements as outlined in the tests. The only way to ensure that the modules conform to these requirements is through a set of tests on a random sample of the modules produced as a part of the production run, making it important to address module quality issues at the manufacturing facility or as close to it as possible.

While subjecting each production run to these rigorous module quality tests makes sense from a quality perspective, this type of testing is not available for small developers and EPC companies that purchase modules in small quantities from module producers. Large buyers often have their own staff or engage a third-party quality assurance company at production centers to ensure quality because of their purchase volume. However, the transaction costs are too high for small RTPV developers, and most module manufacturers will not allow these developers to run these tests.

Module quality issues could be addressed through:

- **Third-party testing and aggregated procurement in the short term:** Aggregating and procuring modules through larger distributors will help support testing module quality at the production site at a lower cost. This would involve EPC companies and developers, especially small vendors procuring modules through a single entity. This would result in better purchasing power and economies of scale at the module manufacturer's end as well as result in lower transaction costs for testing.

  The first step is to develop a strategy for aggregating module procurement. Costs of implementing module quality testing (MQT) will remain relatively high unless the modules to be tested are aggregated. This step will include developing a demand aggregation strategy to pool demand from solar PV rooftop module developers and EPC companies. It will also include identifying the mechanisms by which this will be undertaken, including how costs and results can be shared. A second step is creating a module procurement aggregator. This step includes identifying an agency to coordinate aggregation of orders from the RTPV industry in India. Aggregation at an agency level will lead to a number of downstream benefits:

  - Economies of scale for procuring modules
  - Bargaining power with module manufacturers
  - Improved quality control
  - Lower cost of module quality testing.

- **Mandating module quality testing by the distribution utility over the medium term*:*** Module quality testing can also be mandated by discoms and can be implemented using a third-party testing and validation agency. This agency would provide certification for specific lots of modules produced that would be checked by the discom at the time of commissioning. However, costs of testing will remain high unless conducted in large batches. Discoms would be a suitable agency to implement this at the initial stage because they are the only government agency that visits each solar rooftop project site. This would allow testing and certification of modules before project development.

  Developing a module quality testing and certification protocol is a key step in this process. MQT is a standard process for most large developers who either have trained technical staff or hire the services of laboratories, such as Underwriters Laboratories (UL) and TÜV Rheinland (TÜV), to undertake MQT. Designing an MQT protocol would include putting a standardized process with requirements in place. It will outline the testing parameters that will be evaluated, the sampling methodology that will be used, and the manner in which the results will be provided and interpreted. The MQT will provide guidance to developers, EPC companies, and consumers on component quality used in manufacturing the modules, the quality acceptance tests performed on these modules, and the results of these tests, including details of how these tests were performed.

- **Rating of module quality as a part of the VRF over the long term*:*** Rating by an independent agency as part of the VRF would also allow developers, banks, and consumers to understand the quality of the modules from various module manufacturers. This would be done after commissioning and would be time-consuming because a huge amount of data would have to be collected, analyzed, and released. Implementing module quality certification might work more effectively once the market matures

Figure 6 shows how this framework can be implemented.

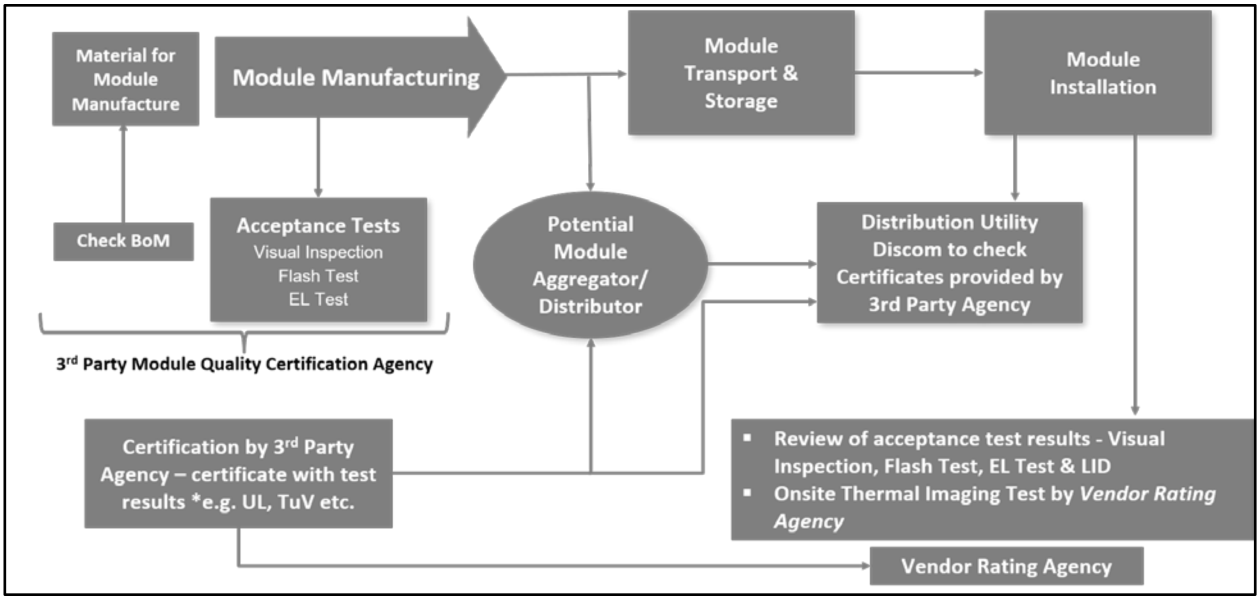

Figure 6. Implementation Framework for Module Quality Assurance

5.1.2 Safety Quality Assurance

Protection and safety are major concerns for utilities and, although time consuming, RTPV protection and safety issues should be addressed by the distribution utility during the commissioning process. Currently, safety checks are largely ignored, and some safety features are not mandated. This is exacerbated by a lack of consumer awareness. Small RTPV projects are often not a priority for discom engineers in India, especially when site inspection and report generation are time consuming, and most engineers do not have access to tools and adequate training. Some state regulations mandate safety features that discoms must uphold (e.g., the Bangalore Electricity Supply Company (BESCOM) has interconnection process mandates and audit safety features, and Kerala CEI has published standardized single-line diagrams that include safety device specifications), but there is room for improvement.

Based on the major safety issues discussed in this report, utilities are the best stakeholders to ensure that junction boxes and electrical and lightning protections meet the required standards, that site access is adequate, and to provide design certification of structures. Figure 7 shows how this process can be facilitated.

