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RAF013/2526 Plug-in PV Systems in the United Kingdom

Electrical Safety, Compatibility and Implementation Considerations

June 2026

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CLARITY FROM COMPLEXITY

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The views expressed in this report are those of Arceio and do not necessarily reflect the views of the UK Government or any of the organisations acknowledged above.

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Executive Summary

The Department for Energy Security and Net Zero (DESNZ) commissioned this study to assess whether plug-in photovoltaic (PV) systems can be safely used in UK homes when connected directly to existing domestic socket outlets, without modification to fixed wiring, protective devices, or consumer units. The study provides a UK-specific evidence base to inform future policy and regulatory decisions on the potential role of plug-in PV within the UK electricity system.

Plug-in PV systems are small scale photovoltaic generation systems designed to connect to existing domestic socket outlets through standard 13 A plug arrangements via grid-following microinverters. They are intended to enable consumer-led deployment without the need for electrical installation work and open a route to wider participation in small scale solar generation. This would benefit households unable to access conventional rooftop PV, including renters, flat residents, and those without suitable roof space.

This study assessed representative plug-in PV devices within a strict no-modification boundary. Under this boundary, systems were tested on the basis that they would be connected to representative UK domestic socket circuits without changes to fixed wiring, consumer units, upstream protective arrangements or the installation of dedicated generation circuits. The assessment therefore focused on whether a consumer plug-in model can operate safely and coherently within domestic electrical conditions commonly found in UK homes. The study does not assess cumulative network effects from large scale uptake, long term component ageing, battery-integrated or hybrid systems, or deployment models requiring electrical installation works beyond the no-modification boundary.

The methodology combined standards-referenced analysis, controlled laboratory testing, representative domestic circuit simulation, and targeted fault and stress testing. The empirical programme examined thermal behaviour, protective device interaction, anti-islanding response, reverse power flow, export limitation, voltage and frequency response, startup and shutdown behaviour, and electromagnetic compatibility considerations across representative ring-final and radial spur circuits, including aged sockets, mixed domestic loading, extension leads, and degraded contact conditions. A purposive engineering sample of six commercially available devices was selected to reflect the range of inverter architectures, export ratings, and product form factors in the current market.

The evidence indicates that plug-in PV systems can demonstrate safe and technically coherent behaviour within the tested no-modification boundary. Across key safety test scenarios, devices maintained stable operation, protective devices continued to function, anti-islanding disconnection occurred within required limits, and no sustained unsafe energisation was observed following protective device operation. Thermal behaviour remained acceptable under representative operating and high temperature conditions. No electrical hazard was identified as a result of socket connected plug-in PV operating within the tested export envelope. Reverse-current testing did not identify localised thermal hotspots or evidence of disproportionate conductor loading at the tested maximum export levels.

However, the study identified important limits and variances. Product specific variation was observed in export power limitation behaviour, voltage and frequency threshold behaviour, and conducted emission performance under the applied test conditions. Conducted EMC measurements at maximum rated export power were noticeably higher than the Class B limits applicable to domestic premises, and conformity in this area cannot yet be treated as fully resolved. All of the above variations do not indicate that plug-in PV is unsafe as the majority of devices tested demonstrated the core performance characteristics required for safe and coherent operation. Testing variations indicate that product quality is not uniform across the market and that a UK product specification would be beneficial to address the areas where variance to conformity has been observed.

This study supports the conclusion that plug-in PV is compatible with UK domestic electrical systems, and that a controlled deployment framework is both achievable and justified based on the evidence. The evidence is strongest where devices operate within constrained export levels, meet defined product standards, and are used in domestic environments consistent with the tested assumptions. The UK specific characteristics of domestic electrical installations (such as ring-final circuit topology, BS 1363 fused plug and socket arrangements, and mixed legacy protective device configurations) mean that international deployment experience, particularly from Germany, Austria, and the Netherlands, cannot be applied directly without UK-specific qualification. This study provides that qualification.

This study also shows that deployment safety depends not only on the characteristics of the device itself, but on the condition of the receiving installation and the behaviour of the consumer. Consumer guidance, installation limitations, and suitable product identification are therefore recommended for any future deployment pathway.

The wider regulatory review and stakeholder engagement indicate that plug-in PV occupies a hybrid position between consumer product use and embedded generation. Existing UK frameworks governing product safety, electrical installations, and small-scale network-connected generation each address part of the relevant risk picture, but none currently provides a complete fit for consumer-installed socket connected generation. The principal implementation challenge is therefore not solely one of technical feasibility, but of establishing a clear, proportionate, and enforceable framework across those interacting domains.

Based on the evidence, the study recommends that plug-in PV be enabled for consumer deployment within a clearly defined product and notification framework. Qualifying products meeting the defined technical criteria should be available to consumers to purchase and connect in accordance with the accompanying guidance, without the need for installer led commissioning.

The framework recommended by this study would include the following elements:

1. **A qualifying product category** - clearly defining the technical characteristics required for consumer socket connected deployment, including inverter safety conformity, anti-islanding performance, export limitation, and EMC requirements. The majority of tested devices already meet or approach most of these requirements; the framework would address the product quality gaps identified in this study.

2. **Export and disconnection requirements** - clear and verifiable requirements for maximum export power, voltage and frequency threshold response, and disconnection performance, underpinned by approval type testing in accredited laboratories and manufacturer declaration.

3. **EMC conducted emission requirements at maximum rated power** - current test standards do not specify assessment at maximum output; a UK product specification should require compliance with EN 61000-6-3 Class B limits at full export power, and the independent test evidence should be made available through the product registration and traceability system as well as within product documentation.

4. **Minimum safe domestic use conditions and consumer guidance** - operationally specific guidance covering socket condition, prohibited connection accessories, circuit loading practices, relocation considerations, and the distinction between plug-in PV and permanently installed generation. Guidance should be prominent at point of sale or online and within product documentation.

5. **A simplified consumer registration system** - capturing at minimum the product name and declared export rating, a conformity reference, installation postcode, and date of first connection, with provision for updating location on relocation. This would provide distribution network operators with the visibility needed to monitor cumulative uptake without placing disproportionate burdens on consumers

6. **Product identification and market surveillance** - enabling OPSS and other bodies to distinguish qualifying products from non-equivalent alternatives that have not been certified to all elements of the UK product specification.

A programme of real-world monitoring alongside initial deployment is also recommended, to observe consumer behaviour, connection practices, and any cumulative effects not captured in laboratory assessment.

Early deployment experience would build the evidence base needed to support future revisions to product specifications, BS 7671 provisions for socket connected generation, and network visibility arrangements as the market develops.

1 Background and Context

1.1 Policy context

The United Kingdom's current energy policy places accelerated clean electricity deployment, improved energy security, and wider consumer participation at the centre of electricity system reform. The Government's Clean Power 2030 mission and accompanying Action Plan set out a programme to expand low-carbon generation, modernise networks, and remove barriers to technologies that can contribute to a more flexible, resilient, and affordable power system.[1]

In that context, plug-in PV systems have emerged as a potential means of extending access to small-scale solar generation to households that may be unable to install conventional roof-mounted systems, including renters, flat residents, and households without suitable roof space. These systems are generally marketed as consumer-accessible products that can be connected through a standard domestic socket-outlet rather than through a dedicated fixed electrical installation.

Interest in plug-in PV systems has grown in part because they may offer lower capital cost and easier installation than conventional rooftop PV microgeneration. Their portability may also support a longer return on investment for consumers in temporary or short-term accommodation. International experience, particularly in parts of Europe where balcony solar systems are already available at scale, provides an important point of reference.[2]

However, differences in domestic electrical installation practice, regulatory treatment, and product-market conditions mean that direct transferability to the UK context cannot be assumed. The central question for the UK is whether plug-in solar can operate safely and coherently within the specific characteristics of UK domestic electrical systems and within an appropriate domestic regulatory framework. This study was commissioned to provide evidence relevant to that question.

1.2 Study focus

This study examines small scale PV systems intended to operate through connection to existing domestic socket outlets, without modification to fixed wiring, consumer units, or protective devices. The focus is therefore on the practical safety and feasibility of this defined deployment model, as distinct from conventional rooftop PV installation.

For the purposes of this report, plug-in PV refers to small scale photovoltaic systems using grid-following microinverters as an electrical interface and intended for consumer-led

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[1] Department for Energy Security and Net Zero — Clean Power 2030 Action Plan. Available at: https://www.gov.uk/government/publications/clean-power-2030-action-plan.

[2] VDE-AR-N 4105:2018-11 — Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html.

connection to existing domestic final circuits through standard BS 1363 socket outlets.[3] These systems are typically associated with sub-kilowatt export capacities and are marketed on the basis that they can be deployed without electrical installation work.

This deployment concept differs from established UK microgeneration arrangements. Conventional domestic PV systems are generally integrated into dedicated electrically protected circuits through defined installation routes and are supported by expectations in relation to installation competence, inspection, network notification, and standards compliance.[4] Plug-in PV, by contrast, sits between product use and embedded generation, creating a need for a more detailed operational and safety review.

1.3 Why this study was commissioned

DESNZ commissioned this study to provide an independent, UK-specific technical assessment of whether plug-in PV systems using commercially available microinverters can operate safely and as intended on representative UK domestic electrical circuits under foreseeable conditions of use.[5] The purpose is to support policy and regulatory consideration with evidence grounded in the characteristics of existing plug-in solar products commercially available plug-in solar products assessed under UK installation conditions.

The study is intended to determine whether safe operation is achievable within a clearly defined no-modification boundary and, if so, to identify the principal technical and operational parameters that support that outcome. Where safe operation is not demonstrated uniformly, the study also seeks to identify the conditions, limitations, or additional controls that would be relevant to any future deployment pathway.

The work was commissioned in recognition of a developing policy need. Plug-in PV is increasingly visible through international retail channels and wider public discussion, yet current UK regulatory and technical frameworks were not designed with socket connected domestic generation as a distinct category in mind. The absence of a dedicated evidence base creates a risk of inconsistent interpretation across product safety, electrical installation, and network governance domains.

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[3] BS 7671:2018+A2:2022 — Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://electrical.theiet.org/bs-7671.

[4] Microgeneration Certification Scheme — MCS 001 and associated installation standards govern the installation of roof-mounted solar PV in UK domestic premises. Available at: https://mcscertified.com/standards-library

[5] Department for Energy Security and Net Zero — Plug-in Solar PV Study, Invitation to Tender. Available at: https://www.find-tender.service.gov.uk/Notice/Attachment/A-3667

1.4 Comparative reference point

Experience from other European jurisdictions, particularly Germany, Austria and the Netherlands, provides a useful reference point for policy and implementation. It shows that plug-in PV can be supported within constrained frameworks that export limits, product conformity expectations, and simplified registration.[6]

However, the UK context differs materially in areas including ring-final circuit topology, BS 1363 plug and socket arrangements, mixed legacy protection arrangements, and the diversity of domestic installation conditions. International practice can therefore inform the discussion, but it cannot be adopted uncritically as a substitute for UK-specific technical evidence.

1.5 United Kingdom context

The UK context is important because domestic electrical installations commonly rely on arrangements, practices, and interfaces that differ from those in many markets where plug-in PV is already established. UK homes require the use BS 1363 socket outlets, ring-final circuits and consumer units installed against the version of BS 7671 wiring regulations applicable at the time of installation, and a range of legacy and modern protective device arrangements that shape how socket connected generation will interact with domestic wiring.[7]

Those differences are material because plug-in PV introduces reverse power flow into parts of domestic wiring installations that have historically been designed primarily for load supply rather than embedded generation. This also raises questions about how such microgeneration systems interact with residual current protection, overcurrent protection, thermal conditions at plug and socket interfaces, degraded accessories, extension leads, and mixed domestic loading conditions.

The regulatory context is similarly relevant. Existing frameworks governing product conformity (including BS 1363), electrical installations (BS 7671), and network-connected generation (G98) were not developed around consumer installed, socket connected generation devices. As a result, plug-in PV cannot simply be assumed to fit neatly within existing categories without further analysis.

The study is designed as a structured pre-compliance and feasibility assessment. It is intended to provide a technical evidence base for policy and regulatory consideration, not to confer product approval or certification on any individual device.

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[6] VDE-AR-N 4105:2018-11 — Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html. Netherlands Enterprise Agency (RVO), salderingsregeling and net metering arrangements for small-scale generation: Available at: https://benelux.bureauveritas.com/en/industrial-services/electrical/nen-1010-6-first-inspection-low-voltage-electrical-installations. OVE E 8101:2019 and Kleinanlagen provisions under ElWOG 2010: Available at: https://www.austrian-standards.at/en/shop/ove-e-8101-2019-01-01~p2455313

[7] BS 7671:2018+A2:2022 — Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://electrical.theiet.org/bs-7671

1.6 Purpose of the evidence base

This report is intended to provide a structured evidence base for DESNZ and other stakeholders considering the potential role of plug-in PV within the UK. It does not seek to establish an unrestricted or unconditional route to market, nor does it function as a product certification exercise or a substitute for future standards or regulatory development.

Instead, the report aims to clarify three related issues. First, whether plug-in PV can operate safely within representative domestic conditions under the defined no-modification model. Second, where the boundaries of that conclusion lie, including any important non-uniformities, uncertainties, or product dependent behaviours. Third, what those findings imply for any future consideration of standards, guidance, or controlled deployment.

This report is therefore intended to support proportionate, evidence-based decision making. It provides a technical foundation for subsequent interpretation, rather than a final determination of all products, installation, or regulatory questions associated with wider deployment.

1.7 Structure of the report

The remainder of this report is organised to move from scope and framework, through methodology and empirical evidence, to interpretation and implementation considerations. Chapter 2 defines the scope of the study, the key terms used in the report, and the relevant regulatory and standards context. Chapter 3 sets out the methodology, governance arrangements, and quality controls applied to the study. Chapter 4 presents the empirical results of the testing programme and the technical interpretation of those findings. Chapter 5 considers the implications for deployment and implementation within a future UK context. Chapter 6 sets out the overall conclusions and recommendations arising from the study.

2 Scope, Definitions and Existing Regulatory Framework

2.1 Purpose of this chapter

This chapter defines the technical and analytical boundary of the study, sets out the core terms used throughout the report, and summarises the principal existing regulatory and standards frameworks relevant to plug-in PV systems in the UK. Its purpose is to establish a common reference point for interpretation of the methodology, results, and later implementation considerations.

The chapter does not attempt to resolve all regulatory questions associated with future market deployment. Rather, it identifies the principal frameworks that shape the assessment and explains where plug-in PV sits uneasily within existing categories governing product safety, electrical installations, and small-scale generation.

2.2 Study scope

The study is limited to representative sample of small-scale plug-in PV systems connected through standard BS 1363 domestic socket outlets on existing final circuits within UK homes under a strict no-modification assumption. The assessment examines whether such systems can operate safely and as intended when connected to representative domestic circuits without modification to fixed wiring, consumer units, or protective devices.

The scope includes laboratory and rig-based assessment of representative plug-in PV systems operating in conditions intended to reflect realistic domestic use. The assessment covers normal operation and a range of foreseeable fault, stress, and degraded use conditions, including thermal behaviour, protective device interaction, anti-islanding response, reverse power flow effects, export limitation behaviour, voltage and frequency response, and electromagnetic compatibility considerations.

2.3 Core definitions

For the purposes of this report, plug-in PV refers to a small scale photovoltaic generation system designed to connect to an existing domestic socket-outlet through a standard plug arrangement and to export AC power into the domestic electrical installation using a grid-following microinverter.[8] In this study, the term is used interchangeably with plug-in microgeneration where a more explicit distinction from conventional rooftop PV is required.

The report focuses on systems intended for consumer-led deployment without electrical installation work. Typical use cases include balconies, gardens, external walls, patios, and other accessible domestic locations where small-scale PV modules may be installed and connected to an existing socket circuit.

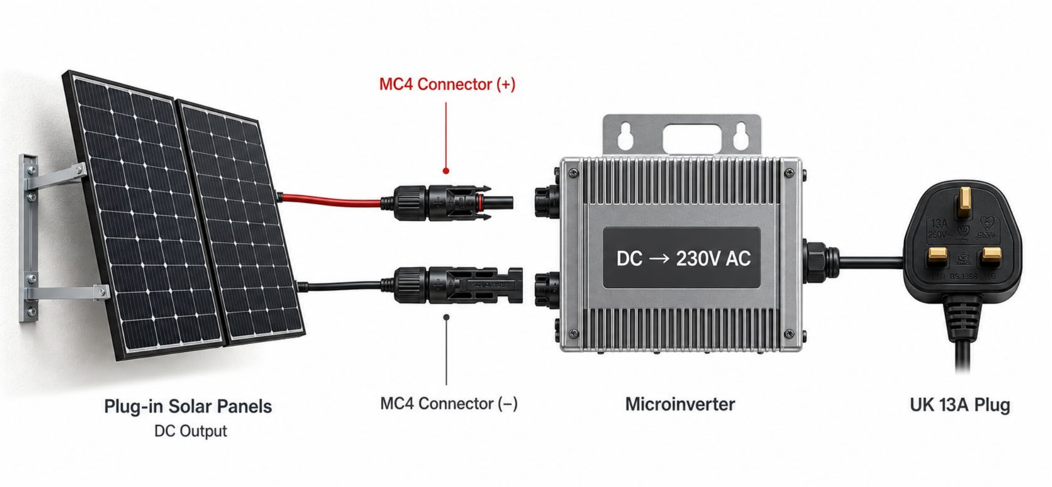

Figure 1: Components of a Plug-in PV system, including Solar PV panels, MC4 DC connectors, microinverter and an AC connection through 13A plug (© Arceio)

The systems examined in this study are within the sub-kilowatt range and broadly aligned with device level export stated capacities in the order of 400 W to 800 W AC output. This reflects the product category currently emerging across parts of the European market and provides a relevant basis for assessing whether a similarly constrained category could be considered in the UK.

2.4 The no-modification boundary

A central feature of the study is the adoption of a strict no-modification deployment boundary. Under this boundary, devices are assessed in a form intended to reflect the core consumer proposition associated with plug-in PV: connection to an existing socket-outlet without changes to fixed wiring, dedicated generation circuits, replacement protective devices, or consumer unit alterations.

This boundary is important because it directly reflects the policy question under examination. The study is not asking whether socket connected PV could be made acceptable if accompanied by conventional electrical installation works or bespoke protective arrangements. It is asking whether a consumer plug-in model can operate safely and coherently within representative domestic installations as they are commonly found.

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[8] BS 1363:2016+A1:2018, 13 A plugs, socket-outlets, adaptors and connection units. London: BSI. Available at: https://www.legislation.gov.uk/uksi/1994/1768/contents/made

The no-modification boundary also provides an important interpretive limit. Where future deployment models might rely on additional mitigations, dedicated accessories, inspection requirements, or changes to existing infrastructure, such pathways fall outside the direct tested boundary of this study and would require separate consideration.

