Guide to Prosumer Electrical Installations

Draft for Public Consultation (DPC)

Additional notes for review:
The purpose of this guide is to provide designers, installers, and practitioners with a clear understanding of the requirements and typical modes of operation for a Prosumer's Electrical Installation (PEI). It outlines the terminology and general design philosophy of PEI, including its various types and modes of operation, and explains the integration of its components. Additionally, the guide offers insights into potential electrical safety issues associated with PEI and details the specific requirements of BS 7671 to mitigate these risks. It also discusses the technical challenges related to PEI and describes the role of energy management systems and the necessary interfaces to optimize PEI operations. The scope of this guide includes, but is not limited to: • Fixed low voltage electrical installations, typically in or directly connected to buildings. • Grid connection with smart metering. • On-site generation, such as photovoltaic panels, wind turbines, and hydro turbines. • Battery energy storage systems. • Energy management systems. This guide draws on the content within BS 7671:2018+A2:2022+A3:2024, associated British Standards, IEC documents and standards, other IET Codes and Guidance titles, and relevant industry documents. Further editing and formatting will be undertaken after the public consultation to ensure a professional and consistent document. For the consultation, we request that you provide information and feedback on the technical content and structure of the work. IET Codes and Guidance publications follow a style based on the British Standards Institution's *Style guide for British Standards of UK origin – Presentation, typography and standard wording* and *Rules for the structure and drafting of UK standards*, which can be found at www.bsigroup.com/en-GB/about-bsi/governance/standards-governance/. If you wish to propose an amendment to spelling or grammar, please make sure that it is in line with these documents.

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Guide to Prosumer Electrical Installations

1 Introduction

Energy flow in electrical installations, especially in domestic and small industrial premises, has been dominated for several decades by instantaneously drawing electrical energy from a metered grid connection for immediate consumption on site. The energy flow has been in one direction only, from the source of generation via the grid to the consumer at the point of use by electrical loads such as lighting or equipment connected to isolators or socket outlets.

Any inclusion of on-site generation of electricity has previously been restricted to larger installations such as hospitals that require critical cover when the mains supply fails. The usual engineering solution in this situation has been to use fossil fuel-based generators that are associated with emissions including carbon dioxide.

The typical mode of installation is either the mains supply or the on-site generator supply. In both, the energy flow is still uni-directional towards the electrical loads. Each energy source is set up with its own supply characteristics, initial protective devices and principal earthing systems.

The deployment of electrical energy storage, i.e. batteries, is not unusual in traditional installations, but its purpose has been restricted to specific critical parts, often at sub-circuit level, in the form of uninterruptible power supplies (UPS) or backups for smaller scale life safety systems such as fire detection and fire alarm systems and emergency lighting. The energy flow from the grid connection to the point of use is diverted via the electrical energy storage installation. This enables life safety systems or business critical systems to remain fully operational in the time gap between an interruption to the mains supply and the site generators taking over.

The decarbonisation agenda will lead to greater demands on electrical installations. Low carbon technologies, such as heat pumps and electric vehicles, are designed to reduce overall carbon dioxide emissions. However, they can also increase maximum demands on electrical infrastructure, often at peak times of the day. This is not necessarily an issue, assuming that certain design philosophies are included in the installation; for example:

a) with electrical energy management systems in place and appropriate planning by the end users, loads can be shifted to a quieter period with fewer electrical demands;

b) billing of electrical installations has become increasingly sophisticated, with dynamic tariffs now available with cheaper rates at off-peak times that are updated constantly;

c) there is a steady increase in on-site electrical generation, its connection to the installation and the ability to export surplus to the grid; and

d) electrical energy storage is no longer the preserve of life safety systems – it can also be used to store the output of on-site generation or to import at cheaper tariffs for use locally to offset expensive imports at peak time tariffs.

Energy flow has become bi-directional, with multiple supply characteristics, more advanced protective devices and integrated earthing systems. Active energy management systems control time of use, and monitor sub-circuit consumption and what part of the installation is used when, to assist with the reduction of both emissions and billing costs.

To keep pace with these changes, the 18th Edition of the IET Wiring Regulations, BS 7671:2018+A2:2022, saw the introduction of Chapter 82 – 'Prosumer's low-voltage electrical installations'. The additional content within the chapter outlines the safe integration of local renewable electrical generation and

electrical energy storage. It also explains, at high level, the role of energy management systems in making the installation more energy efficient and more cost effective.

1.1 Scope and purpose

The purpose of this guide is to:

a) illustrate to designers, installers and other practitioners the requirements of a prosumer's electrical installation (PEI);

b) outline the terminology and general design philosophy of PEI, its types and modes of operation;

c) outline the integration of the respective components of a PEI;

d) provide an understanding of the potential electrical safety issues with PEI and the specific requirements of BS 7671 to mitigate those risks;

e) provide an understanding of the technical issues of PEI; and

f) describe the contribution of energy management systems and the interfaces required to optimise the operation of a PEI.

The scope of this guide is intended to include fixed low voltage electrical installations, typically within or directly connected to buildings. These installations will incorporate some or all of the following components of a PEI:

g) grid connection complete with smart metering;

h) on-site generation including photovoltaic panels, wind turbines and hydro turbines;

i) battery energy storage; and

j) an energy management system.

This guide draws on the content within Amendment 2 (2022) to BS 7671:2018, associated British Standards, IEC documents and standards, other IET Codes and Guidance titles, and industry documents. A full list of reference material is provided within the Appendices.

Local generation sources for safety services are out of scope for this guide, including standby generators for:

k) residential lifts and firefighting sprinkler systems;

l) healthcare installations; and

m) other large scale applications like data centres.

