# Ensuring Compliance in the Installation of Residential Photovoltaic Systems: A Study of Standards and Practices in Finland

Juho Ylipaino, Kari Kallioharju, Aki Kortetmäki
Faculty of Built Environment and Bioeconomy
Tampere University of Applied Sciences
Tampere, Finland

Marko Ylinen
Faculty of Technology
Satakunta University of Applied Sciences
Pori, Finland

Juha Koskela
Faculty of Information Technology and Communication Sciences
Tampere University
Tampere, Finland

***Abstract*— The increasing adoption of residential photovoltaic (PV) systems in Finland has brought significant challenges in ensuring compliance with safety and quality standards. This paper investigates the practices of PV system installers, assessing their adherence to the SFS 6000 standard series and SFS-EN 62446-1 standard, which are harmonized with European (CENELEC) and international (IEC) standards. A detailed survey of 27 certified solar installers highlights critical gaps in commissioning inspections, documentation, and interpretations of the standards, raising concerns about installation safety and reliability. The study proposes actionable recommendations, including enhanced training, clearer documentation, and updates to regulatory guidelines, to improve compliance and promote consistent practices. These measures are essential to support Finland's sustainable energy transition and ensure safe PV installations in a rapidly growing market.**

***Index Terms* -- Photovoltaic systems, Compliance, Standards, Installation practices, Safety and quality.**

## I. INTRODUCTION

The adoption of small-scale photovoltaic (PV) systems has grown rapidly in Finland, driven by rising electricity prices and increasing interest in renewable energy. This surge in demand has attracted numerous new companies and installers to the market, some of which lack the necessary expertise to ensure the safety and quality of their installations.

All electrical installations in Finland, including PV systems, must comply with the Finnish Electrical Safety Act [1]. To ensure compliance with the Act, the electrical safety authority publishes a mandatory list of standards, known as *Luettelo S10* [2]. Adhering to these standards ensures that all requirements of the Act are fulfilled. Among the mandatory standards for PV system installations is the SFS 6000 standard series, which regulates electrical installations up to 1000 VAC and 1500 VDC [3]. These standards are derived from the European harmonization document CENELEC HD 60364 and the international IEC 60364 standards. In January 2023, the Finnish Safety and Chemicals Agency (Tukes) updated the mandatory standards list to include the SFS-EN 62446-1:2016 + A1:2018 standard [2]. This standard, the Finnish national adoption of the European standard EN 62446-1:2016, harmonized with the international IEC 62446-1:2016, governs documentation and commissioning tests for PV systems [4]. This inclusion mandates compliance with the standard for PV system installations in Finland, as per the Finnish Electrical Safety Act. The SFS-EN 62446-1 standard outlines requirements for documentation, commissioning tests, and inspections of grid-connected PV systems, ensuring consistent safety practices and regulatory adherence across the country.

Despite clear standards in place, the rapid expansion of the solar market in Finland has revealed several critical issues. Tukes has reported numerous complaints, particularly concerning poor installation practices, non-compliance with commissioning inspection requirements, and insufficient documentation [5]. The accelerated growth of PV installations has introduced significant safety concerns worldwide, with studies pointing to fire risks caused by faulty installations [6], [7]. However, these challenges are often exacerbated in rapidly expanding markets, where new companies frequently lack experience or knowledge of compliance requirements or basic knowledge of the systems [8].

This study investigates practices, compliance, and challenges related to PV installation standards in Finland. Specifically, it examines, via a comprehensive online survey, how well PV installers understand and adhere to the requirements of the SFS 6000 standard series and the SFS-EN 62446-1 standard. It also explores common gaps in documentation, commissioning inspections, and installation practices, as well as potential measures to improve compliance, including enhanced training and clearer regulatory guidance. By identifying critical areas for improvement, the study aims to enhance the safety and reliability of small-scale PV systems, ensuring they meet the required standards for safe operation. To provide structure, the methodology section details the survey

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design and data collection process. The results section presents key findings on compliance challenges, followed by a discussion of their implications. Finally, the conclusion outlines actionable recommendations and directions for future research.