2.5 In-scope conditions and assumptions

The assessment includes representative UK domestic ring-final and radial spur arrangements, together with variation in socket condition, protective device type, load distribution, and accessory condition. Testing also considers foreseeable domestic behaviours and degraded conditions, including aged sockets, extension leads, mixed domestic loading, and thermal stress.

Table 2.1, Foreseeable Consumer Scenarios

Scenario	Test Coverage
Aged sockets	Multiple conditions
Extension leads	Straight and coiled
High circuit load	Up to design limit
Ring imbalance	Varied positions

These conditions are included because the practical safety of plug-in PV cannot be understood solely through idealised installation scenarios. The study therefore examines not only nominal operation, but also the interaction between plug-in generation and the kinds of circuit conditions and usage practices that may reasonably be encountered in occupied domestic environments.

2.6 Out of scope

At the same time, the study assumes that the receiving installation remains broadly within the range of normal domestic electrical conditions expected in UK housing. Grossly defective wiring, extreme misuse beyond the defined scenarios, or widespread departure from the intended product configuration are outside the scope of this study.

Several other matters fall outside the scope of this study. The report does not provide a statistical census of the plug-in PV market, a full product certification exercise, or a long-term field trial across occupied dwellings. It also does not assess unrestricted consumer modification of products, improvised connectors, altered wiring arrangements, or deployment models requiring electrical installation works beyond the defined no-modification boundary.

The study is also not intended to provide a full network-scale assessment of cumulative uptake effects such as widespread harmonic aggregation, transformer loading, local phase imbalance, or large-scale interaction with other distributed energy technologies. Similarly, battery integrated, DC-coupled, or hybrid systems fall outside the direct scope except where relevant to later implementation discussion.

Tariff arrangements, export remuneration, and wider market mechanisms such as the Smart Export Guarantee are also outside scope. The report is concerned with technical electrical safety, feasibility, and regulatory implications rather than the economic case for deployment.

2.7 Existing UK regulatory context

Plug-in PV sits at the intersection of three principal regulatory and standards domains: product safety, electrical installation practice, and network-connected generation. Existing UK arrangements address many of the relevant technical functions within those domains, but they do not currently provide a fully integrated framework tailored specifically to consumer installed socket connected generation.

The position of plug-in PV under Permitted Development Regulations (PDR) is currently unclear.[9] It is uncertain whether socket connected generation installed on balconies or external walls falls within the existing PDR provisions in Schedule 2, Part 14 of the Town and Country Planning (General Permitted Development) (England) Order 2015, or whether separate planning consideration is required. Resolving this question is identified in Chapter 5 as a necessary part of any future implementation framework.

At the product level, microinverters and associated components are expected to comply with applicable electrical safety and electromagnetic compatibility requirements. At the installation level, BS 7671 and BS 1363 provide the principal framework for low-voltage electrical installations in dwellings, including protection against electric shock, fault current, overcurrent, and the integration of embedded generation.[10]

At the network level, Engineering Recommendations G98 governs the connection behaviour of small-scale generation connected to public low-voltage systems.[11] The Plugs and Sockets etc. (Safety) Regulations 1994 are also relevant, as they require that plugs and sockets sold in the UK comply with BS 1363, and impose duties on suppliers of electrical equipment connected through BS 1363 arrangements.

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[9] Town and Country Planning (General Permitted Development) (England) Order 2015 (SI 2015/596), Schedule 2, Part 14. Available at: https://www.legislation.gov.uk/uksi/2015/596/schedule/2/part/14/made.

[10] BS 7671:2018+A2:2022, Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://electrical.theiet.org/bs-7671.

[11] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://www.energynetworks.org/industry-hub/resource-library/g98-issue-2-amendment-3-2022

In addition, the Plugs and Sockets etc. (Safety) Regulation 1994 (SI 1994/1768), and the Electricity Safety, Quality and Continuity Regulations (ESQCR) establish overarching duties relating to electricity safety and continuity of supply.[12] Together, these frameworks are highly relevant to the study. It should be noted that BS 7671, BS 1363 and G98 were originally developed around assumptions associated with either fixed electrical installations or with installer-led small-scale generation and not including consumer plug-in generation through general purpose socket circuits.

2.8 Why classification is difficult

The central classification challenge is that plug-in PV behaves functionally as microgeneration while being marketed and deployed as a consumer product. It generates electricity, synchronises with the grid, and exports power into domestic circuits relevant to installation and network regulatory frameworks. At the same time, its route to use is based on consumer purchase and plug connection rather than conventional electrical installation relevant to product safety regulation.

This hybrid character creates ambiguity in several areas, including responsibility for deployment suitability, notification expectations, interpretation under existing installation rules, and the extent to which product conformity alone is sufficient to manage system level risks. It also complicates the question of whether such systems should be treated primarily as appliances, generation equipment, or a distinct constrained subset of microgeneration.

This study was focussed solely on plug-in PV, but any microgeneration system that integrates to the UK mains supply with a grid-based synchronisation will use similar microinverters. Complete systems with plug-in batteries, plug-in wind turbines or even plug-in export heat pumps would likely become part of the adopted classification.

This study was focused solely on plug-in PV, but any microgeneration system that integrates with the UK mains supply with a grid-based synchronisation will use similar microinverters. Complete systems with plug-in batteries, plug-in wind turbines, or even plug-in export heat pumps would likely become part of any adopted classification.

2.9 Interaction between product, installation and network frameworks

A key issue for this study is that compliance in one domain does not automatically resolve questions arising in the others. A microinverter may satisfy product level safety and

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[12] Plugs and Sockets etc. (Safety) Regulations 1994 (SI 1994/1768). Available at: https://www.legislation.gov.uk/uksi/1994/1768/contents/made. Electricity Safety, Quality and Continuity Regulations 2002 (SI 2002/2665), reg. 27. Available at: https://www.legislation.gov.uk/uksi/2002/2665/contents/made

electromagnetic compatibility requirements yet still raise questions about interaction with socket outlets, ring-final circuits, protective devices, or network notification arrangements when deployed by consumers in varied domestic environments.

Similarly, electrical installation standards assume certain patterns of connection, protection, and circuit use that do not map neatly onto a plug-connected generation device operating on a general-purpose socket circuit. Network rules, meanwhile, assume a generating unit connected in a manner that is connected in a manner that is visible to and notified with network operators, bounded, and governed through established routes. Plug-in PV therefore spans all three domains simultaneously.

This interaction is one reason why the study adopts an explicitly system level perspective. The objective is not simply to ask whether a product works in isolation, but whether the overall deployment concept remains coherent when product behaviour, installation context, and network expectations are considered together.

2.10 Implications for the rest of the report

The definitions and boundaries set out in this chapter should be read as the interpretive frame for the remainder of the report. The methodology in Chapter 3 is designed around this no-modification boundary and these UK-specific assumptions. The empirical results in Chapter 4 should be understood as findings within this defined deployment concept rather than as universal statements about all forms of plug-in generation.

Chapters 5 and 6 return to the implications of this framing for implementation and future regulatory development. They consider where the evidence supports cautious progression within a controlled envelope, and where important uncertainties or non-uniformities remain.

3 Methodology and Governance

3.1 Purpose of this chapter

This chapter describes how the study was designed, governed, and executed to assess the behaviour of plug-in PV systems under representative UK domestic conditions. It explains the methodological approach, the structure of the empirical test programme, the basis for device and scenario selection, and the quality assurance arrangements used to maintain evidential integrity throughout the study. The chapter is intended to provide confidence that the findings presented later in the report are grounded in a controlled, transparent, and technically credible assessment framework. Further detail on test protocols and individual test records can be found in Appendix A.

3.2 Methodological approach

The study was designed as a structured empirical safety and performance assessment of plug-in PV systems connected to existing UK domestic socket circuits within the defined no-modification boundary. The methodology combines controlled laboratory testing, representative domestic circuit simulation, standards referenced acceptance criteria, and targeted fault and stress testing to assess how plug-in PV interacts with common low-voltage domestic installation arrangements.

The assessment was intentionally developed as a technical engineering investigation rather than as a product certification exercise. Its purpose is not to approve individual products, but to generate evidence on system level behaviour, identify interaction effects between plug-in PV systems and domestic electrical infrastructure, and determine whether material safety or operational concerns arise under realistic or stressed operating conditions. The scope boundary and what the study is not intended to assess are defined in Chapter 2 (Scope, Definitions and Existing Regulatory Framework)

A hazard oriented framework was used to structure the assessment.[13] In practical terms, this means the test programme was built around the specific electrical hazards that socket connected generation could realistically introduce into a UK home; including electric shock risk from exposed or degraded connections, overheating at plugs and/or sockets, interference with other electrical equipment, and failure of the protective devices that are the last line of defence against electrical faults, including thermal performance, reverse power flow, and the impact of mixed import/export on protective device interaction.

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[13] IEC 31010:2019, Risk management — Risk assessment techniques. Available at: https://mdcpp.com/doc/materialDownload/IEC%2031010-2019%20EN.pdf

The test programme also included technical concerns associated with electrical operational behaviours of the plug in microgeneration systems, namely anti-islanding response, export limitation, voltage and frequency tolerance, and electromagnetic compatibility.

3.3 Test programme structure

The empirical programme was divided into two linked phases. The Initial Assessment covered baseline thermal, protection, anti-islanding, endurance, fault-response, and electromagnetic compatibility behaviour under representative domestic conditions. The Enhanced Assessment extended the programme into boundary and dynamic operating conditions, including voltage and frequency excursions, startup and shutdown transients, export limitation behaviour, and dynamic response under changing irradiance conditions.

This two-phase structure was adopted to provide both breadth and depth of assessment. The Initial Assessment was used to establish whether plug-in PV systems behaved coherently and safely under normal and foreseeable domestic operating conditions, while the Enhanced Assessment was used to determine whether that stability remained robust at the edges of the operating envelope.

The methodology intentionally included both standards aligned assessment and deliberately stressed scenarios. This was necessary because some of the key technical concerns relevant to plug-in PV do not arise under idealised nominal conditions alone, but through interaction with degraded accessories, mixed loading conditions, or boundary operating states.

3.4 Device sampling and representativeness

The study used a purposive engineering sample of six plug-in PV devices selected to reflect the principal characteristics of the current and emerging UK and European plug-in PV market. Device selection was intended to provide representative coverage across export ratings, inverter topologies, single-input and dual-input architectures, communications and control features, and differing product form factors.

The tested sample covered devices broadly within the 400 W to 800 W AC export range, consistent with the product category currently associated with consumer accessible balcony and plug-in PV systems in Germany, Austria, and the Netherlands.[14] The methodology prioritised diversity of engineering design over quantity of identical units, because the aim was to observe how different design approaches behaved under common electrical conditions rather than to conduct a statistical market census.

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[14] Renewable Energy Institute, Plug-in Solar: Accessible to All (2023). Available at: https://www.renewable-ei.org/pdfdownload/activities/REI_Plug-in-Solar_Accessible-to-All_EN.pdf. VDE-AR-N 4105:2018-11, Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html

To preserve commercial neutrality and avoid conflating the study with formal certification activity, devices are anonymised throughout the report. The findings should therefore be read as evidence of category behaviour rather than as product approvals or rankings.

3.5 Domestic circuit simulation and test environment

Testing was carried out using instrumented circuit rigs designed to emulate representative UK domestic final-circuit arrangements under controlled UKAS laboratory conditions. The rigs were constructed to represent modern and legacy domestic protection arrangements, including ring-final and radial spur configurations, and to allow controlled variation in socket condition, accessory type, protection arrangement, and load distribution.[15]

The test environment was designed to reflect the practical realities of UK domestic installations rather than idealised bench conditions. Accordingly, testing incorporated new and aged socket outlets, metal and plastic sockets, extension leads, mixed domestic loads, and deliberately stressed conditions associated with degraded contact quality and thermal dissipation. The full range of circuit configurations, socket conditions, and accessory types used across the test programme are summarised in Tables 4.1 and 4.2 in Chapter 4 (Empirical Results) and set out in full in Appendix B (Tables B1 and B2).

Programmable DC sources were used to emulate photovoltaic input conditions with repeatable control over irradiance-related operating states. This provided reproducibility across endurance, fault, and dynamic tests conducted within shielded laboratory environment, while supplementary real-panel outdoor tests were used in selected scenarios to observe behaviour under more realistic irradiance variation and partial shading.

Figure 2 shows one of three instrumented laboratory rigs constructed to represent a mix of modern and legacy UK domestic socket circuits. A Modbus enabled energy meter (top left) allows highly granular data of the power parameters to be acquired and recorded. A metal cased consumer unit (top right) contains the mains RCD breaker and the individual RCBOs for each connected circuit.

- **Ring A** (right) modern RCBO type AC-protected ring-final;
- **Spur B** (centre) modern RCBO type A protected radial spur. In testing an aged extension lead with worn sockets and plugs was connected to this radial spur to test impact of legacy/degraded wiring with aged accessories and extension leads;
- **Spur C** (left) modern RCBO type A protected radial spur.

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[15] BS 7671:2018+A2:2022, Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://electrical.theiet.org/bs-7671

Figure 2: Instrumented laboratory rig using UK domestic socket circuits: (right) RCBO type AC protected ring-final; (centre and left) Spur B modern radial spur, RCBO type A protected. (© Arceio)

3.6 Operating conditions and scenario design

The methodology was designed to examine not only nominal operation, but also the interaction between plug-in PV and realistic domestic load and circuit conditions. Representative domestic loading was therefore created using mixed resistive and non-linear loads rather than relying solely on simplified static resistive arrangements.

Particular emphasis was placed on reverse power flow scenarios because these represent the main distinction between operation of conventional domestic circuits (import) and plug-in generation which provides export power on same circuit. Test scenarios examined current distribution within ring-final and spur circuits, thermal behaviour at accessories and conductors, and protective device response during simultaneous import and export conditions.

In addition to normal operating scenarios, the methodology included stressed and degraded conditions intended to explore sensitivity at the edges of the likely deployment envelope. These included aged socket contacts, coiled extension leads, asynchronous disconnection conditions, high ambient temperature, voltage and frequency excursions, and dynamic irradiance variation.

3.7 Principal test themes

The test programme was organised around a number of recurring technical themes relevant to the plug-in PV safety case. The first four themes i) thermal endurance and contact heating, ii) protection and fault-response, iii) anti-islanding, and iv) electromagnetic compatibility form the core electrical safety assessment. The remaining themes address operational performance characteristics relevant to network connection and consumer deployment conditions. These included:

- **Thermal endurance and contact heating** - whether plugs, sockets, and cable accessories remain within safe temperature limits during sustained generation, including under degraded contact condition.
- **Protection and fault-response behaviour** - whether circuit breakers, RCDs, and RCBOs operate correctly when faults occur during plug-in PV operation, and whether protective devices respond as expected under reverse power flow conditions.
- **Anti-islanding and loss-of-mains response** - whether the inverter correctly detects and disconnects from the grid when mains supply is lost, preventing the system from continuing to energise circuits that may appear dead to network operators or workers.[16]
- **Electromagnetic compatibility and harmonic performance** - whether the inverter introduces electrical noise or current distortion onto the supply that could interfere with other household equipment or degrade power quality on the local network.[17]
- **Startup, shutdown, and dynamic operating behaviour** - how the system behaves during transitions, including start-up, shading related output changes, and disconnection events, and whether these transitions cause transient effects on the domestic circuit.
- **Export limitation** - whether the device accurately constrains its output to the declared maximum export level across the full operating voltage range, and whether that constraint is maintained under varying irradiance conditions.[18]

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[16] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://www.energynetworks.org/industry-hub/resource-library/g98-issue-2-amendment-3-2022

[17] BS EN 61000-3-2:2019, Electromagnetic compatibility (EMC) — Limits for harmonic current emissions for equipment input current up to and including 16 A per phase. London: BSI. Available at: https://knowledge.bsigroup.com/products/electromagnetic-compatibility-emc-limits-limitation-of-voltage-changes-voltage-fluctuations-and-flicker-in-public-low-voltage-supply-systems-for-equipment-with-rated-current-16-a-per-phase-and-not-subject-to-conditional-connection-6

[18] VDE-AR-N 4105:2018-11, Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html

- **Voltage and frequency tolerance** - whether the device operates correctly and safely across the statutory UK supply voltage range (207–253 V) and declared frequency limits and disconnects appropriately outside those limits.[19]

Each test area was linked to a defined technical concern, relevant standards reference, and a corresponding acceptance framework. The intention was to assess not only whether devices functioned in principle, but whether they did so in a manner consistent with a coherent domestic deployment concept under the no-modification boundary.

This thematic structure also supports later interpretation. It allows the report to distinguish between areas where the evidence indicates strong behavioural consistency, areas where performance is more condition dependent, and areas where additional caution or future clarification may be required.

3.8 Acceptance criteria and interpretation framework

Acceptance criteria were defined for each test category using relevant standards, engineering guidance, and protocol-specific safety thresholds. The principal criteria applied were:

- temperature limits for accessories and conductors referenced to BS 7671:2018+A2:2022 and IEC 60364-7-712; [20]
- disconnection time windows referenced to G98 Engineering Recommendation Issue 2;
- export limitation thresholds assessed against the declared rated output;
- harmonic emission limits referenced to BS EN 61000-3-2:2019; and
- voltage fluctuation limits referenced to BS EN 61000-3-3:2013+A1:2019.

The full acceptance criteria for each test category are set out in the relevant appendix sections (Appendices A1 to A14) and were approved as part of the test protocol sign-off process described in section 3.10.

The test methodology combined quantitative criteria, such as disconnection times, temperature limits, frequency and voltage threshold behaviour, and export limits, with qualitative engineering observations relating to stability, control, absence of sustained energisation, absence of abnormal thermal concentration, and absence of physical damage.

The study did not rely solely on binary pass/fail classification. Instead, outcomes were interpreted through a structured conformity framework that distinguished between behaviour

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[19] Electricity Safety, Quality and Continuity Regulations 2002 (SI 2002/2665), reg. 27. Available at: https://www.legislation.gov.uk/uksi/2002/2665/contents/made

[20] BS 7671:2018+A4:2026, Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://electrical.theiet.org/bs-7671. IEC 60364-7-712:2025, Low-voltage electrical installations — Part 7-712: Requirements for special installations or locations — Solar photovoltaic (PV) power supply installations. Available at: https://www.iec.ch/publication/59063

remaining within defined criteria, behaviour approaching thresholds or showing elevated sensitivity, and behaviour exceeding one or more acceptance conditions under realistic or stressed scenarios.