Uninterruptible power supplies are forms of local energy storage for use in specific situations and are out of scope.

Large scale renewable installations and battery storage facilities that are connected to the grid on the high voltage network (i.e. above 1,000 V) are out of scope.

1.2 Changes within BS 7671:2018 (Amendment 2:2022)

The Introduction to BS 7671:2018 (Amendment 2:2022) notes that:

> *“Historically, utility companies have managed the public transmission and distribution network from the point of view of having central production adapted to demand variation."*

It states that the objective of the new Chapter 82 (introduced as part of Amendment 2):

> *"... is to provide requirements, such that, low voltage electrical installations are compatible with the current and future ways to deliver safely the electrical energy to current-using equipment from either the public network or from other local sources.*

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Chapter 82 provides additional requirements, measures and recommendations for the design, erection and verification of all types of low voltage electrical installations. This includes local production and/or storage of energy in order to achieve compatibility with existing and future ways to deliver electrical energy to current-using equipment or to the public network by means of local sources. Such electrical installations are designated as Prosumer's Electrical Installations (PEIs).”

Part 2 provides definitions:

"Prosumer: Entity or party which can be both a producer and a consumer of electrical energy."

and

"Prosumer's Electrical Installations: Low voltage electrical installations connected or not to a public distribution network able to operate:

With local power supplies and/or

With local storage unit

And that monitor and control the energy from the connected sources delivering it to:

Current-using equipment,and/or

Local storage units and/or

Public distribution network"

The scope of Chapter 82 itself states that it includes “requirements for PEIs to achieve safe operation, sustainability and efficient use of energy when integrated into smart grids.”

This guide explores in further detail the requirements of Chapter 82 of BS 7671 and augments that with guidance on the design intent of PEIs and their safe operation. This guide:

— should be read in conjunction with BS 7671; and

— does not change the principal design hierarchy of BS 7671.

There is no alteration to the principles of safety in design or in operation. The transition of an installation to a PEI requires a comprehensive understanding of:

a) possible operating modes including export, import and island;

b) potential connection strategies including individual, collective and shared;

c) Electrical energy supply sources including grid connections, local generation and energy storage;

d) energy flow at any one point in time and how that may change;

e) protective devices and potential fault paths under various scenarios;

f) earthing considerations including design requirements and operational parameters;

g) safe systems of work and isolations; and

h) maintenance and periodic insopection and testing of electrical equipment including energy storage and on-site generation.

This guide is intended for experienced practitioners, or those under supervision, working in the PEI sector.

Fundamental design issues and operational considerations tensure a safe electrical installation, during construction and in service, with multiple sources of energy simultaneously feeding the same installation.

This guide seeks to inform designers, installers and operators alike.

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1.3 History and evolution of electrical installations

The Wiring Regulations were first published by the Society of Telegraph Engineers and Electricians in 1882 as the Rules and Regulations for the Prevention of Fire Risks Arising from Electric Lighting. The most recent iteration was published in 2018 as the 18th Edition of the Wiring Regulations, more formally known now as BS 7671, Requirements for Electrical Installations.

The Regulations have evolved continuously over time as technology and design philosophies have changed. Historically, the main principles of BS 7671 have focused on safety and capacity. This ensures that the design of an installation should:

a) be safe enough to protect operators and users from the dangers of electric shock, allow proper functioning and permit satisfactory maintenance operations;

b) have sufficient design capacity for the existing needs of the installation; and

c) prevent damage to the installation caused by the dangers of heat from overcurrent.

Previous editions of BS 7671 have focused on a set installation model of one electrical connection from the grid and integration of sub-circuits to an installation distribution system.

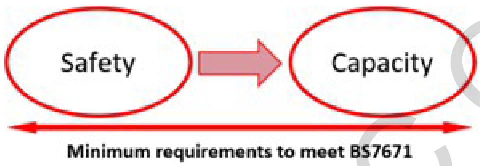

Figure 1.1 — Traditional design hierarchy

Meeting the requirements of the two basic principles of the design hierarchy has, typically, been all that is required for most domestic, commercial, industrial and infrastructure installations. The Wiring Regulations have traditionally focused on satisfactory electrical designs that can function as intended and be operated safely to prevent risk to people and property. Over successive editions there has been evolving guidance on:

d) electrical design capacity to prevent overloaded installations;

e) circuit controls and protective devices;

f) installation methodology to prevent mechanical damage to cables;

g) installation methodology to prevent overheating in use; and

h) operational risks and safety considerations.

Electrical installations compliant with BS 7671 operate from a power supply (either single phase or three phase) from the public supply network to a point of connection, protected by the supply fuse for each live phase. Consumption is measured by an appropriate fiscal energy meter. Within the installation, sub-distribution protective devices are designed to operate within supply parameters that can be measured and are generally consistent. This works in conjunction with an intake earthing system, connected to the installation's own earthing, which should ensure disconnection of the individual circuits in a timely manner in the event of a fault.

The net result is that previously energy flow has only ever been in one direction – from the point of supply (the meter head) to the point of use (the sub-circuit).