## II. METHODOLOGY

This study employed a survey to investigate the compliance practices of PV system installers in Finland. The survey aimed to assess how well PV installers understand and adhere to the requirements of the Finnish Electrical Safety Act, SFS 6000 standards series and SFS-EN 62446-1 standard and to identify gaps in documentation, commissioning inspections, and installation practices.

### A. Survey Design

The survey was structured with over 80 questions divided into 17 sections each focusing on different aspects of PV installations, such as standards compliance, electrical network integration, commissioning inspections, and system documentation (Table I). The questions were designed to align closely with the requirements set forth in the SFS 6000 and SFS-EN 62446-1 standards to ensure an accurate assessment of compliance.

TABLE I. THE SURVEY STRUCTURE

| Section | Theme | Focus Area | Questions |
|---|---|---|---|
| 1. | General Information | General information of respondant and PV system installations | 3 |
| 2. | Standards Compliance | Familiarity with and adherence to PV standards | 3 |
| 3. | Electrical Networks | Integration with property's electrical systems | 6 |
| 4. | System Design | Design and sizing of PV systems | 9 |
| 5. | Inverter Installation | Installation practices for inverters | 2 |
| 6. | Cabling and Conduits | DC-side cabling and conduit installations | 6 |
| 7. | Equipotential Bonding | PV systems equipotential bonding practises and adherence to standards | 6 |
| 8. | Overcurrent Protection (DC) | Use of overcurrent protection in DC circuits | 3 |
| 9. | Surge Protection | AC and DC surge protection practices | 3 |
| 10. | Isolation and Switching | Implementation of isolation switches | 3 |
| 11. | Commissioning Inspection | Comissioning inspection practices and adherence to binding regulatory | 10 |
| 12. | Fire Safety | Installation practices in fire-hazard environments | 5 |
| 13. | Island Mode Operation | PV systems with backup or off-grid capabilities | 5 |
| 14. | Documentation | Compliance with documentation requirements | 1 |
| 15. | Maintenance | Recommended maintenance procedures | 6 |
| 16. | Regulatory Compliance | Adherence to DSO's and authorities guidelines | 4 |
| 17. | Open Feedback | Suggestions for improving regulations and standards or need of guidance | 7 |

Each section of the survey targeted specific elements of the installation process, from system design and cabling to overcurrent protection, equipotential bonding, documentation and commissioning inspections. Questions were both quantitative and qualitative, allowing respondents to provide detailed feedback on their practices and interpretations of regulatory standards.

### B. Participants

The survey was distributed to 74 certified PV system installers listed by Motiva, a Finnish sustainable development organization. A total of 51 responses were received. Of those, 27 installers actively involved in small-scale PV system installations (with system sizes under 50 kW) fully completed the survey. From this point forward, the term "respondents" refers to this group of 27 PV installers. The survey achieved a response rate of approximately 68.9%, with 51 responses out of 74 distributed surveys. Of these, 27 responses came from companies actively involved in small-scale PV system installations, resulting in a final response rate of approximately 36.5%.

### C. Data Collection

The survey was conducted anonymously to encourage honest and accurate responses. Questions were framed to capture both compliance levels and the challenges faced by installers in interpreting and applying the standards. Participants were asked to provide information on their commissioning inspection processes, the availability of required documentation, and their adherence to safety requirements for electrical installations.

Responses were collected and analyzed to identify patterns and deviations in compliance. Particular attention was given to the sections on commissioning inspections and system documentation, as these were identified as critical for ensuring safe and reliable PV installations.

## III. RESULTS

The survey results provide a comprehensive view of the practices, compliance, and challenges faced by small-scale PV system installers in Finland. Responses from 27 respondents, actively involved in small-scale PV system installations, reveal significant variability in adherence to standards, commissioning inspections, and system documentation.

This section presents the key findings of the survey, focusing on three areas: standards compliance and design practices, commissioning inspections, and system documentation.