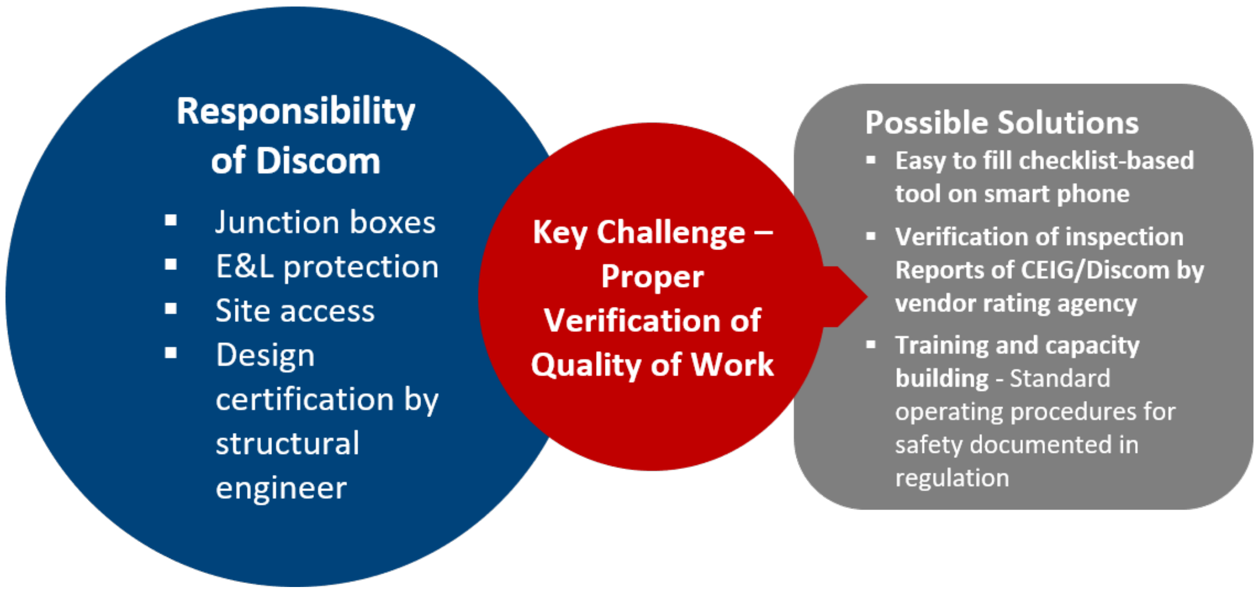

Figure 7. Recommended safety quality assurance process.

Note:the utility plays a major role in safety checks.

Utility personnel are often overburdened; it is important to provide the necessary tools and training to support this process and make it more efficient. There is a need for IT-based tools and applications that can be used to certify these requirements and generate reports, allowing utility personnel the speed and flexibility to capture all of these requirements online. This process would also ensure improved compliance with quality and safety standards prescribed in the regulations.

5.1.3 Vendor Rating Framework

There are currently no mechanisms in place to monitor, evaluate, and rate RTPV vendors in India. A VRF can help measure the quality of systems as well as ensure compliance of these systems to certain established standards. Vendor rating is a procedure whereby a VRA provides solar EPC companies and installers a score or ranking based on factors such as the quality of onsite work (design, components, installation) and the performance of their systems. A VRF can be used as a single point of reference for all stakeholders, including consumers, financial institutions, and developers, to identify top-quality vendors for future solar system installations, operations, and maintenance. As vendors (including EPC companies or installers) and suppliers are held responsible for component and installation quality using this framework, a VRF can provide an effective mechanism to link quality systems to market share by putting in place a procedure to evaluate, rate, and certify vendors based on their track records of designing, developing, and deploying systems. As such, an effective VRF may accelerate the adoption rate of RTPV by providing confidence to customers and discoms that reputed vendors sell high-quality solar products.

An effective VRF would identify all relevant criteria for assessing vendors. It would also provide vendors with information about their performance weaknesses so they can take corrective action. A VRF could provide continuous review of standards for vendors, thus supporting continuous improvement of vendor performance. The main types of vendor requirements would include:

- **Standard quality assurance (QA) plans of vendors:** consumers and the VRA should check the QA plan of vendors, which should include incoming material quality checks, in-process checks, quantitative methods of random testing, final system testing, and acceptable or passing levels.
- **Component procurement guidelines:** these would be a major component of the QA plan. Guidelines will confirm that materials and components used in the system comply with all certifications and confirm that these have gone through thorough and rigorous checks before deploying into the system.
- **Installation and commissioning checklists for inspection and sign off:** the vendor must conduct independent pre- and post-commissioning inspection checks, which would occur at varying levels of detail and technicalities. These checks and their results should be available to the consumers and the rating agency.
- **Design approach guidelines:** VRA should review the entire process of survey and design adopted by the vendor, the tools used by the vendor (for shadow-analysis, structure analysis, generation estimation, etc.), the vendor's approach for developing designs (e.g. string sizing, allowable shadow loss, etc.), and qualifications of vendor staff to conduct these jobs.

5.1.3.1 Benefits of a VRF by Stakeholder

A VRF will provide benefits for each of the stakeholder groups involved with solar PV in India:

- **Vendor Rating Agency:** To develop a comprehensive framework for ranking vendors and designing a business model to make this financially viable, a specialized agency with extensive experience in undertaking ratings across India must be identified. The VRA needs excellent working relationships with industry and experience in training and building capacity. The VRA would develop requirements for rating vendors on appropriate criteria in collaboration with the MNRE and discoms. Technical and research-focused organizations, such as the Confederation of Indian Industry, the Energy and Resources Institute, or Gujarat Energy Research and Management Institute (GERMI), could serve as the VRA.
- **Vendors:** For vendors that volunteer to participate, the VRF will assess their performance and identify their strengths and weaknesses, enabling them to make improvements. Vendors can also use this tool to benchmark quality.
- **Developers:** The VRF will help developers evaluate the performance of vendors, EPC companies, and installers, and identify high-quality vendors. It will provide a platform to access the performance of a specific vendor’s solar PV system in real-world conditions. The quality of construction may vary significantly from one EPC company to another. Hence, the reputation, track record, industry expertise, and bankability of the EPC contractor are critical when assessing the quality of a project. With this framework in place, developers can distinguish the best from the rest. Selection of top-ranked vendors will also provide better performance and workmanship guarantees. Developers operate within an environment of extreme pricing pressure brought on by a competitive-bid process. A VRF will provide developers the ability to make decisions based on quality, price, and vendor reputation.
- **Customers:** The VRF will ultimately enhance the quality of systems installed by customers. It will also promote awareness among customers about the risks of poor-quality solar installations, operations, and deployment, highlight those vendors that have been rated as providing higher-quality services and systems, and weed out low-quality vendors.
- **Investors/Financiers:** The VRF will help investors by providing preliminary assurance of the quality and capabilities of vendors whose systems are to be financed. This will provide financiers with the support needed to identify high-quality vendors and systems without expending much effort. Once the

rating system is mature, financiers may also devise a system where highly rated vendors receive some benefit in loan processing or interest rates.

5.1.3.2 Proposed VRF Operational Approach

This section outlines a potential approach to operating a VRF. Initially, the vendor rating mechanism would be voluntary for vendors—some vendors would see the benefit of ratings through increased sales. An eventual aim of a VRF is to make certification required for every RTPV vendor (EPC company or installer) using an NABCEP-like framework, in order to compete in the market.