This approach was necessary because several observed behaviours were configuration dependent and would have been oversimplified by a purely binary treatment. It also allowed the analysis to reflect the practical distinction between general system stability and product dependent variation at operational boundaries.

3.9 Data integrity, repeatability and uncertainty

All test events were recorded through structured data-capture procedures designed to maintain traceability between raw measurements, processed datasets, and reported findings. Captured records included electrical measurements, oscilloscopic waveforms, thermal data, event timings, photographic evidence, thermal imagery, and observational logs.

Where anomalous or unexpected behaviour was observed, repeat testing or corroborative measurement techniques were used where practical. These included repeat transient capture, baseline comparison tests, alternative measurement paths, and cross-verification using thermal imaging and thermocouple measurements. The purpose was to distinguish repeatable engineering behaviour from isolated artefacts or instrumentation effects.

Where test events could not be completed due to device-specific constraints or pre-existing damage, this is recorded explicitly in the relevant test records, and the associated findings are qualified accordingly in Chapter 4.

3.10 Governance and roles

The study was delivered through a defined governance model combining project leadership, technical oversight, accredited laboratory execution, and independent quality assurance. DESNZ retained oversight of key deliverables and approval authority over major protocol and reporting milestones.

Arceio acted as the project lead, responsible for programme coordination, protocol development, analysis, reporting, and quality assurance. Eurofins acted as the UKAS-accredited laboratory partner responsible for test execution under controlled laboratory and safety procedures.[21] Internal and external technical contributors provided review of standards interpretation, methodological consistency, and electrical safety considerations.

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[21] United Kingdom Accreditation Service (UKAS), Schedule of Accreditation — Eurofins E&E UK. Available at: https://www.ukas.com/wp-content/uploads/schedule_uploads/00002/1574Testing-Multiple.pdf

The governance structure was designed to separate responsibilities across protocol design, laboratory testing, analytical interpretation, and quality review.

3.11 Stakeholder engagement

Structured engagement with a range of technical, regulatory, industry, and policy stakeholders has been undertaken during the study to inform current and future test scenario design, implementation understanding, and regulatory context. Its purpose was to ensure that the study addressed questions of relevance to the principal parties involved in any future UK implementation of plug-in PV, and that the scenario coverage reflected foreseeable real-world conditions rather than solely laboratory assumptions.

Table 3.1, List of stakeholders

Stakeholder	Category	Engagement Focus
DESNZ	Commissioning body	Study oversight, protocol approval, reporting milestones, policy context
OPSS	Market surveillance and product safety	Product safety enforcement, online retail and importer obligations, market surveillance capability
HSE / BSR	Building and fire safety	Higher-risk residential buildings, fire safety interface, post-testing technical discussion
IET	Standards and electrical installation	BS 7671 landscape, installation rules, technical framing for socket connected generation
Energy Networks Association / DNOs	Network connection and notification	G98 notification requirements, network visibility, connection behaviour under consumer deployment
Centrica	Energy supply industry	Implementation pathway under existing BS 7671 landscape, battery systems interface and future market evolution[22]
Manufacturers and Suppliers	Product design and market development	Over-moulded plug design, export limitation architecture, international deployment experience from European balcony PV markets

Three cross-cutting themes emerged consistently across the engagement programme.

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[22] Electricity at Work Regulations 1989 (SI 1989/635). Available at: https://www.legislation.gov.uk/uksi/1989/635/contents/made

- **First**, all stakeholders highlighted the hybrid character of plug-in PV, sitting between consumer product regulation, electrical installation practice, and network-connected generation, as the principal governance challenge requiring resolution.
- **Second**, the importance of over-moulded non-rewirable BS 1363 plugs as a physical safety boundary was raised independently by multiple parties, including product safety, installation, and manufacturer perspectives.
- **Third**, engagement with international manufacturer and supplier representatives confirmed that European balcony PV deployment experience, while not directly transferable to UK ring-final circuit arrangements, provided useful reference on product design conventions, export limitation approaches, and consumer guidance practice.

Engagement with industry stakeholders also clarified an important implementation point regarding BS 7671. As a technical standard rather than legislation, BS 7671 is developed and maintained independently through BSI and IET processes. This means that changes to installation practices follow established standards development routes. However, while BS 7671 is not itself law, it is widely used to demonstrate compliance and legal duties under Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR). This has direct implications for the timescale and mechanism through which any future BS 7671 provisions addressing plug-in PV could be developed and adopted.

3.12 Quality assurance and change control

Quality assurance applied both to laboratory testing and to internally managed analysis and reporting. Laboratory work was undertaken within the quality systems of the accredited testing partner, while internal controls were applied to protocol development, data handling, evidence traceability, threshold interpretation, and final drafting.

Controlled versioning, secure data handling, audit trails, and secondary technical review were used to preserve evidential continuity. Any material change affecting scope, methodology, acceptance criteria, analytical assumptions, or interpretation boundaries was subject to formal change control.

3.13 Methodological boundaries and limitations

The methodology provides a structured and technically bounded evidence base, but several limitations should be noted. The tested hardware sample was representative rather than statistically exhaustive. The study therefore provides evidence across selected device architectures and operating conditions, not a complete census of all products available in the market.

Although the domestic test rig was designed to emulate representative UK installations, no laboratory environment can fully reproduce the full variability of national housing stock, including workmanship differences, historic alterations, undocumented degradation, and installation-specific background electrical conditions.

This study focuses primarily on device-level and circuit-level behaviour and does not assess network wide cumulative effects arising from large scale uptake. It also does not provide long-term ageing effects for plug-in PV systems under prolonged real-world operating cycles. These limitations do not undermine the empirical findings, but they remain important when interpreting the boundaries of applicability and the extent to which findings can be generalised.

3.14 Implications for the report

The methodology described in this chapter should be read as the evidential foundation for the empirical findings and technical interpretation presented in Chapter 4 and the implementation considerations developed in Chapter 5

The results should therefore be understood as findings generated within a controlled, UK-specific assessment framework aligned to the no-modification boundary defined in Chapter 2. This framing is important for later chapters as any future implementation discussion must remain anchored in what was actually tested, where the evidence is strongest, and where uncertainty or product-dependent variation remains material.

4 Empirical Results and Technical Interpretation

4.1 Purpose of this chapter

This chapter presents the empirical findings and technical interpretation from the plug-in PV test programme in a structured, theme-based format aligned with the approved methodology. It reports measured outcomes, recurring patterns, and material variations observed across the tested devices and circuit configurations within the defined no-modification boundary.

4.2 Overview of test findings

Before the detailed findings are presented, this section sets out the test conditions applied across the programme and the acceptance criteria used to evaluate outcomes. These are reproduced here in summary form to allow the findings in sections 4.3 and 4.4 to be read in context without requiring repeated reference to the appendices.

The full technical detail, including precise threshold values, circuit diagrams, and measurement configurations, is set out in Appendix B (Tables B1 and B2) and in the individual test appendices (Appendices A1 to A14).

Table 4.1, Test conditions

Test Area	Conditions Tested	Purpose of Inclusion
Thermal endurance	New socket; aged socket with degraded contacts; coiled extension lead; high ambient temperature	Degraded contacts and coiled leads represent foreseeable UK domestic conditions that increase thermal risk
Protective device response	Type A RCBO; Type AC RCBO; RCD-only board; ring-final and radial spur	Different protective device types are common across UK housing stock and may respond differently to reverse power flow
Anti-islanding	Normal grid supply; simulated loss-of-mains; asynchronous disconnection	Loss-of-mains scenarios test whether the inverter correctly detects grid absence and disconnects safely
EMC / harmonics	Maximum rated export power; reduced output	EMC behaviour at partial output may not reflect worst-case conducted emissions, full power testing required

Export limitation	Nominal voltage (230 V); lower limit (207 V); upper limit (253 V)	Export behaviour must remain within declared limits across the full statutory supply voltage range
Voltage and frequency tolerance	207–253 V supply range; frequency excursions above and below 50 Hz	The UK statutory supply range means devices must perform correctly well beyond nominal 230 V conditions

Table 4.2, Acceptance criteria

Test Area	Satisfactory Outcome	Standard or Basis
Thermal endurance	No accessory or conductor exceeds safe temperature limits under sustained generation	BS 7671 / IEC 60364-7-712 temperature limits[23]
Protective device response	Circuit protection operates correctly during fault conditions; no uncontrolled energisation	G98 Issue 2; BS 7671
Anti-islanding	Inverter disconnects within required time window following loss-of-mains detection	G98 Issue 2 disconnection time windows[24]
EMC / harmonics	Harmonic current emissions and voltage fluctuations remain within permitted limits	BS EN 61000-3-2:2019; BS EN 61000-3-3:2013+A1:2019
Export limitation	Declared output cap maintained across full voltage operating range	Device declaration; VDE-AR-N 4105 reference convention[25]
Voltage and frequency tolerance	Stable operation within the statutory voltage range; correct disconnection outside declared limits	ESQCR 2002 (207–253 V range);[26] G98 frequency thresholds

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[23] S 7671:2018+A2:2022, Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://electrical.theiet.org/bs-7671. IEC 60364-7-712:2025, Low-voltage electrical installations — Part 7-712: Requirements for special installations or locations — Solar photovoltaic (PV) power supply installations. Available at: https://webstore.iec.ch/en/publication/65748

[24] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://www.energynetworks.org/industry-hub/resource-library/g98-issue-2-amendment-3-2022

[25] VDE-AR-N 4105:2018-11, Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html

[26] Electricity Safety, Quality and Continuity Regulations 2002 (SI 2002/2665), reg. 27. Available at: https://www.legislation.gov.uk/uksi/2002/2665/contents/made

4.3 Initial assessment findings

The following sections present the findings from the Initial Assessment phase. Each subsection describes the test objective, the circuit configurations and conditions applied, and the observed outcomes assessed against the acceptance criteria set out in section 4.2. For the full test records, raw data, and detailed threshold values, readers should refer to the corresponding appendix sections referenced at the end of each subsection. Test configurations included Type A and Type AC RCBO-protected circuits, ring-final and radial spur arrangements, new and aged socket outlets, coiled extension leads, and mixed domestic loads, as described in Table 4.1.

4.3.1 Thermal endurance

Continuous operation testing demonstrated stable thermal behaviour across all tested devices during sustained maximum-output operation on representative UK socket circuits. Across the six tested devices, no shutdown, oscillation, protective device operation, or visible physical degradation occurred during prolonged export operation. Acceptance criteria were aligned with BS 1363 temperature rise principles and BS 7671 safety expectations, limited measured rise to 50°C from ambient. Testing was conducted across both Type A and Type AC RCBO-protected circuits, and on ring-final and radial spur configurations, including scenarios using aged socket outlets and coiled extension leads to represent foreseeable domestic variability.

Measured inverter casing temperatures during normal operation ranged from approximately 45.1°C to 54.2°C. Temperatures recorded at the plug and socket interface remained below the applicable reference limits used in the assessment, and no evidence of progressive thermal runaway, unstable export behaviour, or abnormal current fluctuation was identified during steady-state operation.

Minor operational variations were noted on one device requiring initialisation through its companion application before export commenced, but this did not affect the thermal outcomes recorded for this device.

4.3.2 RCBO and residual-current behaviour

Residual current protection testing examined whether inverter export current materially altered RCBO trip behaviour under both live-earth and live-neutral fault conditions. Across all completed events, protective devices operated successfully, and no evidence was observed of sustained inhibition, indefinite delay, or failure of RCBO operation.

Tests for combinations of L-N and L-E fault current injection, across all three test rig circuits were conducted. The test rig uses a combination of RCBO Type A and RCBO Type AC so that impact of non-sinusoidal export waveforms could be explored. In total of 31 inverter-related fault events and one baseline reference event were completed across the representative domestic circuit configurations. In 26 measured events, RCBO trip times remained within the defined trips times in IEC 61009-1, with the 5 ΔIn applicable time of 40 ms. This criteria is derived from IEC 61009-1, which defines the maximum permissible trip time for RCBOs under fault current conditions at five times the rated residual operating current.

The 40 ms limit is also significant from a human safety perspective: sub-40 ms disconnection reduces the risk of ventricular fibrillation from electric shock, which is the primary physiological hazard associated with sustained residual-current exposure.[27]

Four additional events were classified as incomplete. In each case, correct protective operation occurred, but the residual-current event did not trigger the waveform capture needed to record the trip timing. This was attributable to high levels of noise on the export waveforms for these devices, which required oscilloscope trigger levels to be set higher than for devices with lower noise output.

One exceedance was observed under a specific configuration involving a single device on a Type AC ring circuit under live-neutral injection conditions, with a measured trip time of 89 ms against the 40 ms acceptance criterion. No comparable exceedance was recorded elsewhere in the sample.

4.3.3 Ring-final and reverse-current behaviour

Reverse current testing examined whether plug-in PV export created disproportionate current concentration or thermal stress within representative ring-final and spur circuits during simultaneous domestic import and export. Across all completed test configurations, no localised thermal hotspots were identified on wiring, sockets, plugs, or containment.

Thermal imaging showed broadly uniform heat distribution under both spur and ring-final arrangements, including scenarios involving approximately 2 kW of import loading combined with maximum rated inverter export. All tested devices maintained stable operation during this assessment period, and no evidence of persistent imbalance, overheating, or progressive thermal concentration was observed.

One device was excluded from this part of the programme due to pre-existing PV-side connector damage unrelated to the reverse-current test itself.

4.3.4 Short-circuit response

Short-circuit testing examined inverter response and protective device behaviour during controlled downstream AC fault conditions. Across all completed events, protective devices operated as intended and no unsafe thermal or physical behaviour was observed. Four

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[27] IEC 61009-1:2024, Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs). Available at: https://knowledge.bsigroup.com/products/residual-current-operated-circuit-breakers-with-integral-overcurrent-protection-for-household-and-similar-uses-rcbos-general-rules-2

devices were successfully tested under controlled solid short-circuit conditions downstream of the socket connection point.

In each completed case, the RCBO operated correctly, no visible damage was identified during post-test inspection, and measured temperatures at plugs, sockets, and circuit containment remained within acceptable limits. Following fault clearance, all tested devices resumed normal operation without evidence of persistent fault state or degraded operating stability.

As in other parts of the programme, one device was excluded from this test area because of pre-existing PV-input damage identified before the short-circuit assessment commenced. Another device could not be included in part of the programme as it required a 2.4 GHz Wi-Fi network connection to complete its initialisation sequence, which could not be established under the shielded laboratory conditions used for EMC and other UKAS testing.

4.3.5 EMC Conducted Emissions and Harmonic Current Emission behaviour

Conducted emission testing identified exceedance of EN 61000-6-3 Class B (Class B refers to the more stringent of two emission limits setting maximum levels of RF noise as a function of frequency.[28] Class A applies to industrial devices), quasi-peak limits across the tested samples under the operating conditions applied. In accordance with the approved test protocol, all EMC and harmonic assessments were conducted at maximum rated export power, as this represents the worst-case condition for conducted emission performance.

Baseline measurements taken using representative domestic loads without connected plug-in PV devices also exceeded Class B limits, indicating a wider issue with conducted emission performance from mass-market power electronics under the test conditions. The combination of plug-in PV inverters emissions and ‘noisy’ domestic power supplies did not create a constructive interference effect, indicating that the combination of plug-in PV inverters and domestic power electronics did not produce constructive interference or amplify aggregate emissions beyond the individual device contributions.

Harmonic-current performance was generally more compliant than conducted emission performance, with all devices remaining within the defined EN61000-3-2 Class A limits across the assessed harmonic range.[29] One device failed the repeatability requirement, as the unit reduced its power output (thermal management) during the required second run and hence reduced the measured harmonic output. No unsafe operating behaviour, protection instability, or abnormal disconnection behaviour was associated with the measured EMC characteristics during testing.

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[28] BS EN 61000-6-3:2007+A1:2011, Electromagnetic compatibility (EMC) — Generic standards — Emission standard for residential, commercial and light-industrial environments. London: BSI. Available at: https://knowledge.bsigroup.com/products/electromagnetic-compatibility-emc-generic-standards-emission-standard-for-equipment-in-residential-environments

[29] BS EN 61000-3-2:2019, Electromagnetic compatibility (EMC) — Limits for harmonic current emissions for equipment input current up to and including 16 A per phase. London: BSI. Available at: https://knowledge.bsigroup.com/products/electromagnetic-compatibility-emc-limits-limits-for-harmonic-current-emissions-equipment-input-current-16-a-per-phase-4

The empirical result from this part of the programme is one of non-uniform EMC conformity under the applied test conditions (ambient temperature but maximum export power), rather than one of observed unsafe electrical behaviour.[30] The correct technical interpretation is therefore not that plug-in PV causes dangerous EMC behaviour under the tested conditions, but that EMC conformity remains a material product design and deployment consideration that a future UK product specification should explicitly address.

4.3.6 Anti-islanding and loss-of-mains behaviour

Anti-islanding testing examined whether devices ceased energisation following removal of the grid reference under both synchronous and asynchronous disconnection conditions. All successfully tested devices disconnected within the required 500 ms limit defined within G98, with measured disconnection times typically substantially faster than that threshold and closer to disconnection times for RCBOs.

For context, a more stringent physiological threshold of sub-40 ms, equivalent to two cycles of the 50 Hz supply, has been identified in the technical literature as the threshold below which the risk of ventricular fibrillation from electric shock is materially reduced, the same threshold that applies to RCBO trip times under IEC 61009-1.[31]

Synchronous disconnection times were typically recorded in the order of approximately 16 to 19 ms, while asynchronous disconnection scenarios produced times ranging from approximately 7 ms to 68 ms. No sustained energisation, unstable oscillation, or self-sustaining island formation was observed during any completed event.

This is significant at system level because it confirms that the core inverter control logic of the tested devices is compatible with the fundamental safety expectation for small scale grid-connected generation: cease export promptly when the grid reference disappears. These findings were consistent across the completed anti-islanding scenarios; full anti-islanding test records are set out in Appendix A6.

4.3.7 High temperature behaviour

High temperature testing examined device performance under elevated ambient conditions combined with sustained export operation. Across the tested sample, electrical behaviour remained generally stable, with no evidence of shutdown instability, uncontrolled export, or thermal runaway attributable solely to elevated ambient temperature. Quantitative measurements required the measured average THD(V)% to remain stable compared to ambient operation, with acceptance criteria set as ∆THD(V)% increase less +0.5%. The total

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[30] BS EN 61000-6-3:2007+A3:2021, Electromagnetic compatibility (EMC) — Generic standards — Emission standard for residential, commercial and light-industrial environments. London: BSI. Available at: https://knowledge.bsigroup.com/products/electromagnetic-compatibility-emc-generic-standards-emission-standard-for-equipment-in-residential-environments

[31] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://dcode.org.uk/assets/250307ena-erec-g98-issue-2-(2025).pdf

harmonic distortion of the voltage output provides a measure of internal electronic operation, and if any arcing or component failure occurred, a broad spectrum of noise would be generated measured as an increase in THD(V)%.