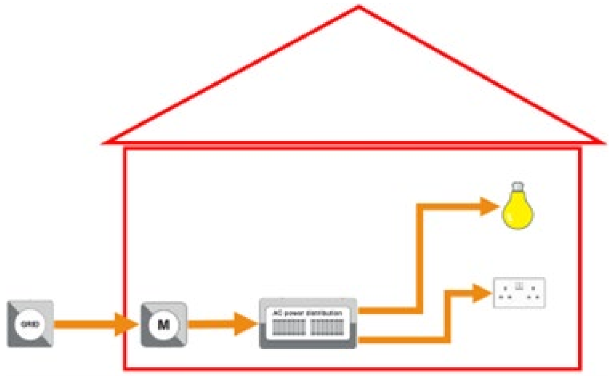

Figure 1.2 — Energy flow in a simple electrical installation

Where it has been used, the function of energy storage within electrical installations has typically been limited to providing operational resilience and supporting electrical loads when mains power is lost for relatively short periods. They are of limited scope and used with specific systems, for instance small scale backup batteries embedded within the control panels of fire alarms or within emergency lights.

Some larger installations, such as data centres and hospitals, have used large scale battery systems to bridge the brief time gap between mains failure and standby generator start up. This design philosophy ensures a continuous electrical supply for critical installations.

1.4 Looking to the future

Electrical installations are becoming much more sophisticated, even in domestic environments. There are diverse requirements, with enhanced levels of safety and automatic intervention to isolate faults. Part 7 of BS 7671 covers special installations or locations, supplementing or modifying requirements in other parts of the Regulations.

Section 712 provides particular requirements for solar photovoltaic (PV) power supply systems and provides guidance on the safe connection of solar energy, the DC installation and AC protection devices. With PV the typical energy flow is modified and becomes more complicated. There is still electrical energy flowing to the loads via sub-circuits. However, the demand usually derived from the intake may be supplemented by additional energy derived from the PV equipment. When the building demand falls below the output of the PV, any excess energy flows in the opposite direction via the meter and back to the grid.

The result is bi-directional energy flow within the electrical installation's infrastructure, which presents design challenges for protective devices and installation safety issues. There are now multiple sources of supply potentially operating at the same time.

It is also important that an appropriate meter is installed to record imports into the installation and exports from it.

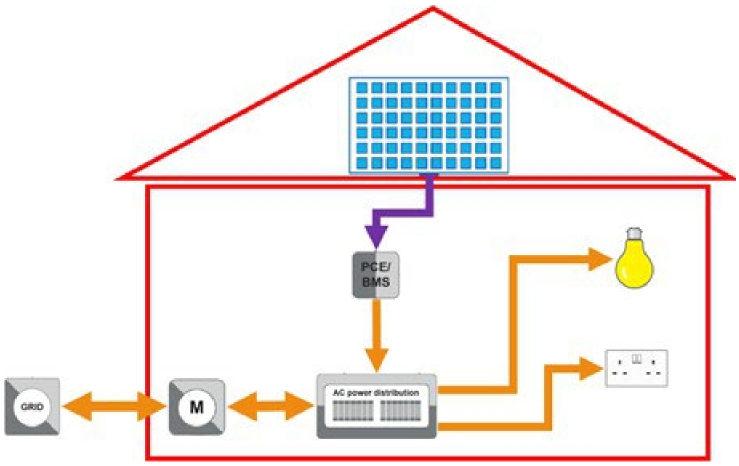

Figure 1.3 — Bi-directional energy flow in a basic PV electrical installation

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The publication in 2018 of the 18th Edition of the IET Wiring Regulations introduced the concepts of energy efficiency in electrical installation in Appendix 17. This informative text gave guidance on understanding the concepts of energy efficiency in electrical installations rather than particular normative requirements.

Appendix 17 was based on an IEC document, now adopted in the UK as BS HD 60364-8-1:2019 (Low-voltage electrical installations - Part 8-1: Functional aspects - Energy efficiency). The document outlines ways to reduce demand at the point of use via:

a) use of active controls and energy management techniques (e.g. through use of building automation and control systems);

b) early consideration of passive mitigation of energy losses in an electrical installation through careful design (e.g. equipment location, cable routes and cable sizes); or

c) connection of active equipment to redress energy losses (e.g. power factor correction and harmonic filters).

Energy efficiency measures can be integrated into the design hierarchy. Safety and capacity should always remain the fundamental priorities, but efficiency can inform the next level of design. It may even override the need for resilience in some parts of the installation.

For more critical installations, such as hospitals or data centres, efficiency may be considered less important than resilience – life safety or business continuity might be the principal drivers. The designer, in collaboration with other key stakeholders, should consider the requirement of the end-users and prioritise accordingly. The needs of efficiency may override resilience in less critical parts of the installation, or vice versa in others.