### A. Standards Compliance and Design Practices

A majority of respondents (96%) reported using Finnish standards, such as SFS 6000 and SFS-EN 62446-1, for PV system design, installation, and commissioning. Additionally, 66.7% relied on supplementary guidelines. However, 44.4% of respondents found these standards unclear or challenging to apply, highlighting a need for improved guidance and training. Awareness of the mandatory standard list published by *Tukes*, which includes the 2023 update to the SFS-EN 62446-1 standard, was high, with 77.8% of respondents familiar with it.

although 18.4% of respondents were unaware of the update, and 7.4% were unaware of list exist.

System design practices showed considerable variability. For instance, 37% of respondents were unfamiliar with or did not apply correction factors for maximum open circuit voltage ($V_{OC,\,MAX}$) and short-circuit current ($I_{SC,\,MAX}$), which are critical for ensuring accurate system sizing under varying environmental conditions. Consequently, 30% of respondents sized inverters based solely on panel string power or deferred the decision to suppliers without considering these correction factors. In contrast, 48% followed manufacturer recommendations for inverter sizing, and only 22% incorporated both correction factors and panel string characteristics in their calculations.

Adherence to technical standards is fundamental for ensuring the safety and functionality of PV systems. The survey revealed that while most respondents were familiar with Finnish standards, significant gaps in their implementation remain. These findings highlight variability in design practices, underscoring differing levels of expertise and awareness within the industry.

### *B. Commissioning Inspections*

The Finnish Electrical Safety Act requires installers to perform commissioning inspections to verify that systems meet legal requirements [1]. According to the survey, 96.3% of respondents perform a commissioning inspection before handing over the system to the client, while one respondent (3.7%) reported not conducting any commissioning inspections. Despite the high inspection rate, only 77.8% of respondents stated that they provide a commissioning inspection report to the client, which is a legal requirement.

Commissioning inspections for PV systems must include measurements for both alternating current (AC) and direct current (DC) sides of the electrical energy system. While 88.9% of respondents performed AC-side inspections, only 55.6% conducted DC-side inspections as required in SFS-EN 62446-1 standard for small-scale PV systems (SFS-EN 62446-1, category 1 system). All respondents performing DC-side inspections also carried out AC-side checks, ensuring partial compliance.

The use of measurement devices varied widely among respondents. A total of 33.3% used dedicated solar PV testers capable of performing all required tests. In comparison, 37% used a combination of general-purpose commissioning testers, multimeters, and clamp meters. While these tools can meet requirements in certain cases, they rely on correct interpretation and additional steps. The remaining 48% used general-purpose meters, such as commissioning testers and multimeters, which alone cannot fulfill all testing requirements without supplementary equipment or procedures.

Proper small-scale PV systems DC inspections require measuring open-circuit voltage ($V_{OC}$) and short-circuit current ($I_{SC}$) or operating current ($I_{OP}$) under specific conditions, including irradiance and panel temperature. However, these measurements were rarely performed. Only one respondent (3.7%) reported measuring both irradiance and panel temperature. That respondent also reported using a dedicated solar PV tester.

Methods for current measurement also varied. A total of 22.2% of respondents did not perform current measurements using the short-circuit method. Most respondents (51.9%) short-circuited the panel string and used a clamp meter to measure current, while 22.2% relied on a dedicated solar PV tester. Some respondents read the operating current directly from the inverter, a common but not recommended practice.

Overall, 55.6% of respondents conducted all required tests in compliance with standards. However, this includes those who substituted current measurements with inverter readings, which is not recommended. Additionally, 7.4% of respondents did not perform AC-side commissioning inspections, which represents a significant deviation from legal and standard requirements.

The survey revealed significant non-compliance with commissioning inspection requirements mandated by Finnish regulations. Only a small proportion of respondents conducted inspections fully in line with the SFS 6000 standard series, SFS-EN 62446-1 standard and the Finnish Electrical Safety Act. Many respondents reported conducting commissioning inspections incompletely, without key measurements, such as DC-side testing, often missing or improperly performed.