One device exhibited physical shrinkage of the AC cable sheath during prolonged high temperature exposure. This was recorded as a material integrity observation, but it was not accompanied by broader evidence of unstable inverter operation, protective device malfunction, or unsafe energisation behaviour within the completed test scenario.

4.4 Enhanced assessment findings

4.4.1 Frequency response

Enhanced testing examined operating behaviour across extended frequency conditions beyond the normal domestic operating range. Expected behaviour was that devices would maintain stable, continuous operation at all frequency set points within the normal frequency band (49.5–50.5 Hz), but the inverter would disconnect within 0.5 seconds of the supply frequency falling below 47 Hz or rising above 52 Hz, in accordance with G98 requirements.

Across all the tested samples, devices remained stable within the normal 49.5 Hz to 50.5 Hz operating band without nuisance tripping, instability, or unsafe behaviour. At the outer frequency thresholds, device-to-device variation was observed.

Most tested devices disconnected rapidly during excursions beyond the relevant G98 frequency thresholds of 47 Hz and 52 Hz, with disconnection times consistent with the G98 requirements. One device remained operational to a higher-than-expected over-frequency point, exceeding the upper threshold before disconnection was observed. Full frequency tolerance test records including device-specific disconnection points are set out in Appendix A9.

4.4.2 Voltage tolerance behaviour

Voltage sweep testing assessed device behaviour across the normal operating range into a broader G98 relevant threshold range, with each inverter operated at maximum export throughout. Across the sample set, all devices remained operational within the normal 216 V to 253 V band and no unsafe behaviour, uncontrolled output, or abnormal heating was observed during those normal-band conditions.

At the threshold extremes, however, disconnection behaviour was not uniform across the sample. Several devices did not disconnect at or before the G98 nominal threshold values. Over voltage disconnection points above 273 V were recorded for some units. For under voltage behaviour, one device had not disconnected at the lower limit of the applied voltage sweep; the test could not be extended further within the available equipment range, and disconnection behaviour below that point therefore remains unconfirmed for that device.

The empirical finding from this test area is therefore one of robust stability within the normal operating voltage band combined with variable product-dependent threshold behaviour at the extended limits (see Appendix A13 for the full voltage tolerance test records).

4.4.3 Startup and shutdown transients

Startup and shutdown testing examined whether connection and disconnection occurred in a controlled manner during energisation and de-energisation events. There are no explicit criteria for acceptance of transients during startup or shutdown. The intention is to ensure that any induced transient should not impart significant energy onto the connected grid or domestic circuitry.

Elements of G98 (no AC-side voltage disturbances during startup or shutdown that would challenge compliance with UK grid connection) and EN61000 that specify voltage spike/sag should not exceed a ¼ cycle of the mains voltage (5ms at 50Hz). Short duration spikes, sags, and ringing effects were observed on selected devices during isolated events. However, these remained brief and within the defined assessment envelope indicating low energy events, with no evidence of prolonged switching instability or uncontrolled export behaviour.

Across the tested devices, startup and shutdown durations were typically in the order of approximately 10 ms to 13 ms. No specific acceptance threshold for startup or shutdown duration is defined in G98 or BS 7671 for plug-in PV systems. The 10 ms to 13 ms range observed in this study is noted as a reference baseline for future framework development rather than as a pass-fail criterion.

4.4.4 Export limitation behaviour

Export limitation testing examined whether devices remained within their declared AC export ratings across changing supply voltage conditions. Operationally, devices remained stable throughout the relevant test sequences, and no abnormal heating, protection operation, or broader instability was associated with export limit testing.

However, device level conformity with stated maximum export ratings was not uniform across the tested sample. Several devices remained below their declared maximum AC output throughout the test sequence, while two lower rated devices exceeded their declared 400 W output ratings during portions of the voltage sweep. No tested device approached the wider single-phase G98 export threshold (see Appendix A11 for the full export limitation test records).[32]

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[32] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://www.energynetworks.org/industry-hub/resource-library/g98-issue-2-amendment-3-2022. VDE-AR-N 4105:2018-11, Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html

4.4.5 Dynamic operating behaviour

Dynamic grid connection testing examined synchronisation and operating stability under variable sunlight conditions (Solar irradiance or PV load in lab). Change in conditions simulated include step changes in PV input, outdoor partial shading, more severe irradiance reductions, and dual-input operation on selected devices which have twin DC inputs for multiple PV arrays.

Across the tested samples and reported scenarios, the systems remained stable under dynamic operating conditions. No sustained oscillation, unstable self-sustaining behaviour, loss of synchronisation, or unsafe reconnection behaviour was observed during the assessment programme.

Supplementary self-oscillation checks using paired inverters following RCBO operation further showed that both units ceased export and did not self-oscillate on either spur or ring-final arrangements (see Appendix A12 for the full dynamic grid connection test records).

4.5 Summary of test outcomes

Across the full test programme, the tested plug-in PV systems demonstrated stable core operating behaviour under representative domestic conditions. Continuous export operation was maintained under controlled DC input conditions, and all functioning tested devices synchronised and disconnected in response to simulated grid events in line with their intended operating principles.

No instance of sustained unintended energisation was observed following protective device operation. All successfully tested devices demonstrated anti-islanding disconnection within the applicable 500 ms G98 acceptance criterion under both synchronous and asynchronous disconnection conditions, with measured times typically substantially faster than the threshold.

Thermal and protection-related behaviour remained stable across most tested conditions. However, the results also showed that observed system behaviour was influenced by interaction between inverter characteristics, circuit loading, and connection quality, including socket condition, and variable domestic loads.

Material device to device variation was also observed at certain operational boundaries, particularly in relation to conducted emissions, export limitation, and voltage and frequency threshold behaviour, as described in sections 4.3 and 4.4

Table 4.3 summarises the principal outcomes from the core test programme. It should be read alongside the detailed findings presented in sections 4.3 and 4.4 rather than as a substitute for the underlying results.

Table 4.3, Summary of principal test outcomes

Test Area	Main Observed Outcomes
Initial Assessment	
Thermal endurance	Stable operation across all tested devices; no shutdown, oscillation, or unsafe thermal behaviour observed under sustained export.
RCBO and residual-current behaviour	Protective devices operated in all completed fault events; one timing exceedance against the IEC 61009-1 40 ms criterion at 5 ΔIn recorded under a specific configuration; no inhibited operation observed.
Ring-final and reverse-current behaviour	No localised overheating or uneven current distribution across ring-final and spur wiring identified in completed tests
Short-circuit response	Protective devices operated correctly; tested devices resumed normal operation following fault clearance.
EMC and harmonic behaviour	Conducted emission exceedances observed across tested samples at maximum rated export power.
Anti-islanding	All successfully tested devices disconnected within the required time limit as specified in G98; no sustained energisation observed.
High-temperature behaviour	Electrical behaviour remained broadly stable; one device exhibited physical cable-sheath shrinkage under prolonged high-temperature exposure.
Enhanced Assessment	
Frequency and voltage tolerance	Stable operation within normal operating bands; threshold-based disconnection behaviour varied between devices at extended limits.
Startup, shutdown, and dynamic behaviour	Connection and disconnection remained fast and controlled; no sustained oscillation or unsafe reconnection observed.
Export limitation	Operational stability remained intact, but conformity with declared device-level export limits was not uniform across the sample.

4.6 Cross-cutting observations from the empirical programme

Across the full test programme, no device exhibited thermal runaway, sustained fault contribution, uncontrolled islanding behaviour, or continued energisation following protective device operation. The dominant empirical pattern was one of stable operation within the tested domestic operating envelope, with important but bounded device to device variation emerging at technical thresholds and under certain stressed conditions.

The most consistent findings related to thermal stability during sustained operation, successful protective disconnection, rapid anti-islanding response, stable operation within normal voltage and frequency bands, and controlled dynamic synchronisation behaviour. The main areas of non-uniformity observed in the empirical programme related to conducted emissions, threshold behaviour under extended voltage and frequency excursions, export limitation conformity on selected devices, and one physical material integrity observation under prolonged high temperature exposure.

The findings support a clear distinction between general operational stability and full conformity consistency. Within the tested operating envelope, plug-in PV systems did not introduce new dominant hazard modes beyond those already associated with conventional appliance connection and small-scale grid-connected power electronics. The strongest areas of demonstrated performance were thermal stability, anti-islanding, protective device compatibility, and stable operation within normal supply bands.

Principal areas where caution remains warranted are EMC conformity, threshold-response variation at extended voltage and frequency limits, and product-specific export conformity. These are not evidence of widespread unsafe behaviour, but they indicate that the category is not yet technically homogeneous enough to be treated as fully standardised across all products and configurations.

These cross-cutting observations, together with the system level interpretation above, form the evidential basis for the implementation considerations addressed in Chapter 5.

4.7 Remaining evidence gaps

Several areas remain outside the direct evidence base of this study. The test programme does not provide a statistically exhaustive market survey, nor does it capture the full variability of real-world domestic installations. It also does not assess network-scale cumulative impacts such as harmonic aggregation, phase imbalance, transformer loading, or interactions with large populations of distributed devices.

In addition, the study does not provide long term ageing evidence for sockets, plugs, extension leads, or inverter components under prolonged real-world operating cycles. That means the results are strongest for the tested operating envelope and the immediate technical question of safety and feasibility, but less definitive on long term durability or large-scale system integration.

These limitations do not weaken the empirical findings within the tested envelope. They do, however, shape the confidence that can be placed in extrapolation to broader deployment scenarios.

4.8 Implications for implementation

The technical interpretation points toward a controlled, rather than unrestricted, deployment pathway. If plug-in PV is to be considered for wider use, the evidence suggests that future arrangements would need clear product criteria, defined export and disconnection expectations, and explicit attention to socket condition and installation quality.

The study also suggests that any future standards or guidance would need to address not only the device itself, but the domestic context in which the device operates. In that sense, plug-in PV is not just a product question; it is a system interaction question. Those issues are taken forward in Chapter 5, which addresses deployment and implementation considerations.

5 Deployment and Implementation Considerations

5.1 Purpose of this chapter

This chapter considers how the technical findings from the study translate into practical deployment conditions for plug-in PV in the United Kingdom. Its purpose is to identify the implementation conditions supported by the empirical evidence and to provide a technically grounded basis for policy and regulatory decisions.

The chapter therefore focuses on the interaction between technical performance, consumer behaviour, domestic installation variability, product conformity, and regulatory coordination. It draws on both the empirical findings and the wider stakeholder and comparative context captured elsewhere in the report.

5.2 Starting point for deployment

The central implementation implication of the study is that plug-in PV systems are compatible with UK domestic electrical systems when operated within the tested no-modification boundary and when products meet appropriate technical requirements. The empirical evidence supports technical feasibility within that boundary, and the relevant implementation question is therefore not whether plug-in PV can be deployed, but how a proportionate and enforceable product and notification framework should be designed.

5.3 Technical preconditions

Products placed on the UK market as plug-in PV systems should meet clearly defined technical requirements. Based on this study’s empirical findings, those requirements should include:

- inverter safety conformity to EN 62109-1;[33]
- anti-islanding performance aligned to G98 functional expectations, verified through type testing;[34]

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[33] IEC 62109-1:2010, Safety of power converters for use in photovoltaic power systems — Part 1: General requirements. Geneva: IEC. Available at: https://www.en-standard.eu/bs-en-62109-1-2010-safety-of-power-converters-for-use-in-photovoltaic-power-systems-general-requirements/

[34] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://dcode.org.uk/assets/250307ena-erec-g98-issue-2-(2025).pdf

- export limitation verified at maximum rated output across the proposed statutory supply voltage operating range (207–253 V);[35]
- conducted EMC performance assessed against EN 61000-6-3 Class B limits at maximum rated export power, not under reduced or partial output conditions; and
- physical AC connection via an over-moulded non-rewirable BS 1363 fused plug as supplied[36]

The majority of devices tested in this study already support most of these requirements. The product quality issues observed, principally in export limitation accuracy under voltage variation and conducted emission performance, are the areas a UK product specification for plug-in PV should seek to address.

The 800 W export cap applied in this study reflects current European market convention, consistent with VDE-AR-N 4105 and associated German balcony PV practice, rather than a hard safety threshold derived from the empirical findings of this study.[37] A UK-specific export limit should be confirmed through the G98 amendment process currently in progress.

The evidence also indicates that implementation should not assume uniform performance across all products marketed as plug-in PV. Product specific variations were observed in export limitation behaviour, threshold operation, and conducted emission performance, which means that a future pathway would likely require clearly defined qualifying product characteristics and a credible means of distinguishing compliant systems from superficially similar products marketed through retail and online channels.

This is especially important in a consumer led market. If the deployment model relies on low friction at the point of purchase and installation, then the burden of technical control shifts more heavily toward up front product eligibility, traceability, and market surveillance rather than professional installation oversight alone.

5.4 Domestic installation assumptions

The evidence generated by the study indicates that safe operation is achievable within representative domestic installations under the tested no-modification boundary. However, it also shows that operational margins are influenced by the condition of the domestic environment, including socket quality, extension lead use, and existing loading patterns.

Products should be accompanied by operationally specific consumer guidance covering acceptable socket types and minimum condition expectations; the distinction between straight

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[35] Electricity Safety, Quality and Continuity Regulations 2002 (SI 2002/2665), reg. 27. Available at: https://www.legislation.gov.uk/uksi/2002/2665/regulation/27

[36] BS 1363:2016+A1:2018, 13 A plugs, socket-outlets, adaptors and connection units. London: BSI. Available at: https://www.legislation.gov.uk/uksi/1994/1768/contents/made

[37] VDE-AR-N 4105:2018-11, Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html

and coiled extension lead use; the unsuitability of travel adaptors and multi-way extension leads not rated for continuous generation loads; recommended circuit loading practices; and the distinction between plug-in PV and permanently installed microgeneration. This guidance should be prominent at point of sale and within product documentation.

The study does not identify a technical basis for requiring full conventional installer led microgeneration procedures for all low power plug-in PV systems. However, it does support the value of clearly defined minimum installation expectations and, in some circumstances, optional advisory checks where the age, condition, or protective arrangements of the installation are uncertain.

5.5 Consumer guidance and behavioural controls

One of the strongest practical messages arising from the study is that deployment safety will depend partly on consumer behaviour rather than solely on product conformity.

The test programme deliberately included degraded socket conditions, coiled extension leads, mixed high load scenarios, and multi-way adaptors as foreseeable variability and misuse scenarios, reflecting the range of conditions likely to be encountered in occupied UK homes.

Testing did not identify new dominant electrical hazard modes attributable specifically to plug-in PV export behaviour under those conditions (see Appendix A, sections A.4–A.10). Devices generally maintained stable operation, protective devices continued to function, and no uncontrolled energisation was observed in the completed test events.

This does not mean these conditions are without risk. It means the tested devices demonstrated sufficient robustness under the specific scenarios applied. Degraded legacy installations and foreseeable consumer connection practices remain relevant considerations for a deployment framework because the study tested a representative but bounded set of conditions rather than the full range of domestic variability.

Consumer guidance and product requirements should therefore explicitly address socket condition, connection accessory suitability, and circuit loading practices; not because testing observed failures in these areas, but because they represent foreseeable variables that inform the deployment assumptions on which the safety case rests.

The customer journey also matters. Plug-in PV is likely to be acquired through retail channels, installed by users with varying degrees of electrical awareness, relocated over time, and potentially combined with other domestic energy technologies. Guidance would therefore need to support not only initial connection, but ongoing use, relocation, and continued safe operation over the product life cycle.

5.6 Product compliance and market surveillance

The evidence indicates that implementation would depend not only on standards but on the ability to identify products that genuinely satisfy the intended deployment criteria. This is particularly relevant in a market where products may be imported through online retail channels, described inconsistently, or presented ambiguously as either consumer appliances or generation equipment.

For the purposes of this study and the recommendations that follow, product traceability refers to the ability to identify, through labelling, registration, or documentation, whether a specific product placed on the UK market meets the defined technical eligibility criteria for socket connected domestic generation.

This is not supply chain traceability in a broader commercial sense. The practical objective is to support OPSS and other market surveillance bodies in distinguishing products that meet UK plug-in PV requirements from superficially similar products that do not.[38]

A future UK model would therefore need product identification and traceability mechanisms capable of supporting market surveillance. That could include clear labelling, product category definitions, documented conformity expectations, and enforcement routes for products that do not meet the intended technical criteria for socket connected deployment.

Without such arrangements, a controlled deployment concept would be difficult to maintain in practice. The category could quickly become blurred by non-equivalent products whose marketing claims imply suitability without demonstrating the same technical performance under UK conditions and standards.

5.7 Network visibility and notification

Although the tested export levels did not indicate major immediate network instability within the scope of this study, plug-in PV still challenges existing administrative assumptions surrounding small scale generation. Current G98 processes are generally structured around installer led generation connections with clearer allocation of notification responsibilities and more direct visibility to network operators.[39]

G98 is currently being amended to accommodate plug-in PV as a distinct category of socket connected microgeneration. The notification arrangement developed under that amendment should be proportionate to the consumer deployment model and should not require installer sign off or full conventional microgeneration commissioning processes.

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[38] Product Safety and Metrology etc. (Amendment etc.) (EU Exit) Regulations 2019 (SI 2019/696). Available at: https://www.legislation.gov.uk/uksi/2019/696/contents/made

[39] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://dcode.org.uk/assets/250307ena-erec-g98-issue-2-(2025).pdf

As a minimum, the notification mechanism should capture:

1. the product type and declared export rating;
2. the installation address;
3. and the approximate date of first connection.

This would provide distribution network operators with the visibility needed to understand cumulative uptake and monitor aggregate export characteristics, without placing disproportionate administrative burdens on individual consumers. The mechanism should also accommodate relocation of devices between UK addresses post initial deployment.

5.8 Alignment across frameworks

A major theme of the study is that product standards, installation rules, and network requirements each address only part of the overall risk picture.

- Product conformity can govern inverter safety, anti-islanding functionality, and some aspects of EMC behaviour
- Installation rules can govern wiring safety and protective device expectations
- Network rules can govern export and connection behaviour

None of these frameworks, taken alone, fully resolve the deployment concept represented by consumer installed plug in generation.

The evidence therefore supports a joined-up implementation approach in which product conformity, domestic installation assumptions, consumer information, and network visibility are treated as connected parts of a single deployment model. This matters because the principal implementation challenge is not merely technical operation at the device level, but the coherence of the overall system into which the device is introduced.

In practical terms, this suggests that a UK implementation pathway will require coordination across product safety authorities, standards bodies, electrical installation stakeholders, network actors, and policymakers rather than relying on any single existing governance route.