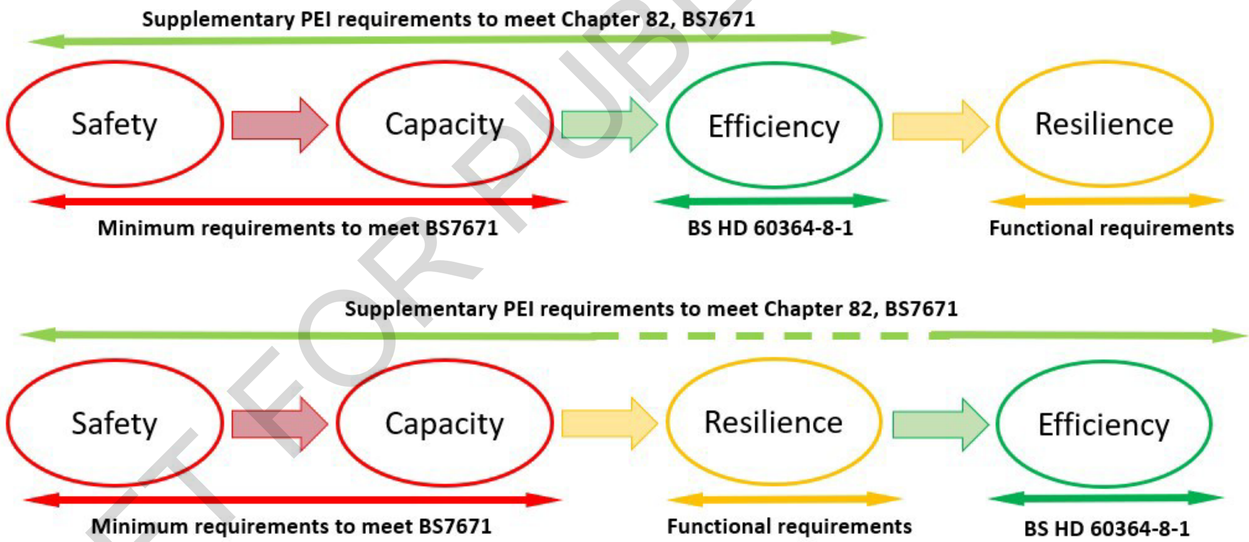

Figure 1.4 — Variations on the design hierarchy

1.5 Energy independence or interdependence

The electrical installation landscape is changing rapidly and Amendment 2 to BS 7671, and Chapter 82 in particular, recognise that. Business models for buying and selling electrical energy are changing too, as illustrated by the emergence of smart meters and tariffs to sell electricity back to the grid. The rising costs of energy in general and the need to keep control of those costs are also a driver.

The next stage of the evolution of electrical installations is driven by a better awareness of:

a) new design philosophies around decarbonisation and energy efficiency; and

b) new innovations around:

- on-site renewable electrical energy generation;
- on site battery electrical energy storage;
- time of use controls and load planning;
- dynamic electrical energy management systems;
- smart meters and dynamic electrical tariffs applied in real time; and
- efficiencies in direct current installations.

Within a typical PEI, designers, installers and maintainers need to recognise that there are now many more design factors and operational risks to consider:

c) multiple sources of energy that can operate simultaneously, including mains grid connection, local on-site renewable sources and battery storage;

d) multiple operational scenarios including grid connected, island or standalone, or shared energy storage facilities with adjacent installations;

e) multiple potential fault paths fed by the various combinations of energy source at any one moment in time;

f) greater variation in fault currents for protective devices to deal with;

g) more careful assessment of safe systems of work to alleviate dangers from alternate energy sources at the point of use;

h) more requirements for operational isolation points and lock off further up the electrical infrastructure; and

i) careful assessment of maximum demand and diversity especially if the PEI operates in island mode, for example on loss of mains supply.

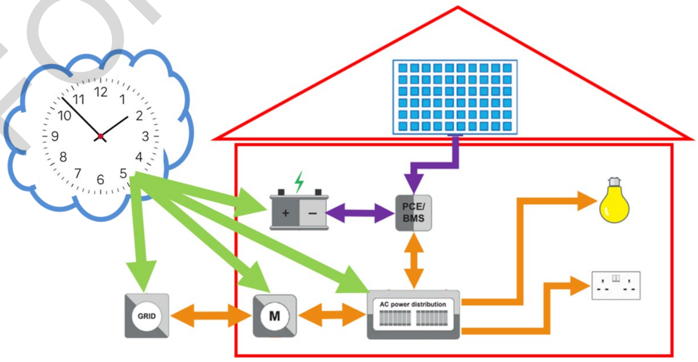

Figure 1.5 — PEI complex energy flow

Central to the successful implementation and operation of a PEI is an electrical energy management system (EEMS). Even for the smallest of installations, such as in a domestic setting, this control is necessary to maximise energy harvesting and minimise energy consumption and associated costs.

Electrical energy consumption is no longer a passive process that accepts unidirectional flow of electrical energy from the grid alone. It is active and responsive to signals and demands from within the installation and externally from the grid. The installation now incorporates energy production which may be intermittent and supported by on-site storage.

Planning the use of loads is important to ensure more consistent, smoother demand for energy from grid supplies and local supplies.

The benefits of active installation management can include:

j) insights on maximum demand/diversity assessments;

k) the ability to shift particular electrical loads to off-peak use;

l) knowledge of generation capacity, which can be weather dependent;

m) oversight of static energy storage with import and export; and

n) integration of vehicle to grid (V2G) energy storage with import and export.

It allows the installation to operate under a number of different active scenarios, for example:

o) to monitor and potentially alter when principal loads consume to optimise costs or to ease strains on local grid capacity;

p) energy storage to make optimum use of local energy production for in-house use;

q) energy exports to maximise revenue; and

r) energy storage, including electric vehicle (EV) charging, to recharge at cheaper (off-peak) tariff periods.

The Energy Networks Association (ENA) publishes a variety of documents to assist with the registration of micro-generation schemes . Engineering Recommendation (EREC) Documents G98 and G99 list several benefits, impacts and challenges. Benefits that the ENA identifies as being associated with increased PEI connections in the wider electricity system include:

— increased energy mix, where connection of localised renewable sources means a lower carbon mix;

— local electricity generation connected closer to the point of use should reduce losses in the electrical installation;

— operational efficiencies in upstream electrical infrastructure increases especially when local generation output matches local load demand;

— use of PEIs in businesses and communities increases awareness of energy efficiency issues and decarbonisation in general; and

— commercial benefits, especially within PEIs, incuding:

  — self-consumption, avoiding energy imports and lowering bills especially when tariffs are higher (peak periods); and

  — The ability to sell electricity that is generated either individually or collectively.