The VRF would look at a vendor's systems and processes as well as sample installations to arrive at a rating. The rating would be time bound and restructured as requirements change. Sampling of systems will allow vendors to take action if issues arise and continuously improve ratings. The VRA would use the framework to establish an internal process and standardized terms and conditions for vendor assessment, adaptable for use by all Indian states. The VRF would also include guidelines for vendor empanelment, tendering, O&M, and after-sales support by vendors. It will create a stringent compliance and monitoring framework to evaluate the services provided by vendors on a regular basis and determine penalties, such as lowering a vendor's rating. Key parameters for rating vendors and evaluating their performance would fall into three categories

- Financial strength—vendor's sales trends and basic financial ratios as an indicator of growth and acceptance in the market by customers
- Technical capacity—assessed through documentation such as standard purchase/work orders, customer handover documents, design and engineering documents.
- Systems and processes—implementation of quality and safety would be reviewed through technical inspections of randomly selected actual system installations covering design, component, installation and O&M aspects. System performance and customer feedback would also be considered. Of the three categories listed here, reviewing a vendor's systems and processes would carry the highest weight.

Appendix C provides a schematic of key parameters on which vendors may be rated.

The process of developing, finalizing, and deploying a VRF will involve this sequence of activities (Figure 8):

1. **Develop a rating methodology and key parameters for rating vendors***:* Define the parameters based on which the vendors would be rated. These would focus on the technical and financial strength of the vendors, their systems and processes to manage and maintain quality, the quality of their manpower, and the quality of the installations developed by these vendors. A sample between 5% and 20% of all systems developed by a vendor would be surveyed based on the criteria and quality to be mapped and rated.
2. **Create an IT application to facilitate the vendor rating***:* The rating methodology and the parameters will be combined with an IT application that will provide a score once the rating has been undertaken.
3. **Identify a Vendor Rating Agency:** Identify the agency that will manage the VRF once it is developed. This would include piloting the process and rolling it out. This step would also include developing a business plan and capacity development plan for the agency as well as understanding the scope of services the agency can provide.

4. **Train rating agency/rating professionals:** Define the learning and training objectives for undertaking a vendor rating and create a training and certification program for the professionals who would rate these vendors.
5. **Market the VRF:** Define the usability of the VRF, including key benefits the VRF will provide to stakeholders. Be sure to include how the VRF will help raise customer awareness levels about the need for high-quality and safe solar PV systems in India.

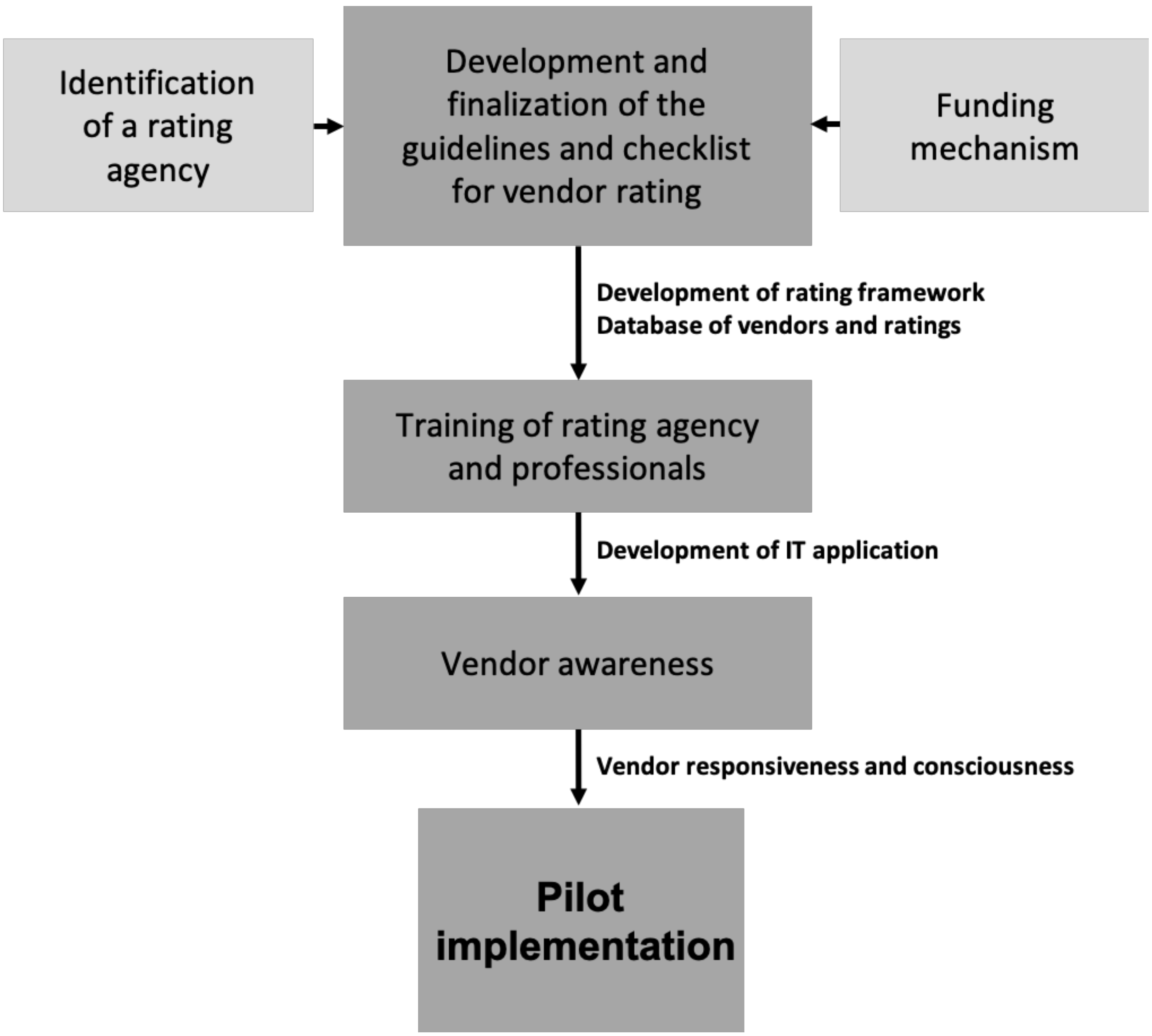

Figure 8. Process for developing and implementing a vendor rating framework

6 Next Steps

A multipronged quality assurance framework is outlined in this report that includes:

1. Module quality assurance through a Module Testing and Certification Agency
2. Electrical safety assurance through utility inspections
3. Quality of system design and implementation through a Vendor Rating Framework.

A detailed path forward for implementing a VRF is presented. Future work is needed to develop a plan for implementing other components of a quality assurance framework that include key institutions and their responsibilities, timelines, and other necessary resources. Ensuring electrical safety will depend heavily on utilities (discoms) that will have to confirm mandatory safety parameters for each system through inspections and sanctioning procedures. An app or similar online tool could help build discom engineer capacity to accomplish these tasks. Module quality assurance through testing and certification would require identification of inspection and certification bodies that would work in tandem with module aggregators, whereby costs of such a certification would be bearable even for small EPC companies and installers.