The study also notes that the position of plug-in PV under Permitted Development Regulations is not currently clear.[40] It is uncertain whether socket connected generation installed on balconies or external walls falls within existing PDR provisions or requires separate planning consideration. Resolving this question should form part of the implementation framework, as ambiguity in planning status could create uncertainty for both consumers and enforcement authorities.

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[40] Town and Country Planning (General Permitted Development) (England) Order 2015 (SI 2015/596), Schedule 2, Part 14. Available at: https://www.legislation.gov.uk/uksi/2015/596/schedule/2/part/14/made

5.9 Optional support and proportionate oversight

The study findings do not support a blanket requirement for electrician installation within the assessed no-modification deployment model. However, it does indicate that some households may benefit from optional professional support where installation condition is uncertain, socket quality is visibly degraded, protective device arrangements are unclear, or the intended connection point is not obviously suitable.

A proportionate model could therefore combine a primarily consumer led pathway with optional or targeted advisory support. This would help preserve the accessibility benefits of plug-in PV, particularly for renters and households unable to pursue rooftop solar, while still recognising that not all domestic environments offer an identical deployment scenario.

5.10 Implementation monitoring and framework review

Given that the Government has confirmed that plug-in PV will be made available to consumers in the near term, the implementation framework should be designed to operate from the point of initial market availability.

A monitoring programme should run alongside initial deployment to observe real world consumer behaviour, connection practices, and any cumulative network or safety effects not captured in this study's laboratory assessment. Monitoring should be treated as an integral part of the implementation framework rather than a separate research activity.

Initial deployment should focus on products meeting the defined technical eligibility criteria set out in section 5.3 (technical preconditions). The lessons from this initial deployment period could inform future revisions to BS 7671 guidance on socket connected generation, product conformity expectations, EMC interpretation, consumer information requirements, and DNO visibility arrangements.[41]

Where evidence from monitoring indicates emerging safety concerns, misuse patterns, or cumulative effects beyond the tested envelope, the framework should include clear mechanisms for updating product requirements or guidance without requiring full legislative revision.

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[41] BS 7671:2018+A2:2022, Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://shop.theiet.org/requirements-for-electrical-installations-iet-wiring-regulations-eighteenth-edition-bs-7671-2018-a4-2026

5.11 Building and fire safety context

The study's laboratory findings are strongest in relation to electrical safety and system behaviour within representative domestic circuits. However, stakeholder engagement highlighted that future deployment would also need to consider broader building safety and fire safety questions, particularly in multi-occupancy buildings, higher risk residential settings, and properties where landlord, managing agent, or building operator responsibilities apply.[42]

This does not mean that plug-in PV should automatically be regarded as incompatible with those settings. It does mean that implementation cannot rely solely on device level electrical conformity where the wider deployment context introduces additional governance questions concerning facade attachment, cable routing, resident behaviour, common areas, fire compartmentation, and accountability for in use conditions.

Accordingly, any future framework may need to distinguish between general domestic deployment and building contexts where additional permissions, restrictions, or oversight mechanisms are justified. That issue is especially relevant where systems are used on balconies, attached to external walls, or operated in buildings with more complex safety governance arrangements.

A dedicated fire safety assessment, covering thermal and ignition behaviour of modules and inverters in balcony and external wall mounting configurations, and interaction with building materials and fire compartmentation, has been identified by stakeholders as a priority area for follow-on work.

5.12 Accountability and responsibility

Plug-in PV creates an important practical question of responsibility allocation. Because the technology sits between consumer product use and embedded generation, accountability does not rest as clearly with one actor as it typically does for either a standard appliance or a conventional installer led rooftop PV system.

The implementation framework should include clearer allocation of responsibilities across manufacturers, importers, retailers, consumers, landlords where relevant, and network actors. This includes responsibility for product conformity, clarity of instructions, suitability of deployment assumptions, notification or registration where required, and response where unsafe products or unsuitable use conditions are identified.

This matters operationally because unclear accountability weakens enforceability. Even where the technical envelope is well defined, a deployment framework will struggle in practice if it is unclear who is responsible for ensuring that products are correctly marketed, appropriately

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[42] Building Safety Act 2022 (c.30). Available at: https://www.legislation.gov.uk/ukpga/2022/30/contents/enacted

installed within the intended boundary, and used in ways consistent with the safety assumptions underpinning the framework.

5.13 Cumulative deployment effects

This study does not directly assess large scale aggregated impacts arising from widespread adoption of plug-in PV. It does not provide a network scale analysis of cumulative harmonic aggregation, local transformer loading, phase imbalance, or interaction between large populations of plug-in PV devices and other distributed technologies such as battery storage or electric vehicle charging.

The evidence supports conclusions about device level and circuit level behaviour within the tested envelope, but wider deployment may create new system questions once device numbers increase materially across neighbourhoods or building types.

As deployment scales, DESNZ and DNOs should consider whether a lightweight mandatory registration mechanism, even a simple online product registration at point of purchase, would provide sufficient visibility to monitor cumulative uptake without creating barriers for consumers.

This is another reason an active monitoring programme alongside initial deployment would be valuable. Early deployment experience, combined with proportionate registration or visibility arrangements, could help build the evidence base needed to understand whether cumulative impacts remain negligible at scale or require additional coordination or remedial measures.

5.14 International relevance for UK implementation

Comparative experience from other European jurisdictions provides a useful indication that plug-in PV can be deployed within a constrained and simplified microgeneration framework rather than being treated as a wholly novel electrical category.

In countries such as Germany,[43] Austria,[44] and the Netherlands,[45] deployment approaches have generally combined export caps, product conformity expectations, simplified registration or notification, and practical consumer guidance rather than full conventional installer led generation processes in all cases.

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[43] VDE-AR-N 4105:2018-11, Power generation systems connected to the low-voltage distribution network. Available at: https://www.vde-verlag.de/standards/0100476/vde-ar-n-4105-anwendungsregel-2018-11.html

[44] OVE E 8101:2019 and Kleinanlagen provisions under ElWOG 2010. Available at: https://www.ove.at/ove-standardization/normen-produkte/ove-e-8101/

[45] Netherlands Enterprise Agency (RVO), salderingsregeling and net metering arrangements for small-scale generation. Available at: https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie/energie-opwekken/zonnestroom

That international experience is relevant because it suggests that a middle ground implementation model is possible in principle. At the same time, the UK context differs materially because of ring-final circuit topology, BS 1363 fused plug and socket arrangements, mixed legacy protective device configurations, and the diversity of domestic installation conditions.

The export limits of 600 W to 800 W applied in Germany, Austria, and the Netherlands reflect national policy and implementation conventions established through VDE-AR-N 4105 and related national frameworks, not hard safety thresholds derived from empirical electrical testing comparable to this study.[46] This study does not independently establish a UK specific maximum export limit. The appropriate UK limit should be determined through the G98 amendment process, informed by the empirical findings here and the international reference points noted above.

The implication is that international practice is useful as a reference point, but not as a substitute for UK specific design. Any UK pathway would need to remain anchored in the no-modification boundary and the domestic electrical realities tested in this study.

5.15 Emerging market evolution

Stakeholder discussions undertaken during the study indicate that plug-in microgeneration is evolving beyond simple PV panel and microinverter systems toward broader integrated domestic energy products. Manufacturers and market participants described increasing convergence between plug-in PV, battery storage, app-based monitoring, export management, and smart-load integration.

As the market context is not static, a framework designed only for simple plug-connected PV modules may quickly become incomplete if the market moves toward integrated plug-in PV with storage systems or modular consumer energy platforms capable of more complex operating modes. The study therefore suggests that future implementation approaches should be sufficiently clear to control the current plug-in PV category, but also sufficiently adaptable to remain relevant as the underlying product ecosystem evolves. Without that flexibility, regulatory treatment may lag behind actual product development and market behaviour.

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[46] VDE V 0100-551-1:2020, Low voltage electrical installations — Part 5-55: Selection and erection of electrical equipment — other equipment — Section 551: Low voltage generating sets. Available at: https://www.vde-verlag.de/standards/0100460/din-vde-v-0100-551-1-vde-v-0100-551-1-2018-05.html

5.16 Proportionate implementation approach

The evidence supports neither an unrestricted “plug and play” interpretation with minimal safeguards nor a full regulatory treatment equivalent to larger embedded generation installations.

Within the tested envelope, core electrical safety functions can operate effectively, thermal behaviour can remain acceptable, and anti-islanding and protective functions can perform as intended. At the same time, the study identifies domestic infrastructure variability, foreseeable misuse scenarios, product non-uniformity, and wider system uncertainties that cannot be ignored.

The most proportionate implementation response is therefore a middle ground approach. Such an approach would combine strict product conformity expectations, defined export limitations, clear consumer information, proportionate notification and visibility arrangements — delivering a controlled deployment model without imposing the full administrative burden of conventional microgeneration installation procedures.

5.17 Chapter conclusion

This study supports implementation of a proportionate product and notification framework for plug-in PV in the UK. That framework should define which products are eligible for socket connected domestic generation, what consumers need to know before connecting them, how DNOs are notified of deployment, and how compliance is monitored once products are on the market.

The technical findings of this study confirm that such a framework is achievable. Core safety functions — thermal stability, protective disconnection, anti-islanding response, and stable operation within normal supply conditions — were demonstrated across the tested devices within the no-modification boundary.

The outstanding areas requiring further specification — multiple device circuit behaviour, and fire safety in building contexts — have been identified as priorities for follow-on work and do not prevent implementation proceeding on the basis of the evidence established here.

6 Conclusions and Recommendations

6.1 Purpose of this chapter

This chapter brings together the overall conclusions of the study and sets out the principal recommendations arising from the evidence. It provides the clearest direct answer to the central question posed at commissioning: whether plug-in PV can be used safely in UK homes when connected via existing domestic socket outlets without modification to fixed wiring, consumer units, or protective devices.

The conclusions and recommendations should be read within the boundaries of the study. The work is a structured pre-compliance and feasibility assessment under a defined no-modification boundary, not a substitute for full certification, long term field deployment evidence, or complete revision of the relevant UK installation and network frameworks.

6.2 Overall conclusion

The evidence generated during this study indicates that plug-in PV systems can demonstrate broadly safe and technically coherent behaviour within the strict no-modification boundary tested. Across the representative domestic circuits, devices generally maintained stable operation, disconnected appropriately under loss-of-mains and fault conditions, and did not exhibit sustained unsafe energisation or uncontrolled thermal behaviour in the tested scenarios.

However, the study does not support the conclusion that all plug-in PV products can be treated as a fully uniform or universally suitable consumer appliance category for unrestricted deployment. Product specific variation from existing technical standards was observed in areas including export limitation behaviour, threshold response under voltage and frequency excursions, and electromagnetic compatibility performance under the applied conditions.

The overall conclusion is therefore conditional on excluding devices from the market that don’t meet the defined technical standards for the product category. Safe operation is technically feasible for suitably certified devices and within stated usage conditions, but not all devices currently being sold in the UK meet the required technical standards they claim to be certified against.

6.3 Direct answer to the study question

The central question for DESNZ was whether plug-in PV can be safely deployed in the United Kingdom without modification to sockets or fixed building wiring. Based on the evidence, deployment appears technically feasible within a clearly defined and controlled framework. Appropriate product standards and safeguards would therefore be needed to support deployment.

Those conditions are the no-modification boundary, qualifying product standards, defined export limitations, and the consumer guidance and notification arrangements described in Chapter 5.

6.4 Principal findings and policy implications

Several findings emerge consistently across the study:

- plug-in PV can operate stably on representative UK domestic circuits within the tested no-modification boundary — meaning no new wiring, consumer unit changes, or additional protective devices are required
- anti-islanding and loss-of-mains disconnection performance was generally strong — devices shut down safely and promptly when the grid supply was removed or interrupted
- protective devices continued to operate under the tested fault conditions — existing circuit breakers and all types of RCBOs tested functioned correctly and were not prevented from tripping by inverter export current
- sustained thermal instability was not observed — no evidence of overheating, fire risk, or progressive thermal deterioration was identified under representative operating conditions
- no sustained unsafe energisation was identified following protective device operation — devices did not continue to export electricity unsafely after a circuit breaker had operated
- product specific variation was observed at technical boundaries, particularly in relation to export limitation, threshold behaviour, and conducted emission performance — indicating that not all products marketed as plug-in PV perform equivalently, and that a UK qualifying product standard is needed

Taken together, these findings support a differentiated view of the technology. The study does not indicate that plug-in PV is inherently incompatible with UK domestic electrical systems, but it also does not support a simplified assumption that all plug-in microgeneration products currently marketed meet all of the various technical standards required for grid connected microgeneration and product compliance certification. A qualifying product standard is therefore needed to define the technical eligibility criteria that products must meet before being placed on the UK market as socket connected generation.

For BSI, the ENA, and OPSS, the findings indicate that the interface between plug-in PV, BS 1363 socket outlets, domestic protection arrangements, and grid connected microgeneration requirements now requires clearer treatment.[47] In particular, future product technical specification work should focus on product eligibility, export limitation, EMC expectations in socket connected use, consumer guidance, and the treatment of plug-in PV as a potentially distinct but bounded subset of small scale generation.

6.5 Recommendations

Recommendation 1: Establish a product and notification framework as the basis for deployment

The evidence supports deployment of plug-in PV within an appropriate framework of product standards, consumer safeguards, and proportionate notification arrangements. Deployment should proceed on this basis with defined technical eligibility criteria. The framework should be proportionate, accessible, and enforceable rather than equivalent in burden to conventional installer led microgeneration.

Recommendation 2: Define a qualifying product category

If plug-in PV is to be enabled, a clearly defined qualifying product category should be established. This category should specify the relevant technical characteristics required for consumer socket connected deployment, including inverter safety, anti-islanding behaviour, export limitation, and relevant electromagnetic compatibility expectations. Products sold into the UK should be supplied with an over-moulded 13A fused plug as part of the microinverter system.[48]

Recommendation 3: Establish explicit export and disconnection requirements

Future deployment should be underpinned by clear and verifiable requirements for maximum export power behaviour, voltage and frequency threshold response, and disconnection performance. G98 and EN 50549 1 (Requirements for Micro Generating Plants to be Connected in Parallel with Public Low Voltage Distribution Networks) provide coverage for elements of these parameters.[49] Parameters should be traceable within a defined accredited measurement system and accreditation should be available for market regulators to examine upon request.

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[47] BS 1363:2016+A1:2018, 13 A plugs, socket-outlets, adaptors and connection units. London: BSI. Available at: https://www.legislation.gov.uk/uksi/1994/1768/contents/made

[48] IEC 62109-1:2010, Safety of power converters for use in photovoltaic power systems — Part 1: General requirements. Geneva: IEC. Available at: https://www.en-standard.eu/bs-en-62109-1-2010-safety-of-power-converters-for-use-in-photovoltaic-power-systems-general-requirements/

[49] ENA Engineering Recommendation G98, Issue 2, Amendment 3 (2022), Requirements for the connection of fully type tested micro-generators (up to and including 16 A per phase) in parallel with a public low-voltage distribution network. Available at: https://www.energynetworks.org/industry-hub/resource-library/g98-issue-2-amendment-3-2022. BS EN 50549-1:2019, Requirements for generating plants to be connected in parallel with public low-voltage distribution networks. London: BSI. Available at: https://knowledge.bsigroup.com/products/requirements-for-generating-plants-to-be-connected-in-parallel-with-distribution-networks-connection-to-a-lv-distribution-network-generating-plants-up-to-and-including-type-b-1

Recommendation 4: Address EMC conducted emission requirements

EMC Conducted Emission testing needs to reflect real life operational conditions and be compliant up to the maximum export power ranges. Current test standards do not require conducted emission assessment at maximum export power, which means existing certification may not reflect worst case in-use conditions.

Plug-in PV systems are destined to be purchased and installed by domestic consumers. As such, EMC testing of systems should pass EN 61000-6-3 Class B emission limits. Test results from an independent test house as undertaken for UKCA and CE marking, should be available to consumers as part of product traceability.[50]

Recommendation 5: Define minimum safe domestic use conditions

Any future deployment route should be accompanied by customer guidance for safe electrical operation and domestic installation in the UK environment. This should include, but not limited to, explicit guidance regarding socket condition, exclude the use of EU/US power adaptors, and highlight circumstances in which professional advice or inspection may be appropriate. The socket that the plug in PV system is connected to should be either indoor or be a suitable IP56 rated unit.[51]

Recommendation 6: Develop strong consumer guidance

Consumer facing information should form part of the control framework rather than being treated as supplementary material. Guidance should be operationally specific, prominent at point of sale, and clear about appropriate connection practices, prohibited or unsuitable arrangements, relocation considerations, and the distinction between plug-in PV and permanently installed microgeneration.

Recommendation 7: Create proportionate visibility or notification arrangements

A proportionate mechanism should be considered to provide visibility of uptake and aggregate deployment characteristics.

As a minimum, registration should capture: the product name and declared export rating; the UKCA or equivalent conformity marking reference; the installation postcode; and the approximate date of first connection. Registration should accommodate subsequent relocation by allowing consumers to update the installation postcode and connection date without requiring a new registration. This would enable DNOs to maintain an accurate picture of cumulative deployment at local network level without placing disproportionate burdens on individual consumers.

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[50] Electrical Equipment (Safety) Regulations 2016 (SI 2016/1101). Available at: https://www.legislation.gov.uk/uksi/2016/1101/contents/made.

[51] IEC 60529:2013, Degrees of protection provided by enclosures (IP Code). Geneva: IEC. Available at: https://webstore.iec.ch/en/publication/2452

Suppliers registered under this mechanism should also be expected to provide security related firmware updates through the same platform, consistent with obligations arising under the EU Cyber Resilience Act for products marketed in Europe.

Recommendation 8: Maintain ongoing market and deployment monitoring

A future implementation route would require continued market, and deployment monitoring will be important to identify emerging risks not evidenced in this study before they become material issues in practice. This should focus on whether products entering the market continue to align with the technical characteristics assumed in this assessment, whether deployment patterns remain consistent with the intended use case, and whether any new safety, security, or compliance concerns begin to appear as volumes increase.

Monitoring should be designed to work, as far as possible, through existing arrangements and evidence sources rather than assuming the creation of a bespoke statutory traceability regime. Relevant inputs could include type testing information, registration data, online and retail market surveillance, targeted product sampling, incident reporting, and intelligence from enforcement bodies and network operators. International experience also suggests that registration data alone may not fully capture deployment levels, so a broader evidence base is likely to be needed.