### *C. System Documentation*

Compliance with documentation requirements varied among respondents. As shown in Table II, the provision of required documentation varied widely among respondents, with only a small fraction delivering the full set of documents as mandated by standards.

TABLE II. DOCUMENTATION PROVIDED TO CLIENTS

| Document | Percentage Providing (%) |
|---|---|
| Basic information of the PV system | 77.8 |
| Datasheets (panels, inverter, mounthing system) | 59.3 |
| Wiring diagram | 40.7 |
| Operation and maintenance instructions | 63.0 |
| Comissioning inspection report | 81.5 |
| **All documents** | **14.8%** |

While 77.8% of respondents provided basic system information to clients, only 14.8% delivered the full set of required documents. Commonly missing items included wiring diagrams (59.3% omitted) and component datasheets (40.7% omitted), such as those for panels, inverters, and mounting structures. Operation and maintenance instructions were delivered by 63% of respondents, while commissioning inspection reports—legally required—were provided by 81.5%. The survey results reveal inconsistencies in documentation practices, indicating differing levels of adherence to standards.

### *D. Other Notable Observations*

The survey revealed additional findings in areas that could influence the safety and reliability of PV systems, such as

inverter installation, cabling practices, potential equalization, and DC-side switching and disconnection.

Respondents reported varying approaches to inverter installation. While 48% ensured proper installation conditions, including non-combustible materials and adequate clearance, 44.4% did not meet the requirements for a fire-safe installation environment. Additionally, 11% neglected providing sufficient free space around the inverter for ventilation, and 18.5% overlooked the required electrical separation for maintainability.

Cabling practices showed significant variation. Most respondents, 88.8%, used double-insulated or conduit-installed cables for DC-side wiring, adhering to safety standards. However, 8% failed to consider or weren't familiar the 70°C temperature rating for cables. On rooftops, 7.4% of respondents admitted to installing cables directly on the surface, contrary to standard requirements. Furthermore, 14.8% installed DC cables unprotected on various surfaces for instance in attics, which does not meet safety standards.

Potential equalization practices varied among respondents. A total of 81.4% connected the PV system to equalization when voltage exceeded 60 VDC. However, only 14.8% connected all required parts, including panel frames and cable trays, to potential equalization.

DC-side switching and disconnection practices showed diverse implementation. Despite the updated 2023 standard recommending the avoidance of DC isolators unless necessary, 44.4% of respondents consistently installed separate DC isolators. Only 25.9% implemented switching and disconnection solutions aligned with the updated standard, using internal DC switches combined with plug connectors.

## IV. Discussion

The survey revealed critical deficiencies in commissioning inspections, system documentation, and installation practices among small-scale PV system installers in Finland. While most respondents demonstrated familiarity with Finnish standards, challenges in practical implementation were evident.

The results of this study highlight critical deficiencies in the installation practices of small-scale PV systems in Finland, particularly regarding commissioning inspections, system documentation, and adherence to technical standards. While the majority of respondents demonstrated familiarity with the Finnish Electrical Safety Act and mandatory standards.

Commissioning inspections emerged as a key area requiring improvement. By the survey results, many respondents failed to conduct all required tests, particularly DC-side measurements, due to cost barriers associated with specialized tools like solar PV testers. Subsidized access to such equipment or shared use programs could address this issue, alongside targeted training to ensure proper application of standards.

Documentation practices were another area where significant variability was observed. While most respondents provided some form of documentation, only 14.8% delivered the full set of documents mandated by SFS-EN 62446-1 standard and Finnish Electrical Safety Act. Critical items like wiring diagrams and datasheets were often missing. These omissions not only compromise compliance but also hinder long-term system safety and maintenance. To address this, incorporating documentation requirements into municipal or local distribution system operator PV system permitting processes—making full documentation a prerequisite for project approval—could help standardize practices and improve compliance rates.

The findings suggest that a significant portion of the missing documentation could be linked to the roles and responsibilities within installation companies. The survey did not explicitly determine whether respondents were responsible for both system design and installation or if these tasks were divided. In practice, the design phase could be handled by another individual or department within the company, while the respondent primarily managed installation and commissioning. If a dedicated designer were responsible for system planning, it is likely that documentation compliance would be higher, as technical documentation such as wiring diagrams and datasheets would typically be prepared during the design process.