This prioritized approach is based on the input from Indian stakeholders as well as reports of earlier studies conducted on some sample site inspections. Given the increased involvement of different stakeholders suggested in this report, agencies may have to adapt to evolving roles and responsibilities in the Indian rooftop and distributed PV sector. In addition to the enhanced engagement with these stakeholders through deliberations and interactions, it will be useful if the USAID PACE-D 2.0 program familiarizes these stakeholders to the similar roles being played by agencies in other regions of the world. There may be numerous things to learn from experience elsewhere and this will contribute substantially to these agencies adopting roles in ensuring high-quality and safer PV systems in India.

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Appendix A – Referenced Published Reports

Studies in India on commissioned PV plants

- Pilot Study on Quality Aspects of PV Plants in India – Strengthening quality infrastructure for solar industry - India
- By PI Berlin, September 2017
- All India Survey of Photovoltaic Module Reliability: 2016
- NCPRE, IIT Bombay & NISE
- UL Engineering challenge 2015 – Team 1
- UL Engineering challenge 2015 – Team 2

Similar Studies in Non-Indian Regions

- 2018 Solar Industry Business and Technology Trends
- Solar Under Storm by Rocky Mountain Institute, October 2017
- Review of Failures of Photovoltaic ModulesBy Photovoltaic Power Systems Program, International Energy Agency 2014

Best Practices and Developers' Guides

- Best Practices Manual and Guide by USAID PACE-D TA and GERMI funded by MNRE
- Interconnection and Inspection of Grid Connected Rooftop Photovoltaic Systems – A Guide for Utility Grid Engineers by USAID PACE-D TA and SCGJ
- Greening the Roofs – A Guide for Solar Entrepreneurs by USAID PACE-D TA and SCGJ
- Evaluation of Solar Proposals – A Guide for Financial Institutions, Solar Developers and EPCs by USAID PACE-D TA and SCGJ
- Utility scale solar photovoltaic plants – a project developer's guide by IFC 2015
- SAPC Best Practices in PV System Installation by NREL, 2015
- Guidelines for GRPV – UL

Quality Component Report

- Module reliability scorecard by DNV GL 2018

Appendix B – MNRE Published List of Standards

Quality Certification, Standards, and Testing for Grid-Connected Rooftop Solar PV Systems / Power Plants

Quality certification and standards for grid-connected rooftop solar PV systems are essential for the successful implementation of this technology. It is also imperative to put in place an efficient and rigorous monitoring mechanism, adherence to these standards. Hence, all components of grid-connected rooftop solar PV system/ plant must conform to the relevant standards and certifications given below:

Table B1. Published List of Standards

Solar Module	
IEC 61215/ IS 14286	Design Qualification and Type Approval for Crystalline Silicon Terrestrial Photovoltaic (PV) Modules
IEC 61701	Salt Mist Corrosion Testing of Photovoltaic (PV) Modules
IEC 61853- Part 1/ IS 16170: Part 1	Photovoltaic (PV) module performance testing and energy rating: irradiance and temperature performance measurements, and power rating
IEC 62716	Photovoltaic (PV) Modules – Ammonia (NH3) Corrosion Testing (As per the site condition like dairies, toilets)
IEC 61730-1,2	Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements for Construction, Part 2: Requirements for Testing
IEC 62804	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation. IEC TS 62804-1: Part 1: Crystalline silicon (Mandatory for applications where the system voltage is >600 VDC and advisory for installations where the system voltage is < 600 VDC)
IEC 62759-1	Photovoltaic (PV) modules – Transportation testing, Part 1: transportation and shipping of module package units
Solar PV Inverters	
IEC 62109-1, IEC 62109-2	Safety of power converters for use in photovoltaic power systems – Part 1: General requirements, and Safety of power converters for use in photovoltaic power systems Part 2: Particular requirements for inverters. Safety compliance (Protection degree IP 65 for outdoor mounting, IP 54 for indoor mounting)
IEC/IS 61683 (as applicable)	Photovoltaic Systems – Power conditioners: Procedure for Measuring Efficiency (10%, 25%, 50%, 75% & 90-100% Loading Conditions)
BS EN 50530 (as applicable)	Overall efficiency of grid-connected photovoltaic inverters: this European Standard provides a procedure for the measurement of the accuracy of the maximum power point tracking (MPPT) of inverters, which are used in grid-connected photovoltaic systems. In that case the inverter energizes a low voltage grid of stable AC voltage and constant frequency. Both the static and dynamic MPPT efficiency is considered.
IEC 62116/ UL 1741/ IEEE 1547 (as applicable)	Utility-interconnected Photovoltaic Inverters - Test Procedure of Islanding Prevention Measures
IEC 60255-27	Measuring relays and protection equipment – Part 27: Product safety requirements

IEC 60068-2 (1, 2, 14, 27, 30 & 64)	Environmental Testing of PV System – Power Conditioners and Inverters a) IEC 60068-2-1: Environmental testing - Part 2-1: Tests - Test A: Cold b) IEC 60068-2-2: Environmental testing - Part 2-2: Tests - Test B: Dry heat c) IEC 60068-2-14: Environmental testing - Part 2-14: Tests - Test N: Change of temperature d) IEC 60068-2-27: Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock e) IEC 60068-2-30: Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle) f) IEC 60068-2-64: Environmental testing - Part 2-64: Tests - Test Fh: Vibration, broadband random and guidance
IEC 61000 – 2,3,5 (as applicable)	Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) testing of PV Inverters
Fuses	
IS/IEC 60947 (Part 1, 2 & 3), EN 50521	General safety requirements for connectors, switches, circuit breakers (AC/DC): a) Low-voltage Switchgear and Control-gear, Part 1: General rules b) Low-Voltage Switchgear and Control-gear, Part 2: Circuit Breakers c) Low-voltage switchgear and Control-gear, Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units d) EN 50521: Connectors for photovoltaic systems – Safety requirements and tests
IEC 60269-6	Low-voltage fuses - Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
Surge Arrestors	
IEC 62305-4	Lightening Protection Standard
IEC 60364-5-53/IS 15086-5 (SPD)	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control
IEC 61643- 11:2011	Low-voltage surge protective devices - Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods
Cables	
IEC 60227/IS 694, IEC 60502/IS 1554 (Part 1 & 2)/ IEC69947	General test and measuring method for PVC (Polyvinyl chloride) insulated cables (for working voltages up to and including 1100 V, and UV resistant for outdoor installation)
BS EN 50618	Electric cables for photovoltaic systems (BT(DE/NOT)258), mainly for DC Cables
Earthing /Lightning	
IEC 62561 Series (Chemical earthing)	IEC 62561-1: Lightning protection system components (LPSC) - Part 1: Requirements for connection components IEC 62561-2: Lightning protection system components (LPSC) - Part 2: Requirements for conductors and earth electrodes IEC 62561-7: Lightning protection system components (LPSC) - Part 7: Requirements for earthing enhancing compounds
Junction Boxes	
IEC 60529	Junction boxes and solar panel terminal boxes shall be of the thermo-plastic type with IP 65 protection for outdoor use, and IP 54 protection for indoor use
Energy Meter	

IS 16444 or as specified by the DISCOMs	A.C. Static direct connected watt-hour Smart Meter Class 1 and 2 — Specification (with Import & Export/Net energy measurements)
Solar PV Roof Mounting Structure	
IS 2062/IS 4759	Material for the structure mounting

Note: Equivalent standards may be used for different system components of the plants. In case of clarification the following person/agencies may be contacted.