The impacts of increased PEI include:

— the size of the generating units and the type of generation technology being deployed;

— the voltage level on the network that the PEI is connected to;

— other constraints in the local grid including allowable levels of export to the wider distribution system; and

— the type of network in the area and connection arrangements (e.g. urban or rural) including earthing arrangements.

Some examples of the challenges posed to distribution networks by PEI include:

s) changes to current flows and shape of the load cycle where they are connected. This could cause:

  — thermal performance to exceed rating limits;

— system voltage to rise adversely; and

— reverse power flows in equipment that is not designed for that.

t) adverse fault levels, caused by intermittent PEI capacity above the rating of network equipment; and

u) power quality affected by PEI, including:

— harmonics; and

— voltage unbalance.

2 Overview of prosumer electrical installations

2.1 Concept of PEI

The concept of a PEI, as set out in Section 823 of BS 7671, is an installation that has multiple supplies capable of operating simultaneously, various loads of varying importance, distribution to those loads, and an electrical energy management system (EEMS) to optimise performance through varying modes of operation.

Annex A82 of BS 7671 provides further explanation of the concepts of a PEI. This is illustrated by Figure 82.1 of BS 7671, which is reproduced and annotated in Figure 2.1.

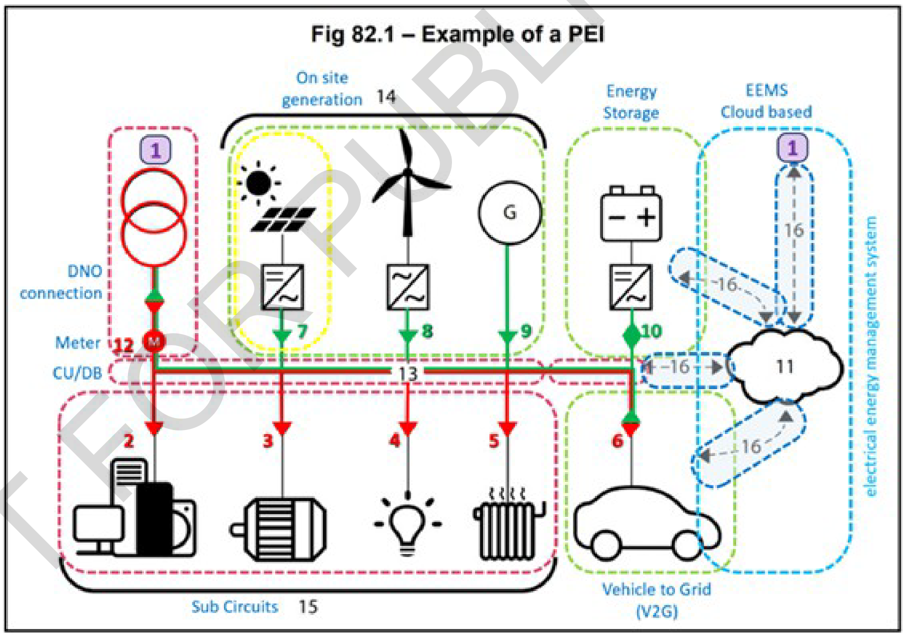

Figure 2.1 — PEI complex energy flow

Section 823 of BS 7671 notes that a PEI will have four principal functions, as indicated in Figure 2.1:

a) supply (Items 1, 7, 8 and 9; also 6 and 10);

b) distribution (item 13)

c) consumption (Items 2, 3, 4 and 5; also 6 and 10); and

d) energy management (Items 11 and 16)

Annex A82 of BS 7671 notes that PEI concepts should be clear on:

e) the role of the end user;

f) the operation of an active energy management system;

g) the purpose of local renewable energy systems; and

h) the operation and purpose of energy storage systems.

2.1.1 Supply

This will be derived from multiple sources including a grid connection from the public network, on-site electrical generators, and renewable energy systems such as photovoltaic systems, wind turbines, water turbines etc.

Battery systems that are used for whole-system energy storage are a special case and are also deemed to be a supply source when it is discharging electrical energy back into the distribution system.

Batteries that are part of a UPS, designed to provide specific backup to local sub-circuit systems, are not deemed to be a PEI supply as they only support defined smaller areas of the overall electrical installation

2.1.2 Distribution

This will include all cabling, isolators, switches, distribution boards, consumer units and protective devices that allow electrical energy to pass from one part of the installation to another.

For the purposes of electrical safety, it is crucial that all parts of the electrical distribution system are designed and installed to operate satisfactorily under normal conditions, to cope with energy flow in various directions, and to react correctly under fault conditions regardless of the supply operating at that point in time.

2.1.3 Consumption

Included under this heading are all electrical loads. These are marshalled via the main distribution board or consumer unit in distribution circuits or final circuits as required by Parts 4 and 5 of BS 7671.

In Figure 2.1, Item 2 refers to home appliances and electronic devices that are often connected to socket-outlets arranged in either ring final circuits or radial circuits.

Item 3 refers to motors that are often arranged in dedicated radial circuits especially in larger commercial installations.

Item 4 refers to lighting that will have dedicated radial circuits and additional local controls for operational reasons and for energy efficiency purposes.

Item 5 refers to heaters. Electrical space heating can take many forms, like simple bar heaters plugged into a socket outlet on a ring final circuit, or storage heaters on dedicated circuits and connected to an overnight tariff infrastructure or heat pumps connected to their own radial circuits. Water heating may also be on electrical radial circuits.

The common theme with Items 2,3,4 and 5 is that the energy flow within that part of the installation is all in one direction. As such, the protective devices need to be selected to react with faults on the connected final circuit only.