This monitoring should be used to detect, in particular:

- clear product category definitions that prevent superficially similar non-qualifying products from being marketed as suitable for socket connected domestic generation without demonstrating equivalent technical performance under UK conditions
- a mechanism for tracking the gap between units placed on the market and units registered for deployment — experience from Germany, where approximately 40% of deployed balcony PV units are estimated to be unregistered, indicates that registration alone is insufficient without complementary market entry controls,[52] and
- mandatory firmware and security update obligations for products with digital elements, consistent with EU Cyber Resilience Act obligations already applicable to products sold in Europe[53]

Where such monitoring identifies materially different market behaviour or previously unobserved risks, this should trigger review of whether further standards development, guidance, enforcement activity, or regulatory intervention is justified.

Recommendation 9: Undertake targeted further work

Further work would be beneficial to support any implementation pathway and to strengthen the evidence base in areas beyond the scope of this study. Priority areas include broader product sampling, additional electromagnetic compatibility characterisation across the full range of

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[52] Bundesnetzagentur, Marktstammdatenregister (MaStR) registration data for balcony power plants, 2024. Available at: https://www.marktstammdatenregister.de.

[53] Regulation (EU) 2024/2847 (Cyber Resilience Act). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202402847

export power modes, long-term ageing and durability effects, real-world field observation, cumulative network impacts under wider deployment conditions.

Specific areas for further work include:

- additional clarification regarding governance, notification, and the treatment of plug-in PV in more complex residential settings;
- supplementary fire safety testing of PV panels designed and made available for plug-in solar equipment, including foreseeable domestic installation and use conditions;
- additional RCBO type-testing covering a broader range of device types, including split-load consumer units and combined arc-fault and residual current devices increasingly present in new UK domestic installations;[54]
- characterisation of net export operating modes, where devices modulate export in response to real-time household demand, including assessment of whether dynamic export management affects anti-islanding, threshold response, or EMC behaviour under partial and variable output conditions; and
- supplementary assessment of battery-integrated plug-in PV products, including electrical safety, thermal and fire performance, charging and control behaviour, EMC, and any implications for anti-islanding, export control, and consumer use under UK domestic conditions.

6.6 Final conclusion

This study should be understood as a structured evidence base identifying where plug-in PV appears technically feasible, where caution remains necessary, and where further clarification or standardisation would strengthen future decision making. It supports the conclusion that the technology is compatible with UK domestic electrical systems provided certain technical controls to guide product quality and installation are undertaken.

The development of a clearly bounded, standards led implementation framework should be progressed that translates the technical feasibility demonstrated in this study into a safe and enforceable real-world deployment model.

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[54] BS 7671:2018+A2:2022, Requirements for Electrical Installations (IET Wiring Regulations, 18th Edition). London: BSI / IET. Available at: https://knowledge.bsigroup.com/products/requirements-for-electrical-installations-iet-wiring-regulations-3

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Appendices

Appendix A

Project Number: PRJ 5707
Client: Department for Energy Security and Net Zero (DESNZ)
Contractor: Arceio Limited
Laboratory Partner: Eurofins E&E UK

Detailed Test Results

Plug-in PV Systems in the United Kingdom

Electrical Safety, Compatibility and Implementation Considerations

Document Status: Controlled Technical Reference
Document Version: v2
Date: 8 May 2026

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A.1 Purpose and scope

This appendix presents the empirical findings from the plug-in PV test programme. It should be read alongside the methodology, standards mapping, and acceptance criteria in the main report and Appendix B.

It records the observed behaviour of the tested devices against the agreed technical criteria under the defined no-modification boundary. Detailed procedures, rig configurations, and instrumentation settings are set out in Appendix B and the controlled protocol; this appendix reports observed outcomes, exceptions, and interpretation.

A.2 Reporting approach

Each subsection describes the test objective, the conditions applied, and the principal observed outcomes. Where relevant, it notes partial completions, exclusions, or device-specific issues that affected testing but did not alter the overall interpretation.

The results are presented as an evidential summary rather than a certification statement. Final pass/fail determinations are made in the main analysis, informed by the observed data and the acceptance framework.

A.3 Overall summary of empirical results

Across the full test programme, the tested plug-in PV devices demonstrated broadly stable and coherent electrical behaviour within the representative domestic configurations assessed. No thermal runaway, sustained fault contribution, or uncontrolled energisation following protective device operation was identified.

The strongest and most consistent findings related to thermal stability, protective device compatibility, anti-islanding performance, and stable operation within normal voltage and frequency bands. Areas requiring more caution were conducted emissions, export limitation consistency, and threshold behaviour at the edges of the voltage and frequency envelope.

Table A.1, Master summary of results

Test Category	Planned Devices	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
A1 Endurance	6	6	6	0	0	Stable operation, no thermal or protection issues
A2/A3 RCBO trip	6	31	26	1	4	One exceedance; no systemic impairment
A4 Ring/Reverse current	6	11	10	0	1*	No thermal hotspots observed
A5 Short-circuit	5	4	4	0	1*	Safe fault handling; protection operated correctly
A6 EMC/Harmonics	6	6	0	6	0	All failed Class B; context dependent baseline issues
A7 Anti-islanding	6	16	15	0	1*	All within 0.5 s (typically <20 ms)
A8 High Temperature	6	5	3	2	1*	One physical degradation; otherwise, stable
A9 Frequency tolerance	5	5	4	1	0	Stable normal band; Device 2 over frequency outlier
A10 Startup/shutdown transients	5	5	5	0	0	Fast controlled switching; minor transients compliant
A11 Export limitation	5	5	3	2	0	Two 400W devices exceeded stated limits
A12 Dynamic grid behaviour	5	5	5	0	0	Stable under irradiance changes and dual input
A13 Voltage tolerance	5	5	0	5	0	Normal band stable; threshold disconnect non-uniform

A.4 Thermal endurance and continuous operation (A1)

Continuous operation testing demonstrated stable thermal behaviour across all tested devices during sustained maximum-output operation on representative UK socket circuits. Across the six tested microinverters, no shutdown, oscillation, protective device operation, or observable physical degradation occurred during prolonged export operation.

Measured inverter casing temperatures ranged from 45.1C to 54.2C, remaining below the applicable BS 1363 reference limits for accessible metallic surfaces. Temperatures recorded at the plug and socket interface also remained below terminal temperature rise thresholds throughout the test duration, and no evidence of progressive thermal runaway, unstable export behaviour, or abnormal current fluctuation was identified during steady-state operation.

Table A.2, Thermal and Endurance Performance Results

Test Category	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
Ambient baseline	**1**	**1**	**0**	**0**	**58 W baseline load**
Loads baseline	1	1	0	0	1160 W domestic load
Device A (800W)	1	1	0	0	Maximum casing temperature 45.1°C
Device B (600W)	1	1	0	0	Maximum casing temperature 51.9°C
Device D (800W)	1	1	0	0	Maximum casing temperature 54.2°C
Device E (400W)	1	1	0	0	Partial dataset; thermal criteria satisfied
Device F (400W)	1	1	0	0	Maximum casing temperature 46.5°C
Device G (800W)	1	1	0	0	Maximum casing temperature 48.8°C
Total	**6**	**6**	**0**	**0**	

Device-specific variation was limited primarily to operational characteristics rather than safety performance. Device G required application-based initialisation before stable export commenced, while Device E recorded partial monitoring data due to instrumentation interruption, although thermal pass criteria remained satisfied.

Figure A.1, FLIR Thermal Images

Figure A.1 Thermal distribution under reverse current conditions. FLIR thermal images of rig-final circuit during testing in Eurofins test laboratory, Castleford (© Arceio)

A.5 RCBO and residual current protection performance (A2–A3)

Residual current protection testing examined whether inverter export current influenced RCBO trip behaviour under both Live-Earth and Live-Neutral fault conditions. Across the tested configurations, RCBO operation remained reliable, with protective devices operating in all completed fault events.

A total of 31 inverter test events and one baseline reference test were completed across three representative domestic circuit configurations. Measured RCBO trip times ranged from below 4 ms to 38.4 ms in 26 recorded events, remaining within the 40 ms acceptance criterion defined by BS EN 61009-1, while one exceedance of 89 ms was recorded for Device B on the Type AC ring circuit under Live-Neutral injection conditions.

Four events on the aged spur configuration were classified as incomplete because oscilloscope trigger thresholds did not capture the timing waveforms despite confirmed RCBO operation. No device prevented, delayed indefinitely, or inhibited RCBO operation under any tested condition, and microinverter shutdown following RCBO operation aligned with expected anti-islanding behaviour.

Table A.3, RCBO Trip Time Performance Results

Test Category	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
Baseline	1	1	0	0	4.58 ms reference trip
Live–Earth (A2)	16	13	0	3*	RCBO operated; timing waveform not captured
Live–Neutral (A3)	15	13	1**	1*	**Device B exceeded 40 ms criterion
Total	**32**	**26**	**1**	**5**	**All RCBOs operated**

A.6 Reverse current and ring-final interaction (A4)

Reverse current testing assessed whether plug-in PV export introduced disproportionate current concentration or thermal stress within representative UK ring-final and spur circuits under simultaneous domestic import load. Across all completed configurations, no localised thermal hotspots were identified on wiring, sockets, plugs, or trunking during combined import and export operation.

Thermal imaging demonstrated broadly uniform heat distribution under both spur and ring-final arrangements, including conditions involving approximately 2 kW import loading combined with inverter export backfeed. All tested devices maintained stable operation, and no evidence of overheating, conductor imbalance, or progressive thermal concentration was observed.

Table A.4, Ring Circuit Interaction Behaviour Results

Test Category	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
Spur circuit	5	5	0	1*	No thermal hotspots detected
Ring final circuit	5	5	0	1*	No thermal hotspots detected
Total	**10**	**10**	**0**	**1***	**Uniform thermal distribution observed**

Device B was excluded from this assessment due to pre-existing PV-side damage unrelated to the reverse current test itself.

A.7 Overcurrent and short-circuit behaviour (A5)

Short-circuit testing examined inverter response and protective device operation during controlled downstream AC fault conditions. Across all completed events, protective devices operated as intended and no unsafe thermal or physical behaviour was observed.

Four devices were successfully tested under controlled solid short-circuit conditions downstream of the socket connection point. In each case, the RCBO operated correctly, no visible damage was identified during post-test inspection, measured temperatures at plugs, sockets, and containment remained within acceptable limits, and following fault clearance all tested devices resumed normal operation without persistent fault state or instability.

Table A.5, Overcurrent and Short Circuit Performance Results

Test Category	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
Overcurrent and short circuit	4	4	0	1	Device B excluded due to pre-existing PV input damage

In all cases the protecting RCBO device operated during the test event. The upstream RCD operated during three of the four test events, with non-operation in the remaining case attributed to instantaneous waveform conditions at the moment of fault application and considered consistent with expected supplementary RCD behaviour.

A.8 EMC Conducted Emission and Harmonic Current measurements (A6)

Conducted emission testing identified consistent exceedance of EN 61000-3-2 Class B quasi-peak limits across all tested devices under the applied laboratory conditions. This was one of the most uniform findings in the test programme.

All six tested devices exceeded Class B conducted emission quasi-peak limits during operation at maximum rated export. Five of the devices also exceeded the Class B average levels. Domestic products operating in the same circuits did not produce evidence of constructive interaction with plug-in PV emissions, and no amplification effect was observed beyond the individual device contributions.

Harmonic performance against EN 61000-4-7 was generally stronger than conducted emission performance, with five units tested within the EN 61000-3-2 Class A limits. One unit failed the variability requirement because thermal management reduced its power output during the repeat run, which reduced the measured harmonic output.

No unsafe operational behaviour, instability, or protection-related issues were associated with the recorded emissions behaviour during the assessment period.

Table A.6, EMC and Harmonics Observations Results

Test Category	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
Conducted emissions	6	0	6	0	All exceeded Class B quasi-peak limits
Harmonics	5	4	1	1	Device B failed; Device G incomplete
Total	**11**	**4**	**7**	**1**	**Baseline domestic loads also exceeded Class B limits**

Figure A.2, Conducted Emission Spectrum Charts

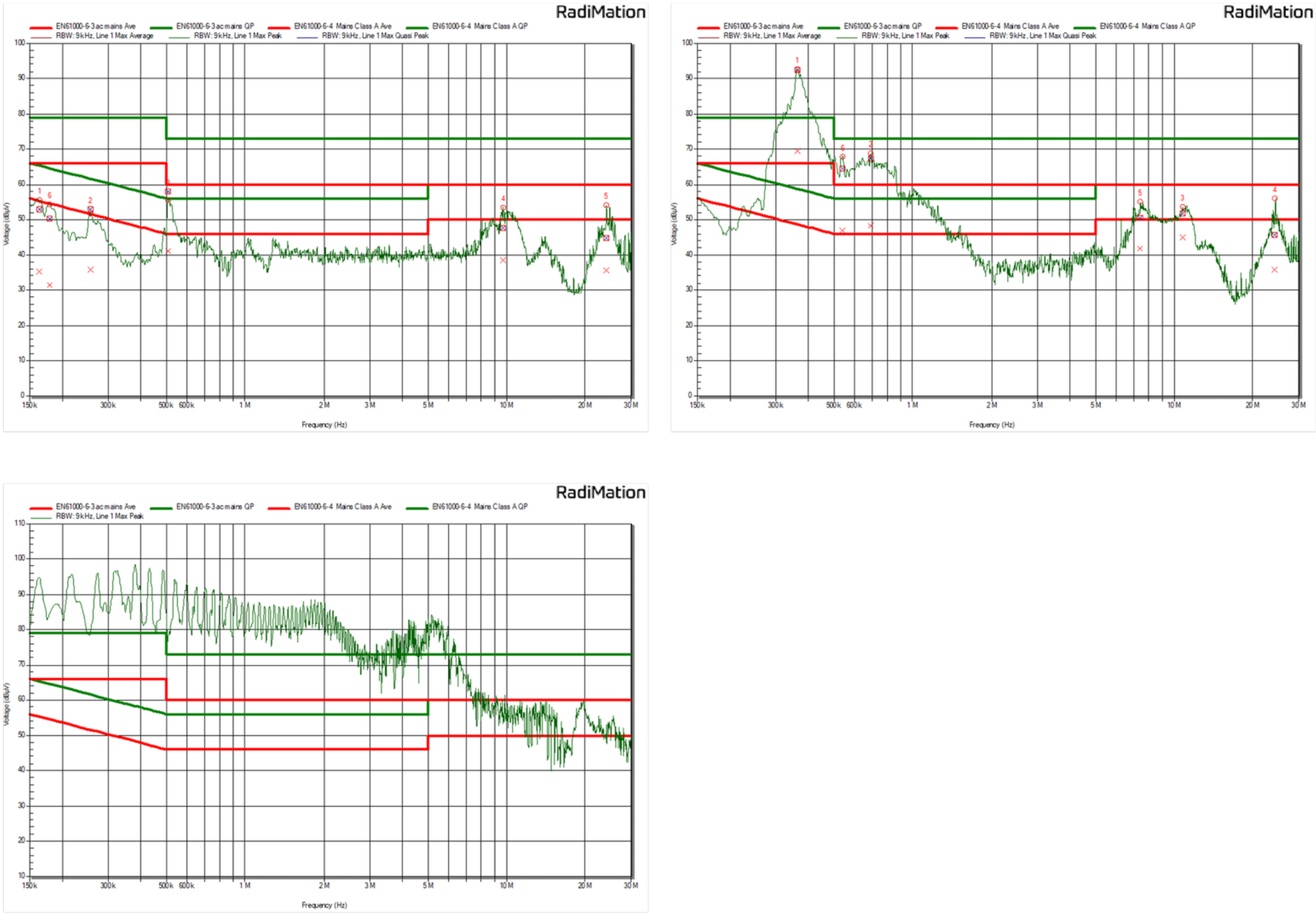

Figure A.2 Selected Conducted Emission spectrum charts including Class A and Class B quasi-peak and average emission limits as measured in Eurofins test laboratory, Yate (© Arceio)

A.9 Anti-islanding and disconnection performance (A7)

Loss-of-mains testing demonstrated rapid and consistent disconnection behaviour across all functioning devices under both synchronous and asynchronous supply interruption conditions. All successfully tested devices ceased energisation within the 500 ms acceptance criterion defined by G98 and EN 50549-1.

Measured synchronous disconnection times were typically between 16.4 ms and 19.2 ms. Asynchronous disconnect tests, incorporating a 54 ms Live-Neutral delay intended to simulate worn or degraded plug conditions, produced measured disconnection times ranging from 7 ms to 68 ms, with no sustained energisation, unstable oscillation, or delayed disconnect behaviour observed during any completed test event.

Table A.7, Anti-Islanding and Disconnection Performance Results

Test Category	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
Synchronous disconnect	5	5	0	1	16.4–19.2 ms; Device G did not connect
Asynchronous disconnect	10	10	0	0	7–68 ms; no sustained energisation
Total	**15**	**15**	**0**	**1**	**All tested devices satisfied 500 ms criterion**

Device G did not complete this assessment due to inability to establish grid connection during the relevant test sequence.

A.10 High temperature operation (A8)

High temperature operation testing examined inverter stability and waveform behaviour at the upper edge of declared ambient operating temperature. Across the tested sample, electrical performance remained stable under elevated thermal conditions, although one instance of physical material degradation was observed.

Three devices completed the assessment without thermal instability, shutdown behaviour, or measurable deterioration in waveform quality. Device F maintained acceptable electrical behaviour throughout the test sequence but exhibited shrinkage of the AC power cable sheath following high temperature exposure and was therefore classified as a failure on physical integrity grounds rather than electrical instability.

Maximum inverter casing temperatures ranged between 56C and 60.8C, while measured changes in THDV remained within the defined acceptance threshold.

Table A.8, Thermal Extreme Behaviour Results

Test Category	Tested Events	Pass	Fail	Incomplete / Excluded	Notes
High temperature operation	4	3	1	1	Device F failed on cable sheath shrinkage; Device B not tested

Device F AC cable after 50°C chamber testing, exhibited sheath shrinkage but no electrical instability.

Figure A.3, Chamber Testing and Cable Sheath Degradation

Figure A.3 Chamber testing and cable sheath degradation, Castleford (© Arceio)

A.11 Frequency tolerance behaviour (A9)

The enhanced assessment examined device behaviour under controlled grid frequency variation, with the objective of confirming stable operation within the normal operating band of 49.5–50.5 Hz and timely disconnection outside the extended 47–52 Hz envelope. All devices operated normally within the normal band, with no instability, nuisance disconnection, or unsafe behaviour observed.