- Ministry of New and Renewable Energy (Govt. of India)
- National Institute of Solar Energy
- The Energy & Resources Institute
- TÜV Rhineland
- UL (Underwriters Laboratory)

Appendix C – Schematic of Key Parameters for Vendor Rating Framework

Areas	Total Score	Grade 5	Grade 4	Grade 3	Grade 2	Grade 1
Financial Capability	20%	Above 17%	Above 14% and below 17%	Above 10% and below 15%	Above 5% and below 10%	Below 5%
Technical Capability	30%	Above 25%	Above 20% and below 25%	Above 15% and below 20%	Above 10% and below 15%	Below 10%
System and Process	50%	Above 45%	Above 36% and below 45%	Above 26% and below 36%	Above 15% and below 25%	Below 15%
Total	100%					

	Parameters	20%
Financial Capability	Debt Equity Ratio	4%
	Profit after Tax	4%
	Net Worth	4%
	Revenue / Turnover	4%
	Banker's Feedback	4%

	Parameters	30%
Technical Capability	Assets	3%
	Work experience of at least 3 years.	3%
	Experience in designing systems	3%
	Number of technical workforce	3%
	Number of certified	3%
	Certifications	3%
	Use of system related software	3%
	Number of Qualified Engineers	3%
	Experience in providing supply integration and installation, O&M and other services for atleast three years.	3%
	At least one project out of the aggregate 1 MW should have a capacity equal to or greater than 100 kW.	3%

	Parameters	50%
System and Process	Procurement policy of the firm	2%
	Quality checks as per standards and norms	2%
	Installation checks as per standards and norms	2%
	Consumer feedback	2%
	modules	2%
	Quality / certifications and gaurantee for inverters	2%
	Commissioning	2%
	Overvoltage protection	2%
	Lightning protection	2%
	Manufacturer guarantees	2%
	Minimal shadowing effect	2%
	Roof perforations in accordance with technical rules and standards	2%
	PV system / surge protection / protection against electrical shock	2%
	The wiring system was chosen and installed that it will withstand the expected external forces such as wind, ice, temperature and sun radiation	2%
	All electric circuits, protective devices, switches and connection terminals are labeled	2%
	A schematic circuit diagram displayed on site	2%
	A general overview displayed for emergency workers	2%
	All symbols and labels are suitably and permanently fastened	2%
	PV modules are, in accordance with manufacturer's guidelines, properly fastened and stable, and rooftop connection components are weather-resistant	2%
	Daily monitoring of the inverter - check operation display	2%
	Yield contract guarantee insurance	2%
	Cleaning of the modules twice a year during the contract period	2%

Appendix D – Summary List of Issues Analyzed by RTPV Project Development Stage

Table D1. Design, Component and Installation Related Quality and Safety Issues

Design Related Quality and Safety Issues	Frequency	Impact	Respondent (%)
Part or full shadow on the array throughout the year or some days of the year	H	H	60
Inclined array on super structure or on sloping roofs looks good but is difficult to clean and maintain and repair	H	M	75
Wrong enclosures of JB / SCB / DCDB / ACDB	H	H	70
Under specifications of protection devices like isolators, MCBs, MCCBs	H	H	60
Structure not able to withstand high wind pressure due to wrong material, loosely fixed members and modules, wrong design; not suitable for wind zone according to the standard	H	H	90
Provision of insufficient (or lack of) working space in form of walkways, railings, staircases, lifelines	H	H	60
Inadequate earthing provision	H	M	80
Over estimation of energy and emphasis on capital cost	H	H	70
Designing array without shadow considerations	H	H	75
String design exceeds MPPT voltage range of inverter	H	H	60
String mismatch	H	H	50

Component Related Quality and Safety Issues	Frequency	Impact	Respondent (%)
Mild steel used for structure - rusting (even with anti-rust paint)	H	H	70
Low-quality module mounting structures - design errors that result in an inability to withstand estimated dead load and wind pressure	H	H	90
Lack of due diligence to determine base roof strength and quality	H	H	70
Incomplete, ineffective, or nonexistent certifications	H	H	70
Galvanizing not uniform, not of required thickness; leading to corrosion	H	H	70
Low gap between ridge of the corrugated metal sheet roofing and module back surface; increase in module temperature	H	H	60
Too thin structure components (angles, tubes, squares, C or I section) resulting in warping and bending of structure	H	M	70
Structure Certificate not submitted; Certificate is incomplete; Certificate does not serve the purpose	H	M	70
Poor quality components (cells, EVA, back sheet, JB, etc.) used in module manufacturing	H	M	90
Missing module certificates (or invalid / mismatching)	H	M	70
Procurement of modules without due diligence and inspections	H	H	90

Installation and O&M Related Quality and Safety Issues	Frequency	Impact	Respondent (%)
Lack of inspection by qualified and experienced engineer leaves many areas for improvement that cannot be rectified later	H	H	90

Structure components, hardware and fixing to the roof	H	H	90
Walkways, railings, earth pits are not checked	H	M	90
CEIG / Discom inspection does not completely cover PV side aspects	H	M	70
Handling of modules prone to accidents and unseen module damage	H	M	60
Modules tightened at different torques producing stress on modules and exposing to damage under high wind conditions	H	M	70
In O&M, SPDs not periodically inspected to check if these have been sacrificed and need replacement	H	M	60

Appendix E – Complete List of Issues and Possible Corrective Actions

It is to be noted that in the field responses and observations, as EPC or installers are party to all the identified issues as well as best practices, the parties to take corrective actions do not include these two stakeholders. However, it is understood that all these actions are to be implemented by EPC and installers only. The party mentioned in the 'party to take corrective action' is over and above these two.