Item 6 refers to electric vehicles. For most installations this will simply be a plug-in point to allow the vehicle to recharge. Energy flow will typically be in one direction only and the protective device will be selected to cope with the electrical load profile of the vehicle.

Recent innovations in design philosophy and technology allow for a vehicle to be used as a battery storage system; hence export back to the electrical installation and ultimately back to the grid connection is possible. This bi-directional energy flow is known as vehicle to grid (V2G). Protective devices should be selected to operate satisfactorily with energy flow, and potential fault currents, in both directions.

Item 10 refers to energy storage. This is battery storage that will harvest surplus energy from the on-site generators when they are operating. The storage may also draw energy through the distribution system from the grid connection when tariffs are cheaper. The energy may then be used at other times either within the installation or exported back to the grid when tariffs are more expensive.

Item 10 will require careful selection of protective devices as energy flow will regularly be changing direction.

2.1.4 Energy management

Item 11 represents an electrical energy management system, portrayed in the diagram as a cloud-based system using the internet. Annex A82 of BS 7671 provides more information about the expectations of that EEMS (see also Section 2.1.6 in this guide).

The success of any PEI will be dependent on the functionality of the EMS and its ability to control electrical loads, electrical supplies and monitor energy consumption and production.

Item 16 represents the interface between the cloud-based controls and the actual individual components of the PEI. This will include an interface to each of the supply methods including energy storage, on-site generation and the grid connection.

For a PEI to operate at its optimum it would be advantageous for each of the electrical loads to be monitored and potentially controlled by the energy management system. Such controls would allow for load planning to shift some loads to off-peak tariff times, or to load shed when grid connections are temporarily lost and reduce strain on local generation.

2.1.5 Role of the end user

The end user is central to the successful operation of the PEI. The end user should assess and control their usage of electrical energy based on their own needs and any constraints on the grid connection or availability of on-site generation.

With an appropriate installation, they should be able to take advantage of any periods of low electrical loads to store electrical energy either from on-site renewable generation or from low priced grid connections.

Whilst many of the functions of the PEI will be automated and monitored via a central user interface, there remains a need for the end user to be informed. They should be able to plan electrical energy use and check on both production and consumption.

Intervention will also be required for routine maintenance and essential repairs. Information about equipment and any local variations on safe systems of work should be retained by the end user and shared with the maintainer on request.

2.1.6 Active energy management

The purpose of an active energy management system (EMS) is to balance the needs of the installation and the grid. An active EMS should be capable of:

a) supporting the end user to constantly monitor and manage electrical consumption and production, usually via a cloud-based interface that provides real time information; and

b) communicating with the wider electrical grid. This exchange of information will assist the wider grid, and the distribution system operator (DSO) in particular, and is key to ensuring a smart and flexible electricity system.

It should be capable of sending data relating to consumption, usually via smart metering, and receiving signals from the DSO if urgent action is required to reduce less critical loads within the installation during periods of supply constraint. It can also receive signals from the DSO to request input to the grid from on-site electrical energy storage.

2.1.7 Renewable energy systems

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The use of renewable energy sources on any part of the electrical distribution infrastructure is a criticial element of addressing challenges of climate change by reducing carbon dioxide emissions and other associated pollutants.

Renewable energy systems may include large scale photovoltaic (PV) systems and wind turbine arrays that generate megawatts of electrical power and connect directly to the grid.

For a typical PEI, a renewable energy system is likely to be considered as microgeneration and consist of a modest number of PV panels generating a just few kilowatts. Small scale wind turbines are also available in various configurations that can provide a few hundred watts. In locations where there is a running water source it may be feasible to install a water turbine.

Whatever the renewable source, it has an important role in supporting electrical loads, especially at daily peak times. In some off-peak periods it is conceivable that the renewable source (for example, wind or water) may even support significant portions of the electrical load.

2.1.8 Energy storage systems

Energy storage systems provide flexibility in a PEI and more reliability for the end user. A principal concern with renewable energy systems is the intermittent and unpredictable nature of supply. It is not practical to plan when to use a particular electrical load if it is not known when a renewable supply will be available.

Electrical energy storage systems (EESS) can mitigate the risks associated with intermittent supply by:

a) harvesting surplus energy from local renewable sources irrespective of the time of day it is produced;

b) supporting electrical loads during peak hours and hence reducing costs if tariffs are high at that point;

c) reducing grid constraints by offsetting the power required from the grid; and

d) harvesting energy from the grid when tariffs are low or there is a surplus of grid generation.

The energy storage system may also be called on to support the electrical installation during loss of mains supply. This function should not be confused with a UPS installation.

There is a need for planning around this scenario. An active energy management system may need to be programmed to shed some of the less important electrical loads to ensure the remaining loads do not exceed the combined output of any renewable sources still online and the remaining capacity of the energy storage system.

2.2 Smart grid and PEI

Successful operation of a PEI is dependent on the functionality of an EEMS and the interaction between the EEMS and the grid connected smart grid. An EEMS is used by the end user to monitor and control local energy consumption, local energy production, and any local energy storage. In simple terms, the smart grid defines similar activities on the wider electrical distribution network.

It is necessary for the two data-based systems to communicate dynamically and support a number of operational scenarios. For example, exchange of information in real time will:

a) enable the PEI to assist in periods of supply constraint by supporting its own loads for a while or load shedding to reduce demand on the gird connection;

b) allow the smart grid to request energy exports where the PEI has surplus energy to provide;

c) allow the PEI to take advantage of lower tariffs to support its own loads including recharging local energy storage; and

d) allow accurate measurement of electrical energy imports and exports, prevailing tariffs when that happens and itemised billing.