Table A.9, Frequency Tolerance Behaviour Results

Device	Max Rated Output	Operation in 49.5-50.5 Hz	Under-Frequency Disconnect	Over-Frequency Disconnect	Outcome	Notes
Device 1	800 W	Pass	47.0 Hz (10 ms)	52.0 Hz (20 ms)	Pass	Export power reduced slightly above 50.2 Hz.
Device 2	600 W	Pass	47.0 Hz (20 ms)	54.0 Hz	Fail	Over frequency response outside intended upper threshold.
Device 3	800 W	Pass	47.0 Hz (10 ms)	51.5 Hz	Pass	Small reduction in export current during sweep.
Device 4	400 W	Pass	48.0 Hz	51.5 Hz	Pass	No unsafe behaviour observed.
Device 6	400 W	Pass	47.0 Hz (70 ms)	52.0 Hz (20 ms)	Pass	Minor increase in export current observed during sweep.
Totals	**-**	**5/5 Pass**	**-**	**-**	**4 Pass / 1 Fail**	**Stable operation in normal band across all tested devices.**

Outside the normal band, most devices demonstrated controlled disconnection behaviour consistent with the intent of the test. However, meaningful product-to-product variation was observed at threshold conditions, with Device 2 disconnecting only at 54.0 Hz on the over-frequency side and therefore not aligning with the intended upper threshold used in the protocol.

Across the sample set, the evidence indicates stable performance within normal UK frequency variation, but non-uniform threshold response outside that band.

Figure A.4, Grid Frequency Variation

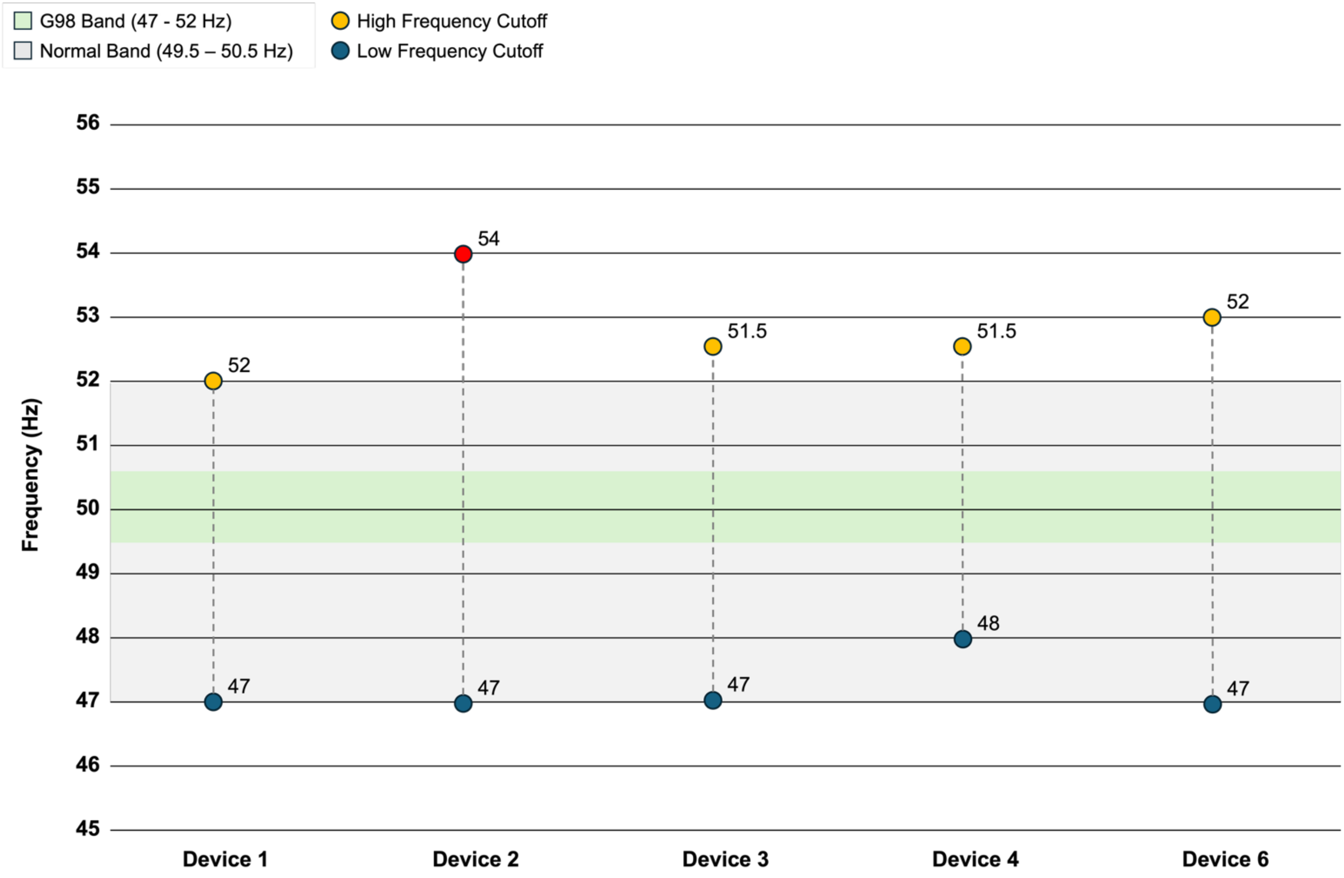

Figure A.4 Grid frequency variation across sample set, Yate (© Arceio Limited)

A.12 Startup and shutdown transients (A10)

Startup and shutdown transient testing assessed whether inverter systems generated harmful surges, spikes, or unsafe transient behaviour during repeated connection and disconnection events. Across the tested devices, startup and shutdown behaviour was generally fast and controlled.

Startup durations were consistently around 10.2–11.96 ms, while shutdown durations were of a similar order at approximately 11.8–13.32 ms. Short-duration spikes, sags, and ringing effects were observed on selected devices, but these remained brief and were assessed as compliant within the defined test framework.

Table A.10, Startup and Shutdown Transient Results

Device	Startup Duration	Shutdown Duration	Outcome	Notes
Device 1	0.01072 s	0.01248 s	Pass	Short startup spike observed on one run; repeat event smaller.

Device 2	0.01196 s	0.01264 s	Pass	Ringing observed post disconnect; remained below normal waveform voltage.
Device 3	0.01020 s	0.01180 s	Pass	Normal startup and shutdown behaviour recorded.
Device 4	0.01120 s	0.01236 s	Pass	No abnormal transient behaviour observed.
Device 6	0.01192 s	0.01332 s	Pass	Short duration sag event observed on startup; assessed as pass.
Totals			**5/5 Pass**	

No harmful transient behaviour, unsafe switching response, or evidence of connected equipment compromise was identified.

A.13 Export power limitation (A11)

Export power limitation testing assessed whether each device remained at or below its stated maximum AC export power across a controlled supply voltage sweep from 196 V to 253 V. The results were mixed rather than uniform across the sample set.

Three higher-rated devices remained below their stated nameplate limits throughout the sweep, although some operated materially below nominal rating at certain voltages. By contrast, two lower-rated devices with a stated 400 W maximum output exceeded that value during part of the test sequence, indicating that device-level export limitation did not align consistently with declared nameplate values across the sample.

Table A.11, Export Power Limitation Results

Device	Max Rated Output	252 V Export	230 V Export	197 V Export	Outcome	Notes
Device 1	800 W	599.8 W	613.5 W	593.3 W	Pass	Very flat response; materially below stated output.
Device 2	600 W	761.7 W	753.1 W	742.2 W	Pass*	Remained below tested ceiling used in sheet,

Device 3	800 W	792.8 W	794.3 W	770.4 W	Pass	Closest to nameplate; no sustained exceedance.
Device 4	400 W	427.2 W	435.3 W	435.5 W	Fail	Exceeded stated 400 W limit across all recorded points.
Device 6	400 W	406.0 W	403.1 W	361.4 W	Fail	Exceeded stated 400 W limit at higher voltage points.
Totals					**3/5 Pass**	

No abnormal heating, instability, or protective device operation was observed during the assessment.

A.14 Dynamic grid connection behaviour (A12)

Dynamic grid connection testing considered representative scenarios involving irradiance changes, outdoor partial shading, severe irradiance reduction, dual-input behaviour, and supplementary self-oscillation checks. Across the tested scenarios, stable behaviour was reported and no sustained oscillation, unstable reconnection, or loss of synchronisation was observed.

The evidence indicates that the tested devices maintained stable dynamic behaviour under changing generation conditions representative of foreseeable domestic use. Supplementary self-oscillation checks also indicated that units disabled correctly following RCBO trip conditions and did not self-oscillate in the absence of a valid grid reference.

Table A.12, Dynamic Grid connection Behaviour Results

Test Scenario	Representative Conditions	Outcome	Notes
Laboratory irradiance step change	100-50 percent step change	Pass	No sustained oscillation or loss of synchronisation reported.
Outdoor partial shading	Sunny day, installed PV panels, partial shade at 100-80 percent	Pass	Stable behaviour reported under more realistic conditions.
Severe irradiance reduction	100-30 percent step change	Pass	No unsafe reconnection behaviour reported.

Dual-input behaviour	Bank 1 off / Bank 2 off	Pass	No instability reported during single-bank operation.
Supplementary self-oscillation check	Two inverters, RCBO trip on spur and ring	Pass	Units disabled and did not self-oscillate.

A.15 Voltage tolerance behaviour (A13)

Voltage tolerance testing assessed device behaviour across controlled voltage sweeps extending from the normal operating range into the broader G98 threshold range. All devices remained operational within the normal 216–253 V band, and no unsafe behaviour, uncontrolled output, abnormal heating, or visible instability was observed during the sweeps.

However, disconnection behaviour at the threshold extremes was not consistently aligned with the stated acceptance criterion across all devices. Several devices did not disconnect at or before the nominal G98 boundary values in one or both sweep directions, meaning that A13 should not be characterised as a universal pass condition despite strong normal-band stability.

Table A.13, Voltage Tolerance Behaviour Results

Device	Normal 216-253 V Band	Over-Voltage Disconnect	Under-Voltage Disconnect	Outcome	Notes
Device 1	Pass	258 V	193 V	Fail	Tails off above 254 V; stable export otherwise.
Device 2	Pass	273.5 V	140 V	Fail	No disconnection within intended under-voltage threshold.
Device 3	Pass	275.6 V	182 V	Fail	Unsmooth response to voltage changes noted.
Device 4	Pass	263 V	180 V	Fail	Stable in normal band; threshold response outside criteria.
Device 6	Pass	264.9 V	176.9 V	Fail	Stable in normal band; threshold response outside criteria.
Totals	**5/5 Pass**	**-**	**-**	**5/5 Fail**	**Normal band stability strong; threshold**

					disconnection variable.

These results support the conclusion that normal operating band voltage tolerance was generally robust, while threshold-based disconnection behaviour at the extended limits was more product dependent.

A.16 Cross-cutting observations

Across the combined A1–A13 programme, no device exhibited thermal runaway, sustained fault contribution, uncontrolled islanding behaviour, or continued energisation following protective device operation. The strongest areas of demonstrated conformity related to anti-islanding and loss-of-mains response, thermal stability under sustained operation, successful operation of existing RCBO/RCD protection systems, stable dynamic synchronisation behaviour, and controlled operation within normal UK voltage and frequency bands.

The principal areas where non-uniform or non-conforming behaviour was observed related to conducted EMC emissions against EN 61000-6-3 Class A and B quasi-peak limits, device-specific threshold response during extended voltage and frequency excursions, and export power limitation relative to stated nameplate ratings on selected devices. These findings do not in themselves indicate unsafe operation within the tested configurations, but they do establish that product-specific conformity and boundary-condition behaviour remain material considerations for wider deployment interpretation.

Appendix B

Project Number: PRJ 5707
Client: Department for Energy Security and Net Zero (DESNZ)
Contractor: Arceio Limited

Test Protocol and Standards Mapping

Plug-in PV Systems in the United Kingdom

Electrical Safety, Compatibility and Implementation Considerations

Document Status: Controlled Technical Reference
Document Version: v3
Date: 14 April 2026

B.1 Purpose

This appendix sets out the methodology, hazard framework, acceptance criteria, and test architecture used for the plug-in PV study commissioned by DESNZ. It establishes the baseline testing philosophy, the strict no-modification assumption, the hazard matrix covering A1 to A13, the data capture framework, and the standards basis for interpretation.

This appendix supersedes earlier protocol versions and serves as the controlling technical reference for the test programme. It integrates the feasibility-phase RAMS, the standards mapping exercise, and the targeted enhancement test procedures developed after Eurofins Review.

B.2 Objectives

The objectives of the test programme are to:

1. Define the test protocol for balcony and plug-in PV systems designed for connection to standard domestic 13 A socket-outlets.
2. Map the principal hazards to the corresponding test methods A1 to A13.
3. Establish acceptance criteria aligned with BS 7671, BS 1363, EN 61000 series requirements, and relevant UK regulations.
4. Confirm the no-modification basis under which all systems were assessed.
5. Define the data capture and metadata structure used for the test programme.
6. Define the sample selection, anonymisation approach, and sequencing across representative circuit configurations.

B.3 Scope

The study is limited to representative small-scale plug-in PV systems connected through standard BS 1363 domestic socket-outlets on existing final circuits within UK homes under a strict no-modification assumption. The assessment covers operation on representative domestic circuits without changes to fixed wiring, consumer units, or protective devices.

The scope includes laboratory and rig-based assessment under conditions intended to reflect realistic domestic use. It covers normal operation and foreseeable fault, stress, and degraded-use conditions, including thermal behaviour, protective device interaction, anti-islanding response, reverse power flow, export limitation behaviour, voltage and frequency response, and electromagnetic compatibility considerations.

The study is not a market census, a certification exercise, or a long-term field trial. It does not assess unrestricted consumer modification, improvised connectors, altered wiring arrangements, or deployment models requiring electrical installation works beyond the defined no-modification mounting boundary.

B.4 Test Philosophy

The core assumption of the study is that systems are assessed as complete plug-in appliances connected directly to existing 13 A socket-outlets without alterations to wiring, protective devices, or consumer units. This reflects the intended consumer deployment model and defines the boundary for the safety assessment.

Testing is conducted under conditions intended to represent realistic domestic scenarios, including mixed resistive and inductive loads, ambient temperatures between 20C and 50C, aged sockets, fault conditions, and controlled voltage and frequency excursions where required.

Devices are anonymised in reporting as Device 1 to Device 6, with internal traceability retained in controlled project records.

B.5 Test Matrix and Procedures

Table B.1, Initial Assessment (A1–A8)

Test	Hazard Addressed	Key Parameters	Acceptance Criteria
A1 Endurance	Thermal overload	Maximum power, aged socket	Temperature rise within limits; no damage.
A2/A3 RCBO Trip	Residual current	5 x IΔn, Live-Earth and Live-Neutral	Trip within defined time limit.
A4 Reverse Current	Backfeed risk	Mixed import and export AC power	No localised hotspots; circuit temperatures remain acceptable.
A5 Short Circuit	Faults withstand	EN 61008 conditional behaviour	Safe shutdown; no damage; normal recovery on reset.
A6 Emissions	EMC compliance	150 kHz to 30 MHz conducted emission and harmonic measurements	EN 61000-3-2 Class A limits.

A7 Anti Islanding	Grid safety	Relay-based disconnect	Export ceases within the specified time following loss of mains.
A7.1 Async	Staggered disconnect	Live-Neutral delay	Disconnection occurs within the overall required time.
A7.2 Waveform	Power quality	Oscilloscope capture	Waveform behaviour remains qualitatively acceptable.
A8 High Temperature	Thermal limits	50°C chamber	Stable operation; limited THD(V) change.

Table B.2, Enhanced Assessment (A9–A13)

Test	Hazard Addressed	Key Parameters	Acceptance Criteria
A9 Frequency Tolerance	Grid frequency behaviour	49.5–50.5 Hz band, extended thresholds	Stable within band; disconnection outside limits.
A10 Startup / Shutdown Transients	Transient response	Repeated start-stop cycles, high-bandwidth capture	No harmful transients or unsafe behaviour.
A11 Export Power Limitation	Export limit / G98	196–253 V sweep, maximum PV input	Export remains at or below device limit.
A12 Dynamic Grid connection Behaviour	Stability / synchronisation	Load and irradiance variation, step changes	Stable synchronisation; no unsafe reconnection.
A13 Voltage Tolerance	Grid voltage behaviour	216–253 V normal range; extended sweep for disconnection assessment	Stable operation within band; timely disconnection outside thresholds.

B.6 Hazard Matrix Summary

The principal hazards mapped to the test programme are:

- **Thermal:** A1, A4, A8
- **Protection failure:** A2/A3, A5
- **Reverse power:** A4
- **EMC/Power quality:** A6
- **Anti-islanding:** A7/A7.1
- **Operational stability:** A9–A13
- **Fault response:** A5, A11
- **Misuse/degradation:** Aged socket scenarios across programme

Scope limitations are explicitly noted. These include qualitative assessment of staggered pin disconnection, no full IEC 62116 resonant islanding test, and a fixed 50 Hz supply assumption. These limitations do not invalidate the core safety assessment but define the boundary of inference.

B.7 Data Capture Schema

The study used a controlled data capture structure covering electrical, thermal, harmonic, transient, and fault-response data. The schema included metadata, circuit type, ambient conditions, timestamps, and operator/device identification, together with measured parameters such as Vrms, Irms, power, power factor, THD(V), THD(I), temperatures, and trip times.

Oscilloscope captures, thermocouple logs, infrared imaging, and harmonic measurements were used where relevant to each test. Raw and processed data were maintained within the project evidence pack using controlled naming and traceability conventions.

B.8 Applicable Standards

The study was interpreted against the following principal standards and references:

- BS 7671, including protection and disconnection principles.
- BS 1363-1, BS 1363-2, and BS 1363-3:2023, for plugs, sockets, and temperature rise.
- EN 61008 and EN 61009, for RCD and RCBO behaviour.
- EN 61000-3-2, for conducted emissions and harmonics.
- IEC 62116, as a context-only reference for anti-islanding methodology.
- G98, as a context-only reference for small-scale generation behaviour.

- EN/IEC 62109, as a context-only reference for inverter thermal safety.
- ENA engineering recommendations, including G98, G99, and P28, for grid interaction, disturbance, and connection context.

Where standards are context-only, they were used to inform interpretation rather than to represent a formal certification route within this study.

B.9 Governance and Change Control

The study was governed through defined project roles and controlled review arrangements. The Project Lead had overall delivery responsibility, the Technical Lead provided standards alignment and technical oversight, the Senior Electrical Engineer supported electrical safety and compliance review, the QA and Methodology Advisor provided methodology oversight, and Eurofins E&E UK acted as laboratory partner for UKAS-related testing and RAMS support.

Protocol sign-off was completed for version 3 on 8 May 2026. Any deviation from the approved protocol requires formal revision and DESNZ approval.

B.10 Device Mapping

The devices were anonymised in the report as Device 1 to Device 6. The mapping below records the device category, rated power, and manufacturer-declared compliance information used for context in the study.