Table E1. Complete List of Issues and Possible Corrective Actions

CATEGORY	COMPONENT	Subcomponent	Issue Definition	Corrective Action Envisaged	Party to Take Corrective Action	
					Guidelines/Mandates	Checks/Inspection
PV Modules	Material	Cells	Cells not selected through incoming material quality checks during manufacturing	QA plan of module manufacturer must be documented with buyer	Industry	Independent inspector
		Cells	Develop micro-cracks during manufacturing	EL testing report of each finished module must be taken with each purchased module	MNRE	Customer
		Cells	Damaged / chipped cells in the modules	Visual inspection of at least sample lot of consignment must be done by buyer	Industry	Customer
		Laminate	Wrong or lower quality EVA used in manufacturing	Bill of Material must be taken with each consignment along with internal laboratory EVA test report	Industry	Independent inspector
		Laminate	Expired material used in manufacturing	Bill of Material must be taken with each consignment along with internal laboratory EVA test report	Industry	Independent inspector
		Back sheet	Wrong or lower quality back sheet	Bill of Material must be taken with each	Industry	Independent inspector

			used in manufacturing	consignment along with internal laboratory back sheet test report		
			Expired material used in manufacturing	Bill of Material must be taken with each consignment along with internal laboratory back sheet test report	Industry	Independent inspector
		Junction box	JB with wrong casing material	IEC certification BOM must be supplied	Industry	Independent inspector
	Transportation and on-site handling	Loose modules transportation	Modules packed without padding material and without properly designed movement-resisting container	Manufacturer must comply with IEC 62759 Part 1	Industry	Customer
		Loose modules transportation	Loose modules, unpacked from manufacturer's packing, stacked wrongly (horizontally) by supplier / dealer during transportation	Only vertically stacked and properly packed, with spacers in between, modules must be transported to the purchaser or site	Industry	Customer
		Loading and Unloading	Manual operations prone to accidents and damage to modules and persons	Material lifting equipment must be used for loading, unloading as well as lifting to the installation roof site	Industry	Customer
		Lifting modules to roof installation area	Single person carrying packed or unpacked module or two persons carrying stack of modules has high possibility of	Handling must be according to the manufacturer's manual and at least two persons must carry module, if done manually	Industry	Customer

			damage and warranty being void			
	Certificates	Invalid / Mismatching certificates	Different models supply than as listed in the certificate	Valid IEC certificates for the supplied module type / model to be submitted as part of the record	MNRE	Customer
		Invalid / Mismatching certificates	Expired time validity	Valid IEC certificates for the supplied module type / model to be submitted as part of the record	MNRE	Customer
		Invalid / Mismatching certificates	Different Bill of Material than certificate	IEC test report along with certificate must be supplied with the module type so that the BOM also can be verified	Industry	Independent inspector
	Installation of modules	Unlevelled surface or misaligned structure	Creates stress on modules	Alignment of structure as well as modules must be ensured in tandem with module manufacturer's installation manual	Industry	Customer
		Too low a tilt angle (less than 8 degrees)	Nearly horizontal installation makes surface drainage of water impossible	Minimum 8 degrees tilt must be mandatory for any array installation	Industry	Customer
		Tightening torque not maintained	Modules tightened at different torque produce stress on modules and also expose these to damage in high wind conditions	The proper tightening torque must be applied to each module according to the manufacturer's manual	Industry	Independent inspector
	Module cleaning method	Walking on modules for washing	O&M persons walking on modules	Proper walkways and pathways must be installed to avoid	Industry	Customer

				standing or walking on the modules		
		Only water sprays on module	Waste of water and only water does not always clean the modules thoroughly	Pressurized water along with manual (wipers) cleaning must be used	Industry	Customer
		Use of chemicals for washing	Corrosive chemicals react with glass surface and can also impact module frame	Only pure soft water or tested chemical must be used for module washing	Industry	Customer
		Hard brushes	Scratching of modules	Brushes used in module cleaning must be soft and made up of nylon bristles	Industry	Customer
		Time gap between washing and cleaning with wipers	Longer time between these two activities allows water to evaporate and dust again sticks to the glass	Cycle should be managed in such a way that module is wiped before it becomes dry	Industry	Customer
Module Mounting Structure	Material	Galvanized Iron (GI) not used	Rusting due to use of MS with anti-rust paint, which wears out over a (short) period	Use of HDG only	MNRE	Customer
	Material	GI used for structure	Galvanizing is not uniform, is not of required thickness and hence possibility of rusting	Galvanizing of 80 microns and uniform galvanizing	Industry	Independent inspector

	Material	GI used for structure	Structure members are worked upon after galvanizing, which leads to exposed non-galvanized area for corrosion	HDG only after all work and on finished members only	Industry	Customer
	Material	Aluminum structure	Wrong composition alloy used because many extruders use older scrap material	Aluminum extruder's certificate of product	MNRE	Independent inspector
	Material	Aluminum structure	Wrong grade of Aluminum may be used	Aluminum of minimum 6063 or better strength alloy must be used	MNRE	Independent inspector
	Material	Aluminum structure	Un-anodized aluminum used	All aluminum structure components must be anodized	MNRE	Customer
	Design	Supporting dead load of modules over the lifetime	Low thickness components or wrong choice of components may result in deformation or twisting or warping of structure	Minimum 2 mm HDG structure components must be used	Industry	Customer
	Design	Withstanding wind pressure	Structure may not withstand the high velocity winds due to wrong material, loosely fixed members and modules, wrong design. Designs may not be complying to IS 800 / 801 / 802;	Each design or its original base design must have design certificate of withstanding wind pressure according to wind zones of IS875; Anywhere minimum withstanding capacity must be 150 KMPH	MNRE	Independent inspector

			may not be suitable for particular wind zone according to the standard			
	Design	Easy replacement	Structure is not modular in nature and hence any repairs or replacement of structure component or module requires higher downtime of system in addition to higher cost	Design must show easy replacement modularity of module as well any structure component or part thereof	Industry	Customer
	Material	Combination of galvanizing process and material thickness	120 microns uniform galvanizing is possible only if thickness is higher than 5 mm; Structure of minimum 2 mm thickness should be compulsory with 80 microns galvanizing; even 3 mm thick GI is also too high for most of the structures, unless it is super structure	Minimum 2 mm thickness of GI structure component with hot dipped galvanizing of 80 microns	MNRE	Independent inspector
	Fasteners	Fasteners	Fasteners are not SS304, any other material exposed to environment immediately rusts and fasteners become lose	All fasteners must be SS 304 grade only	MNRE	Independent inspector

	Anchoring	Anchoring on sloping roofs	Pastes, Glues or Solutions used in non-penetrating methods may weaken due to atmospheric exposure	In case pasting solution is opted for fixing structure to the roof, it must be with specially produced glue or paste or solution and manufacturer must have had aging tests performed, which must be submitted	Industry	Customer
	Anchoring	Anchoring on sloping roofs	Less distance between ridge of the corrugated metal sheet roofing and module back surface	Minimum distance between ridge of corrugated type roof and bottom of module must be 100 mm	Industry	Customer
	Anchoring	Anchoring on sloping roofs	Provision of insufficient (or nil) working space in form of walkways, railings, staircases, lifelines, etc.	Design must incorporate walkways after every 2 rows of modules in portrait type and 4 rows of landscape type installation	Industry	Independent inspector
	Anchoring	Anchoring on sloping roofs	Water leakage tests before and after installation and water proofing if necessary	Water leakage test pre installation of structure and post installation of PV array must be carried out with both parties signing the report	Industry	Customer
	Anchoring	Anchoring on flat RCC roofs	unsuitable method for old age terraces and different types of waterproofed surfaces	In case even chipping is not allowed on the flat terrace, the foundation / grouting designed must be wide enough to anchor the structure legs properly to the surface	Industry	Independent inspector