The data links between the smart grid and PEI will be defined by the contractual arrangements between the PEI end user and the energy supply company. As well as the PEI end user (energy consumer), other stakeholders in the data chain will include communication service providers, data service providers, energy suppliers, electricity network operators and other authorised organisations.

There will be a need to determine:

e) what information the smart grid will require and what the EEMS is able to provide;

f) what information the smart grid will provide and what the EEMS is required to do with that information;

g) what communications protocol is acceptable;

h) who has access to the data provided by the EEMS;

i) what level of control of the actual installation any communication link will give, e.g. load shedding of sub-circuits or export from energy storage facilities, and how that is authorised.

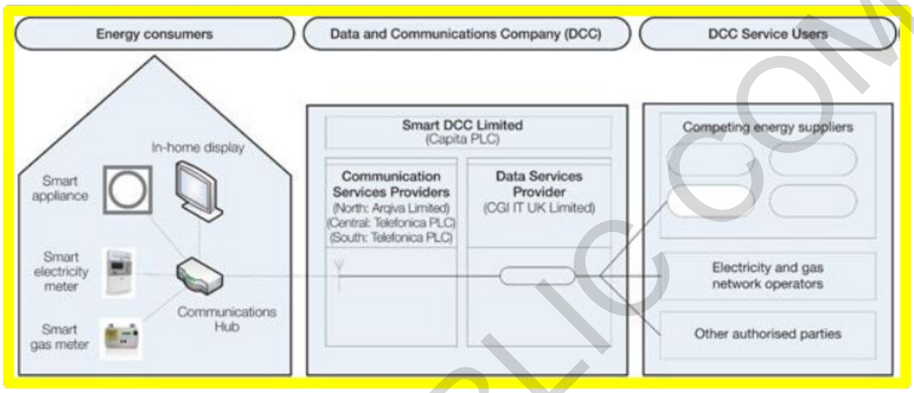

Figure 2.2 — Smart grid network

2.2.1 The case for electrical safety

It is important to note that electrical safety within any electrical installation is absolutely paramount. The use of automated or semi-automated controls to add electrical loads and additional sources of supply does not obviate the need for safety. This includes when they are potentially activated from remote locations, for example a DSO signal to export from on-site energy storage or to initiate load shedding during peak periods.

Safety is a fundamental criterion of the electrical design hierarchy and Regulation 822.2 of BS 7671 reinforces that:

> *"The implementation of the requirements provided (of the smart grid) shall not impair the safety of the PEI."*

Regulation 822.2 also requires that all protective measures shall remain fully operational irrespective of the source of supply. If this is not feasible then they should be automatically replaced by other measures to provide an equivalent level of electrical safety.

This will include correctly rated protective devices designed to operate with appropriate energy flow direction, earthing configuration and sub-circuit safety monitoring where it is deployed.

2.2.2 Reliability and function

The renewable energy sources and energy storage components of a PEI should be reliable and provide consistent output in line with the requirements of BS 7671.

It is important that appropriate protection measures and controls are in place to ensure that power quality parameters such as voltage and frequency are met, to allow the installation to run safely and efficiently under direct feeding mode and island mode.

The requirements for island mode are reinforced in Regulation 822.3 of BS 7671:

> *"These requirements are important for the use of island mode. It is essential for the PEI to comply with similar requirements on stability, availability and quality in island mode as for connected mode."*

The power quality parameter conditions should also be met under reverse feeding mode and exports from a PEI to the grid should not cause issues further upstream on the grid infrastructure.

For designers and operators of PEI, further guidance on the actual requirements for the power quality parameters can be found in ENA EREC G98 and EREC G99.

ENA EREC G5 describes the requirements for the avoidance of harmonic voltage distortion. It also outlines the connection and assessment processes for compliant harmonic sources and resonant plant.

2.2.3 PEI, EEMS and supply constraints

Regulation 822.4 of BS 7671 states that the design, construction and commissioning of a PEI should take into account the requirements of both the electricity supplier and the end user. Reconciling these requirements means an EEMS is necessary to tie all the components together and provide a fully integrated control system.

To record exported and imported energy for energy management and billing purposes, a smart meter will be necessary. Smart meters form part of the communications side of a PEI. They measure energy use and also communicate that consumption in real time through a national network to the energy supplier for billing purposes. At the PEI the smart meter is connected to a communications hub and links to a user interface, or in-house display (IHD), so that the property's account holder can monitor energy use.

Table 2.1 — Domestic meter type

Domestic Meter type	Domestic tariff	Description	Costs (£ - ££££)
Smart meter (SMETS2 or Secure TM SMETS1)	Half-hourly reading and flexible rate	Single meter with varying electricity prices updated daily and based on wholesale costs Encourages load shifting away from 1600 – 1900 peak hours Equipment should have time controls to switch off during potential expensive periods	£ (off-peak hours vary daily) £££ (peak hours can also vary)

Smart meter (SMETS2 or Secure TM SMETS1)	Half-hourly reading and two set rates	Single meter offering limited period of low-cost off-peak electricity overnight Normal tariff outside this period Useful for overnight charging of electric vehicles or electrified heating Equipment will need time controls to switch on during cheaper periods	£ (off-peak hours defined in contract) £££ for general use

The purpose of the controls is to monitor loads at the distribution boards or consumer units. Controls can also be used to monitor and operate individual loads. This can assist with load diversity, reduce energy consumption at peak times and introduce loads at off-peak times. When necessary, energy storage can be recharged at off-peak times when tariffs are cheaper.