Table B.3, Anonymised Device Mapping

ID	Category	Power	Certifications
Device 1	Balcony PV kit	800 W	CE, UKCA/CA Mark IP67 EN 50549-1 G98 compliant
Device 2	Balcony PV kit	600 W	CE, RoHS VDE EN61000-3-2/-3-3 EN62109 (Safety) EN50438 IP65.
Device 3	Microinverter	800 W	CE, RoHS IP67 (NEMA 6) EN 50549-1:2019 VDE-AR-N 4105:2018 VFR 2019 IEC/EN 62109-1/-2 IEC/EN 61000-3-2/-3 G98 / G99 compliant.
Device 4	Microinverter (single DC input)	400 W	CE, IP67 EN 50549-1:2019 VDE-AR-N 4105 IEC 62109-1/-2 EN 61000-6-1/-2/-3/-4 EN 50549-1 (FR) G98, G99 G98/NI, G99/NI UTE C15-712-1, CEI 0-21.
Device 5	Microinverter	800 W	CE, RoHS, ISO9001 IP67 VDE-AR-N 4105 VDE 0126 EN 50549-1 IEC 61727 / 62116 G98, G99 AS 4777.2, CEI 0-21 C10-11, UNE217002.

Device 6	Balcony PV kit (single DC input)	400 W	CE, IP67 VDE 0126 VDE-AR-N 4105 EN 50549-1 RD 1699 G98.

The certification and marking information are provided for context only and was not independently verified as part of this study.

Controlling Reference

The full signed v3 test protocol dated 14 April 2026 remains the authoritative technical document approved by DESNZ and Arceio. This appendix presents the core methodology and standards mapping for publication clarity, while the complete signed protocol is retained in the project evidence pack for controlled reference.

Appendix C

Project Number: PRJ 5707
Client: Department for Energy Security and Net Zero (DESNZ)
Contractor: Arceio Limited

Test Rig, Instrumentation, and Data Handling

Plug-in PV Systems in the United Kingdom

Electrical Safety, Compatibility and Implementation Considerations

Document Status: Controlled Technical Reference
Document Version: v3
Date: 13 May 2026

C.1 Purpose

This appendix documents the test rigs, circuit configurations, instrumentation, and calibration used for the plug-in PV assessment programme. It provides technical readers with traceability to the physical test environment and measurement systems underpinning the results presented in Appendix A.

Detailed procedures, exact instrumentation settings, and rig-level implementation notes are retained in the controlled project evidence pack. This appendix records the configuration, principles, and quality assurance basis sufficient to support interpretation of the test findings.

C.2 Test Boundary Overview

The diagram below illustrates the test boundary applied throughout the programme. It shows the no-modification deployment assumption, the representative domestic circuit elements under assessment, and the measurement and control points used in the study. All testing was conducted within this boundary; nothing outside it was assessed or modified.

Figure C.1, ‘No-Modification’ Test Boundary

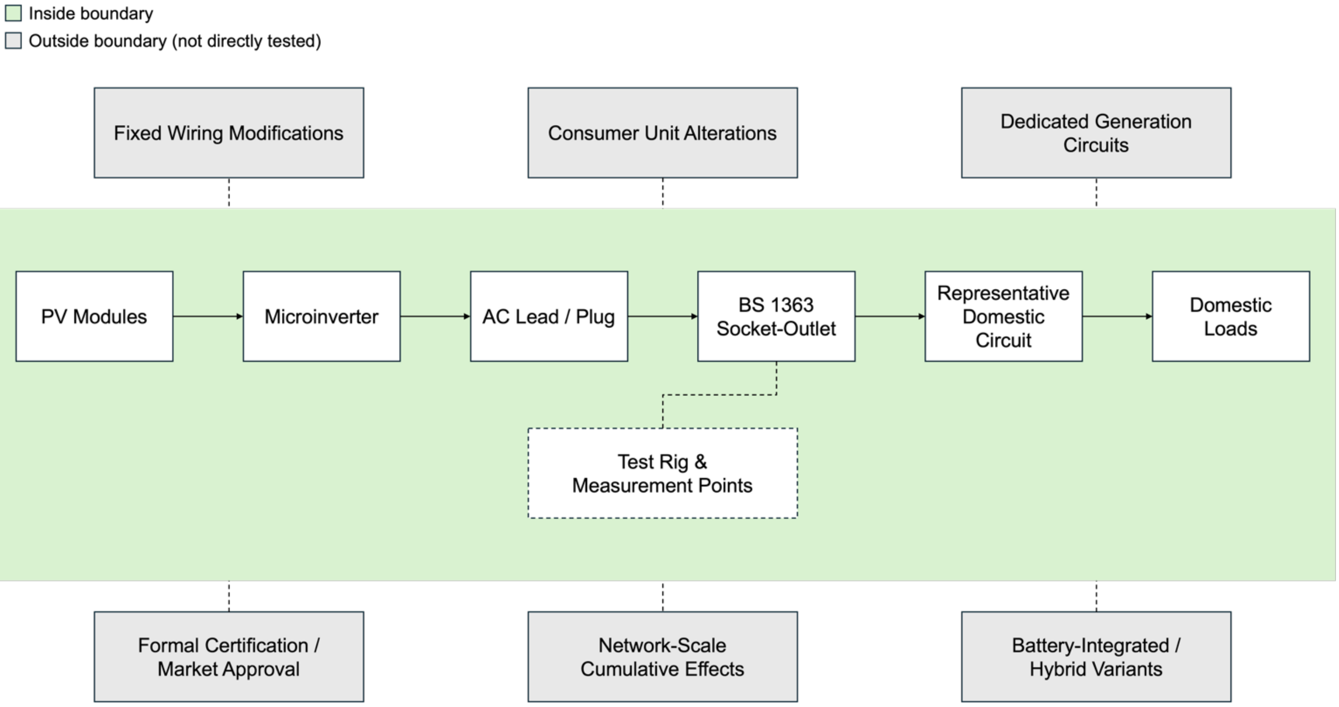

Figure C.1 ‘No-Modification’ Test Boundary (© Arceio)

The boundary confirms that plug-in PV devices were assessed as complete appliances connected to existing socket-outlets, with no changes to fixed wiring, consumer units, or protective devices. Measurement points were located at the RCBO, socket and plug interface, inverter casing, conductor routes, and fault injection locations.

C.3 Test Rig Configurations

Three purpose-built rigs emulated representative UK domestic final-circuit arrangements. Together they covered modern protected ring-final circuits, modern radial spur circuits, and legacy or degraded configurations.

Table C.1, Test Rig Summary

Rig	Configuration	Circuit Protection	Key Features
Rig 1	Ring A — Modern ring-final	32 A Type A RCBO	2.5/1.5 mm² twin and earth conductors; PME earthing; distributed BS 1363 sockets; modern metal-clad accessories.
Rig 2	Spur B — Modern radial spur	Type A or Type AC RCBO (scenario dependent)	Modern plastic socket accessories; representative spur loading conditions.
Rig 3	Spur C — Legacy/degraded	32 A MCB with upstream 30 mA RCD	Mixed new and aged socket accessories; additional extension lead configurations; stressed contact and loading conditions representative of legacy domestic installations.

All rigs were designed to allow repeatable plug-in connection, controlled fault injection, distributed loading configurations, thermal imaging access, and contact instrumentation.

Figure C.2, Instrumented ring-final rig with FLIR

Figure C.2 Instrumented ring-final rig with FLIR, Yate (© Arceio)

C.4 Relay Disconnect Box (Anti-Islanding)

A supplementary relay rig was used for A7 and A7.1 anti-islanding and disconnection testing. It provided twin SPDT relays enabling both simultaneous and asynchronous Live-Neutral disconnection, with a 54 ms Live-Neutral stagger applied to simulate the behaviour of a worn or partially inserted plug.

Disconnection events were captured using high-speed oscilloscope waveform capture of voltage and current decay on Live and Neutral outputs. This arrangement provided the technical basis for the asynchronous disconnection assessment described in Appendix A, Section A.9.

C.5 Instrumentation and Measurement Systems

Instrumentation covered the principal measurement locations required for the test matrix, including protective devices, socket contacts and plug pins, inverter casings, cable terminations and conductor routes, and fault injection locations.

The measurement suite included electrical power analysers for Vrms, Irms, real power, power factor, and harmonic content, thermocouple logging for steady-state and transient thermal measurements, FLIR infrared imaging for thermal distribution and hotspot identification, a LISN and spectrum analyser for EMC and conducted emission measurements, and oscilloscope capture for transient, fault, and disconnection events.

Sampling rates and instrumentation were selected to provide adequate resolution for both steady-state and transient phenomena at 50 Hz and inverter switching frequencies.

C.6 Test Environment and Loading

Ambient conditions:

- Baseline laboratory testing: 20°C ±5°C, representative of indoor domestic conditions.
- Elevated thermal testing: Environmental chamber at approximately 50°C, representing the declared upper operating limit of the assessed devices

Domestic loading:

- Resistive loads representing common domestic heating appliances.
- Non-linear electronic loads representing computers, routers, and similar devices.
- Switched domestic appliances to introduce realistic load variation.
- Combined import conditions of up to approximately 2 kW

Reverse power flow scenarios were included to simulate partial demand offset and ring-circuit backfeed conditions representative of foreseeable plug-in PV use.

C.7 Calibration and Quality Assurance

All instrumentation used in the programme was UKAS or NPL-traceable. Calibration status was logged in the project procurement and QA register and verified at the start of each test cycle.

Anomalous results were subject to repeat testing or corroborative methods where required. Baseline comparisons without PV connected were maintained throughout the programme to support result interpretation. Thermal imaging and thermocouple data were cross verified for consistency on applicable tests.

Data integrity was maintained through structured capture across electrical, thermal, waveform, and event-timing domains, with version-controlled repositories and metadata identifiers applied to all test records.

C.8 PV Source Emulation

Programmable DC sources were used to emulate small-scale domestic PV module outputs within the operating envelope relevant to the devices assessed. Sources were configured to provide at least 1000 W capacity, adjustable across the relevant voltage and current range, and set to representative current-voltage characteristics consistent with manufacturer-declared operating envelopes. Supplementary outdoor testing with real PV panels was used for irradiance variability and partial shading scenarios in the dynamic grid-connection behaviour assessment.

C.9 Ancillary Connection Hardware

Ancillary connection hardware was selected to represent the range of connection accessories a consumer might reasonably use alongside a plug-in PV system. This included standard BS 1363 extension leads in both straight and coiled configurations, multiple socket adaptors, and aged or degraded accessories where required by the test scenario.

The purpose of this hardware selection was to capture interaction effects between plug-in PV export and realistic domestic connection infrastructure, including the degraded contact resistance and thermal performance associated with aged or heavily loaded accessories.

Figure C.3, Real Time Frequency Tolerance

Figure C.3 Laptop capturing real time frequency tolerance results, Yate (© Arceio Limited)

C.10 Safety and Control Features

All rigs incorporated emergency isolation switches, overcurrent protection on both DC and AC supplies, relay-based Live-Neutral disconnection capability, and controlled fault injection modules.

These features ensured that testing could be conducted safely within a UKAS-aligned laboratory environment, and that fault events could be applied, observed, and cleared in a repeatable and controlled manner.

Appendix D - Glossary and Abbreviations

Term / Abbreviation	**Definition**
AC	Alternating current. The form of electrical current supplied by the public electricity network and used within domestic socket circuits.
Anti-islanding	A protection function requiring a grid connected inverter to cease energisation when the public supply is lost, so that it does not continue to energise an isolated section of network or installation.
Arceio	Arceio Limited, the contractor responsible for delivery of the study.
A1-A13	The numbered test procedures used in the study, comprising the Initial Assessment (A1-A8) and Enhanced Assessment (A9-A13).
Asynchronous	Asynchronous refers to one pin being disconnected before the other as could be experienced in very worn plug/socket combinations.
Balcony PV	A small-scale solar PV system, often consumer facing, intended for plug-in or simplified domestic deployment, typically using one or more PV modules and a microinverter.
Baseline condition	A reference operating state used for comparison, often measured without a plug-in PV device connected or before a disturbance is introduced.
Borderline	A conformity classification used where behaviour approached a defined limit or showed elevated sensitivity without constituting a clear failure.
BS 1363	The British Standard series covering plugs, socket outlets, adaptors and connection units used in UK domestic electrical systems.
BS 7671	The British Standard for electrical installations in the UK, commonly referred to as the IET Wiring Regulations.
Class B conducted emissions	A conducted electromagnetic emissions limit category commonly applied to electronic equipment used in domestic environments.
Conformity framework	The structured approach used in the study to classify observed behaviour as Pass, Borderline, Fail, Incomplete, or Excluded, depending on the test outcome and evidence quality.
Controlled test rig	A purpose built and instrumented laboratory circuit arrangement designed to emulate representative UK domestic electrical conditions under repeatable and safe testing conditions.
Current-voltage (I-V) characteristic	The electrical relationship between current and voltage used to represent PV module behaviour, reproduced in the study using programmable DC power supplies.
DC	Direct current. The form of electrical current produced by photovoltaic modules before conversion by an inverter.

DNO	Distribution Network Operator. The licensed company responsible for operating and maintaining local electricity distribution networks.
Dynamic irradiance response	The behaviour of a PV system or inverter under changing sunlight conditions, including rapid reductions or increases in available PV input.
EMC	Electromagnetic compatibility. The ability of equipment to operate satisfactorily in its electromagnetic environment without introducing unacceptable disturbance to other equipment.
EN 50549-1	A European standard covering requirements for generating plants connected in parallel with low-voltage distribution networks.
EN 61000 series	A family of standards covering EMC, including harmonics, voltage fluctuations, immunity, and emissions.
EN 61008 / EN 61009	Standards covering residual current protective devices, including RCDs and RCBOs, and their operating behaviour.
Environmental chamber	A controlled chamber used to impose elevated ambient temperatures during high temperature testing.
Excluded	A test classification used where a device or event was not assessed in the relevant sequence for an identified technical reason, such as pre-existing damage.
Export	Electrical power supplied from the plug-in PV system into the domestic circuit or toward the wider network.
Export limitation	A control function or performance characteristic intended to constrain AC output so that export remains at or below a specified limit.
Fail	A conformity classification indicating that one or more defined acceptance criteria were exceeded.
FLIR	Forward looking infrared thermal imaging. Used in the study to identify temperature distribution and localised hotspots.
Frequency tolerance	The ability of a device to operate stably within a defined grid frequency range and disconnect appropriately outside it.
G98	Engineering Recommendation G98, which sets requirements for the connection of small-scale generation equipment in parallel with public low-voltage distribution networks.
Grid reference	The stable mains voltage and frequency conditions that a grid following inverter uses to synchronise and determine whether it may export power.
Grid following inverter	An inverter that synchronises its output to the voltage and frequency of an existing electricity supply and ceases export when that reference is lost.
Harmonics	Distortion components at integer multiples of the fundamental mains frequency, used in the study to assess power quality behaviour.

Hazard framework	The structured set of identified technical concerns used to design the test programme and map risks to specific assessment procedures.
Incomplete	A test classification used where a test event was initiated but not fully evidenced or completed, for example missing waveform capture, despite partial confirmation of behaviour.
Initial Assessment	The first phase of the programme, covering A1-A8 baseline tests on endurance, protection, EMC, anti-islanding, and thermal behaviour.
Inverter	Power conversion equipment that converts DC electricity from PV modules into AC electricity suitable for domestic use and grid interaction.
Irradiance	The level of solar energy incident on a PV module, emulated in the study using programmable DC sources and supplementary outdoor testing.
LISN	Line Impedance Stabilisation Network. A test device used in EMC measurements to provide a defined impedance and enable conducted emission assessment.
Loss-of-mains	The condition where the public electricity supply is removed or no longer available as a valid grid reference.
Low-voltage network	The public or internal electrical network operating at domestic supply voltage levels.
Microgeneration	Small scale electricity generation, typically connected at household or building level.
Microinverter	A small inverter, often connected to one or two PV modules, designed to convert DC from the module(s) into grid synchronised AC output.
Mixed import/export condition	An operating condition in which some parts of the domestic circuit are importing electricity while the plug-in PV device is simultaneously exporting power into the same installation.
No-modification boundary	The central deployment assumption used in the study, under which plug-in PV systems are assessed without alteration to fixed wiring, protective devices, or installation topology.
Pass	A conformity classification indicating that behaviour remained within the defined acceptance criteria for the tested scenario.
PLL	Phase locked loop. A control function used by inverters to synchronise with the frequency and phase of the electricity supply.
Power factor (PF)	A measure of the relationship between real power and apparent power in an AC circuit.
Power quality	The characteristics of electrical supply relevant to stable and compatible operation, including waveform distortion, harmonics, and voltage behaviour.
PV	Photovoltaic. A technology that converts light into electrical energy.
PV simulator	A programmable DC power source configured to emulate PV module electrical behaviour under controlled conditions.

RCBO	Residual current circuit breaker with overcurrent protection. A protective device combining residual current and overcurrent protection functions.
RCD	Residual current device. A protective device intended to disconnect supply when residual current exceeds a defined threshold.
Ring-final circuit	A common UK domestic socket circuit arrangement in which conductors form a ring returning to the consumer unit, typically protected at 32 A
Risk based test design	A methodology in which tests are selected and structured to examine identified hazards, boundary conditions, and safety relevant interaction effects.
Socket outlet	A BS 1363 domestic electrical outlet used for plug-in appliances and, in this study, plug-in PV systems.
Spur circuit / radial spur	A branch or radial section of a domestic socket circuit supplying one or more outlets from a final circuit.
Steady state operation	Stable operating conditions maintained over time without rapid transient change
Synchronous disconnection	Synchronous disconnection is when the live and neutral pins of a 13A plug are withdrawn from the socket at the same time.
THD(I)	Total harmonic distortion of current.
THD(V)	Total harmonic distortion of voltage.
Thermal runaway	A condition in which rising temperature drives further temperature increase in an uncontrolled manner. No evidence of thermal runaway was identified during the programme.
Transient	A short duration electrical event occurring during switching, disturbance, startup, shutdown, or fault conditions.
True RMS	True root mean square measurement, used to capture effective AC voltage or current values accurately under distorted waveforms.
Type A RCBO/RCD	A protective device designed to respond to alternating residual current and pulsating DC residual current.
Type AC RCBO/RCD	A protective device designed primarily to respond to sinusoidal alternating residual current.
UKAS	United Kingdom Accreditation Service, the national accreditation body for conformity assessment and testing organisations.
Voltage tolerance	The ability of a device to operate safely and stably within a defined voltage range and disconnect appropriately beyond threshold conditions.
Waveform	High speed oscilloscope recording used to characterise transient or short duration electrical behaviour.

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