	Super Structure	Super (raised) structure	Raised to 4 M height with direct module fitting with silicon sealing between modules may wear out over the period thereby water leaking through the array area	If raised structure with only PV array installation is decided, the design must have proper water drainage above and between modules and also the sealant must be replied periodically depending on the type used	Industry	Independent inspector
	Super Structure	Super (raised) structure	Raised to 4 M height with tin sheets and modules fixed above many a time does not have O&M access and areas	Any raised structure also must have walkways as stated earlier and also a permanent type staircase / fixed ladder for easy approach during O&M	Industry	Independent inspector
	Module mounting	Fixing modules on structure	Wrong nut-bolts / clamps / brackets may cast shadow on part of module surface	Clamp wherever used, must be at least 3 mm thick, must have minimum 5 mm overlap with the module and the length covered on each module must be at least 40 mm	MNRE	Customer
	Module mounting	Fixing modules on structure	Drilling new holes in module frame for fixing nut-bolts	Module manufacturer's installation manual must be strictly followed. No new drilling is permitted on the module frame	Industry	Customer
	Module mounting	Fixing modules on structure	Not using washers / non-reactive separators between different metal of structure members / module frame	As there are more than one metal type involved in rooftop installation, proper use of washers or separators that are non-reactive to the metals must be mandatory	Industry	Customer

	Module mounting	Fixing modules on structure	Wrong assumption that any design of clamp / bracket provides conductivity between modules and structures and therefore not doing actual earthing for modules	Earthing between modules must be carried out with specially designed clamps or nut bolts or directly using the provided earthing holes on the frame	Industry	Independent inspector
	Module mounting	Fixing modules on structure	Not following module manufacturer's installation manual	Module manufacturer's installation manual must be strictly followed.	MNRE	Independent inspector
	Base Roof	Base roof strength certification	Roof itself may be weak and may collapse due to new load over time period	For a building older than 10 years or where there exists doubt about the strength of the building or where there is a sheet metal roof with an underlying structure, a base roof strength certificate of withstanding the additional loads created due to module installation, with respect to dead load, wind load / uplift, etc. must be mandatory by qualified structural engineer or chartered engineer	Industry	Independent inspector
	Certification	Testing and Certification	Certificate not submitted; Certificate is incomplete; Certificate does not serve the purpose	All certificates mentioned in the procedure must be shared with the customer and this must be maintained as record	MNRE	Independent inspector

System design	String design	String voltage beyond the inverter MPPT range or border cases where at different temperatures voltage may go beyond MPPT range	Low efficiency functioning of inverter	Number of modules should be decided as per inverter highest efficiency voltage at particular temperature and design document should be available for approval	Industry	Independent inspector
		Unbalanced strings to an inverter that does not allow unbalanced inputs	Lower generation by inverter due to imbalance	String design document and matching with inverter should be available for checking	Industry	Independent inspector
		Strings not matching structure table design thereby requiring jumping string cable between tables	Higher losses in cables and effect on full string; possibility of loosening of connectors	Structure should be designed after electrical stringing is decided based on inverter and module selection	Industry	Independent inspector
	Array layout	Array layout design ignoring shadows during the year	Loss of generation and long-term effect of hotspots and degradation	Full year shadow analysis must be carried out and document must be available and shared	Industry	Independent inspector
		Modules of different orientation and / or tilt angles connected on same MPPT	Overall energy output would be as low as lowest generating modules	System design document must be available, and must clearly show that design has considered differently oriented and tilted modules or include a justification and estimated energy loss if this cannot be avoided	Industry	Independent inspector
		Design not accounting for easy access to array and maintenance	This demotivates O&M personnel from carrying out necessary preventive and	Proper access from existing entry point in building must be designed and permanent	MNRE	Customer

		movements over lifetime	corrective maintenance	access must be provided as part of the system		
		Inclined array on super structure aesthetically good looking but difficult to clean and maintain and repair	Modules at edge may not be cleaned properly and may be very difficult to replace when necessary	Access to raised structure with safe passages and ladders must be provided and approved by customer and O&M persons	Industry	Customer
	Combiner boxes	Wrong enclosures of JB / SCB / DCDB / ACDB	Possibility of fire spread	Fire retardant material according to IEC standard only must be used	Industry	Independent inspector
		Too tightly packed boxes	The protection devices would work at very high temperature and hence possibility of damages	Proper design with enough breathing space to be left in the boxes	Industry	Independent inspector
		Wrong choice of protection devices like isolators, MCBs, MCCBs	Improperly rated (higher or lower) devices may not offer required protection in case of faults	Protection devices like must be designed with proper safety factor based on conductor current	SERC / Discom	Independent inspector
	Inverter fixing	Inverter fixed on wooden or plywood or any such material	Fire spread would be quick on this material	Inverter must be installed on fire resistant material	MNRE	Customer
		Inverter fixed without enough space for ventilation or access for fan repairs	Temperature rise in the inverter would reduce efficiency and lower the life of components	Inverter manufacturer's instructions must be followed	MNRE	Customer

Inspections	During installation	Lack of inspection by qualified and experienced engineer leaves many areas for improvement that cannot be rectified later	System performance not tested and hence customer may be at loss; plus, safety may be compromised	Inspection by customer	MNRE	Customer
	During installation	Module inspection is not done on arrival before fitting	Micro cracks, visible faults like chipped cells, corrosion of module frame or damaged shape of module is not noticed	Inspection by developer/customer for installer's work and incoming material	MNRE	Developer / Customer
	During installation	Structure components, hardware and fixing to the roof	Corrosion, wear and tear may lead to loosening of structure and possibility of accidents	Inspect for material, workmanship, and methods	Industry	Developer / Customer
	During installation	Cables and their conduits and routing are not checked	Routing and fixing of cables to walls and floors can be faulty and not as per design or pre-accepted norms	Inspection by customer	Industry	Customer
	During installation	Walkways, railings, earth pits are not checked	Very difficult to change the pay-out post-installation and the mistake remains for lifetime thereby increasing accidents possibility	Inspection by customer and O&M contractor	MNRE	Customer

	During installation	Safety precautions and use of personal protection equipment (PPE) by installer are not checked	Unsafe work and high possibility of accident	Inspection by developer for installer's work	Industry	Developer / Customer
	Post-installation	Tests are not performed by inspector - self checks are not sufficient -	System performance not tested and hence customer may be at loss	Doer - Checker _ Approver chain needs to be established	Industry	Developer / Customer
	Post-installation	Electrical Inspectorate inspection not for all system capacities	Safety may be compromised	Training to CEIG for overall system safety and operation	CEIG	CEIG
	Post-installation	Electrical Inspectorate inspection does not completely cover PV side aspects	System performance not tested and hence customer may be at loss	Inspection needs to be done by independent inspector for overall system safety and operation	CEIG	CEIG
	For Synchronization	Discom engineer inspection many a time does not cover all aspects	Safety risk to the system and to the building assets	Training to Discom engineers for complete checking	Discom	Discom
	During O&M	Surge Protection Devices (SPDs) utilized and burned	Safety may be compromised	Inspection by customer	Industry	Customer
Documentation and Communication	Offer stage communication with customer	Over estimation of energy	Dissatisfied customer due to lower than promised generation	Standardized offer document with energy estimates and variable that may affect generation	Industry	Customer