Furthermore, while Decree of the Finnish Ministry of the Environment (718/2020) require a special designer (erityissuunnittelija) for PV systems [9], in practice, the appointment of such a role remains rare, particularly in small-scale installations. In many cases, system design and installation are handled by the same person or by general electrical contractors, who may not prioritize comprehensive documentation. This absence of a clearly designated special designer may contribute to the widespread deficiencies in mandatory documentation, as the responsibility for ensuring compliance is not clearly assigned.

Further discrepancies in installation practices, including deviations in inverter placement, cabling, and potential equalization, suggest a need for clearer communication of updated requirements and more consistent enforcement. Variability in DC-side switching practices, such as the continued use of outdated isolators, highlights the importance of bridging gaps in both knowledge and resources.

While the survey provided valuable insights, certain limitations should be acknowledged. The anonymity of responses and the relatively small sample size limit the generalizability of the findings. Furthermore, the reliance on self-reported data introduces potential biases. For example, according to the Finnish Electrical Contractors' Association (STUL), there are approximately 20,000 installers working in member companies [10], many of whom perform as electrician. In contrast, this study received responses from only 27 installers actively involved in small-scale PV installations. This small sample size highlights the need for broader participation in future studies to capture a more representative picture of industry practices. Additionally, completing Motiva's certification for solar PV system installers is voluntary, meaning not all individuals involved in PV installations are required to hold this certification. On the other hand, it is possible that the results of this study are better than the general practices in the industry, as certified installers can be assumed

to have a better understanding of PV system operation compared to non-certified installers.

Another uncertainty relates to the anonymity of the survey responses. Although the survey was distributed to certified solar PV system installers, it is not possible to verify with certainty who responded. As a result, it is conceivable that some responses may have come from individuals without the qualifications to perform electrical installation work. Nevertheless, based on the results and the detailed open-ended responses, it can be reasonably assumed that the respondents possess training and an understanding of electrical work practices.

## V. Conclusion

This study examined the practices, compliance, and challenges related to small-scale photovoltaic (PV) system installations in Finland, focusing on their adherence to the SFS 6000 standard series, the SFS-EN 62446-1 standard, and the requirements set forth by the Finnish Electrical Safety Act. Data was collected through a comprehensive survey distributed to certified PV installers, with 27 actively involved in small-scale PV installations completing the survey. The survey targeted key areas such as commissioning inspections, documentation practices, and adherence to technical standards, providing valuable insights into the challenges faced by installers.

The findings revealed significant gaps in compliance, particularly in commissioning inspections and system documentation. While most respondents were familiar with Finnish standards, their practical application was inconsistent. For instance, DC-side measurements were often omitted, and critical documents, such as wiring diagrams and datasheets, were frequently missing. These deficiencies highlight the need for targeted measures to improve compliance and ensure the safety and reliability of PV installations.

To address these challenges, immediate efforts should focus on enhancing commissioning inspections. Subsidizing access to specialized tools, such as solar PV testers, and implementing targeted training programs can help bridge knowledge and resource gaps. Additionally, integrating documentation requirements into permitting processes could standardize practices and ensure that clients receive the necessary information for safe system operation and maintenance.

Future research should expand the scope of data collection to include a broader range of installers and incorporate field inspections to validate compliance levels. These efforts would provide a more comprehensive understanding of the practical challenges faced by the industry and support the development of targeted interventions.

In summary, the findings underscore the urgent need for industry-wide collaboration to address deficiencies in compliance and improve the safety and reliability of PV installations. By focusing on enhanced training, better regulatory guidance, and practical support for installers, the industry can ensure higher levels of compliance and foster greater trust in renewable energy systems. By addressing these deficiencies, the industry can enhance the quality and safety of small-scale PV installations, supporting Finland's transition to renewable energy and fostering consumer trust in PV systems.


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## Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-4 to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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