	Offer stage communication with customer	Wrong promise of timelines	Time over run leading to dissatisfaction and delayed payments	Correct timeline projection for different types and capacities of systems	Industry	Customer
	Offer stage communication with customer	Over emphasis on capital cost	Lack of focus on quality and safety of system, customers not reporting low generation or complete stoppage of system	Awareness campaign for potential customers	MNRE	Industry
	Offer stage communication with customer	ignoring O&M role of customer	Wrong notion of fit-it-forget-it! Customers not cleaning modules	Standardized offer document with complete O&M requirements	Industry	Customer
	Reports of Inspections	Conformity to design and drawings is not established	Customer comes to know about an issue only after something gone wrong	Customer and EPC sign off on set of documents including diagrams, design documents, certificates and so on	Industry	Customer
	Warranty certificates of components	Customer comes to know that he had received nil or wrong document as warranty certificate	No warranty claims entertained	Warranty certificates of different components samples provided in awareness campaign	Industry	Customer
	SLDs or 'as is drawings'	Absence of these drawings makes O&M and repairs difficult for different agency	Difficulty for O&M person attending to the system after a time gap when installers are not traceable	Customer and EPC sign off on set of documents including diagrams, design documents, certificates and so on	Industry	Customer
Signages and Markings	Component markings and signages	Absence of signages and markings	O&M persons, different than installers, find it difficult to understand all	Signages made standard and mandatory	SERC	Discom

			components and specifications			
	Component markings and signages	Low quality stickers - peeling off or fading over time	Difficulty in identification and understanding of technical specifications	Signages made standard and mandatory	SERC	Discom
	Markings	Absence of ferrules	Cable replacement or testing and checking becomes difficult	Cable management standards made public	Industry	Customer
Cables	DC cables	Wrong type of cables	Early wear and tear of cables due to exposure and temperature	Cable specifications and certificates made mandatory and checked	SERC	Independent inspector
	DC cables	Wrong size (thickness) of cables	Heavy losses over the system and that too increasing over years due to degradation	Cable specifications and certificates made mandatory and checked	Industry	Independent inspector
	Cable routing	Longer routes than optimal	Heavy losses over the system	Correct cable routing principles	Industry	Customer
	Cable routing	Cables obstructing water flow (drainage) on the terrace or roof	Waterlogging due to obstructions leading to damage to cables and joints	Correct cable routing principles	Industry	Customer
	Cable routing	Restricts movement of persons for O&M	Possibility of accidents and avoidance from persons in going to some areas of the plant	Correct cable routing principles	Industry	Customer

	Cable fixing	Fixing at roof level without spacers	Waterlogging due to obstructions leading to damage to cables and joints	Cable fixing methods and principles document	Industry	Customer
	Cable fixing	Fixing at walls and parapets with loose fittings	Cables disengaging from walls and hanging cables, Stress on joints	Cable fixing methods and principles document	Industry	Customer
	Cable joints	Wrong selection of connectors – so called 'compatible'!	Loosening of connections, short circuit or sparks	Clear guidelines for types of cable jointings; mandating only one make and model of connectors to be used in the plant same to the ones used in the module	MNRE	Independent inspector
	Cable joints	Nil or wrong crimping of cable ends	Cable disengaging from joints, short circuit or sparks	Mandatory use of crimping tool and guideline for cable jointings	MNRE	Independent inspector
	Cable enclosures	PVC pipes or other wrong material of casing	Wear and tear of casing thereby exposing cables to atmosphere	Standards for cable casings	Industry	Customer
Protections	Surge protection devices	Wrong election of type of SPD	No real protection from surges in voltage	Clear guidelines for use of type of SPD	SERC	Independent inspector
	Surge protection devices	SPDs are not periodically inspected to check if these have been sacrificed due to a fault and if these need replacement	Protection is absent after one use of SPD	Procedure of periodical checking of SPDs	Discom	Discom

	Over current protection devices	Not used on individual string or none at all on DC side	Very unsafe DC side of the system and any fault can cause fire, damage	Regulations and guidelines must include clear mention of OCP devises	SERC	Discom
	Isolators	Periodical testing of operation not carried out	May not work (really isolate) when needed most	Procedural guidelines within Discom for periodic checklists	SERC	Discom
	Anti-Islanding protection of inverter	No periodic testing	A fault may develop, and inverter protection can malfunction	Procedural guidelines within Discom for periodic checklists	SERC	Discom
Lightning protection system	Inadequate coverage area of lightning arrestor	Use of small size LA or right LA installed at lower height	May not cover the entire array area and hence no protection against lightning in that part	LPS design to be standardized and information made available	SERC	Discom
	Conductor fixing touching the building surfaces	Fault may connect with building or part of it and may not provide path to ground / earth	In case of actual lightning the equipment and assets may get damaged	Correct way of fixing conductor from LA to earth pit must form part of guidelines	Industry	Customer
Earthing	Provision	Inadequate earthing provision	In actual fault conditions equipment or assets may get damaged	Clear guidelines for number and type of earthing	SERC	Discom
	Testing	No testing of earthing after installation	Earthing may not be the lowest resistive path to fault current	Clear guidelines for number and type of earthing	SERC	Discom
	Testing	No periodic testing	Earth resistance may be higher and so the fault may not be grounded	Procedural guidelines within Discom for periodic checklists	SERC	Discom

System installation	Shadow	Part or full shadow on the array throughout the year or some days of the year	Lower generation and long-term effect on module degradation or cell burning	Shadow analysis document must be part of the communication between customer and EPC	Industry	-
	Inverter installation	Fixing method	Accident prone installation and difficulty in maintenance	Follow inverter manufacturer's manual	Industry	Customer
	Inverter installation	Enclosure	Higher temperature thereby degrading inverter performance	Well ventilated but protective housing or enclosure suitable to site condition	Industry	Customer
	Inverter installation	Settings on site	Electrical settings on site that do not comply with CEA regulations	Settings guidelines for inverter models	Industry	Discom
Operation & maintenance	cleaning of modules	water quality	Hard water forms depositions on module glass	Only soft water to be used; if not available, softener must be installed and maintained	Industry	Customer
		water quality	Hard water affects module frame	Only soft water to be used; if not available, softener must be installed and maintained	Industry	Customer
		time of cleaning	Cleaning with water during high temperature of glass during daytime may crack the glass	O&M guidelines must include module cleaning methodology	Industry	Customer
		Frequency of cleaning	Low frequency of cleaning leads to low generation and also burning of cells	O&M guidelines must include module cleaning methodology	Industry	Customer

		Method of cleaning	Use of excessive water - wastage of precious water	O&M guidelines must include module cleaning methodology	Industry	Customer
		Method of cleaning	Wrong material may form scratches on glass	O&M guidelines must include module cleaning methodology	Industry	Customer

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This work was authored, in part, by the National Renewable Energy Laboratory (NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the United States Agency for International Development (USAID) under Contract No. IAG-17-2050. The views expressed in this report do not necessarily represent the views of the DOE or the U.S. Government, or any agency thereof, including USAID.

NREL/SR-7A40-74833 | July 2020
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