If the grid supply fails and the installation becomes dependent on the local generation or energy storage facility, the controls can be used to reduce overall load demands, prioritise particular loads (e.g. lighting at night) and enable the installation to operate independently for longer.

Smart grid connections, associated communication systems, local controls and EEMS provide a range of sophisticated tools for the installation. As a combined system they play an integral role in optimising when electrical energy is used, at what tariff and when the installation can export to the grid. At times of supply constraint, they can assist with various strategies including load shedding, export surplus renewable energy and exporting from energy storage to the grid.

The communication hub can also link to smart appliances to facilitate additional controls over individual loads, often through a web portal or a smart phone app.

3 Energy efficiency

3.1 The context for PEI

The typical operational profile for a PEI is a complex mix of time of use tariffs, on-site renewable energy generation, on-site energy storage and electrical energy export and imports, all responding dynamically to real time monitoring, signals and controls.

Full evaluation of the design and operational energy efficiency in electrical installations requires the periodic assessment of a number of concepts and measures outlined in BS HD 60364-8-1. The information in BS HD 60364-8-1 provides details on some of these energy efficiency concepts and measures.

Not all energy efficiency measures will involve technology – some will be passive to minimise energy losses in the use of electrical loads. Others will be more active and seek to reduce unnecessary electrical energy consumption. The level of control will influence the assessment of energy efficiency of the installation itself.

When considering the implementation of PEI, it is important to ensure that energy efficiency within an electrical installation has been assessed first. Optimising the loads actually connected, when they will operate and what controls will be provided are important components.

Simply adding battery storage and local generation to an electrical installation should not be seen as a reason to continue business as usual. More technology is only an aid to decarbonisation and will only take the electrical installation so far to reduce energy costs and reduce emissions. There must also be a focus on design and timely maintenance to drive efficiencies, and also on user behaviour, assisted by technology.

The implementation of PEI and assessment of efficient electrical installations should be an opportunity to rationalise and improve. There will be less strain on the system, components will last longer before needing replacement and costs will be reduced.

3.2 Cost efficiency

Improvements to energy efficiency in each installation will have benefits such as reducing energy costs. Smart energy meters allow the use of flexible tariffs for billing purposes. Half-hourly billing against industrial and commercial properties has been available for a while with cost penalties for energy use during peak periods. Flexible tariffs have entered the domestic housing energy market in recent years and are offered by a number of supply companies.

Restricting use of electrical loads to particular times of the day will also reduce costs and can assist with efficiencies of the whole electrical network.

Flexible tariff systems alter the cost of electrical energy depending on when it is used. Although there are no specific penalties for domestic installation peak period use, costs do vary continuously throughout the whole day and at designated peak times can be significantly higher than at off-peak times.

A PEI operated correctly should be able to maximise income from energy exports and minimize costs from energy imports. This would include optimizing use of energy storage on site and shifting non-essential loads to off-peak times so that they can be operated more cheaply, for example electric vehicle charging and home laundry.

3.3 BS 7671 and energy efficiency

For issues on energy efficiency, BS 7671 references BS HD 60364-8-1 and defers to that document to assist with designing, installing and operating a more energy efficient electrical installation. The British Standard is based on CENELEC Harmonised Document HD 60364-8-1 Functional Aspects – Energy efficiency. The recommendations are for optimising efficiency in electrical installations, including local production and energy storage.

The scope notes that the installation of on-site renewables does not directly improve the energy efficiency of electrical installations. There is an indirect correlation though. Where they can reduce losses on the public electrical networks is by offsetting. Local electrical energy production means less energy consumption from the grid and less losses on the grid.

There is guidance on related issues such as:

a) understanding and planning the load energy profile in the installation;

b) monitoring the availability of local energy generation and storage;

c) designs and installation methods that reduce energy losses from the outset;

d) understanding the tariff structure offered by the supplier to optimise costs; and

e) the use of energy according to customer demand so that critical loads can operate as required and less critical loads can be used in lower tariff periods.

It is important to note that PEIs need careful control to maximise the investment made and optimise use of the energy that is provided. It is important to monitor electrical energy consumption, in kilowatt hours, throughout each day. Hourly records are recommended as a minimum. Technology is available to provide monitoring over shorter periods and should be considered.

Half-hourly readings are already a requirement of many non-domestic premises if the installation has a peak electricity demand of 100 kVA or more. Where the installation uses less, the requirement for half-

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hourly monitoring of energy use is optional and it may be worth considering to take advantage of the energy monitoring benefits of such a system.

Smart meters continuously monitor the amount of energy that is consumed or exported in the installation and record the figure within every half hour of the day. Recording energy use in this way makes the settlement process more accurate. That, in turn, allows for billing that uses more dynamic electricity tariffs supporting lower prices for off-peak use, and penalising for excessive energy use at peak times. Users of devices such as electric vehicles can take advantage of the lower tariffs.

There are also collective environmental benefits in smart electrical installations shifting electrical loads so that overall consumption is smoother through the whole day with fewer peaks and troughs. This reduces the need for standing electrical grid generating plant that is not being utilised efficiently.

Electrical energy management systems (EEMS) are a feature of the energy efficiency measures outlined in BS HD 60364-8-1 and a requirement of a PEI. It is important to recognize that with EEMS there is close synergy between PEI and energy efficiency.

3.4 Low-voltage installations and equipment

A key part of a PEI is understanding and controlling the final circuits supplying the electrical loads (see Section 2.1.3). These are marshalled via the main distribution board or consumer unit in separate circuits as defined in Regulations 314.1 and 314.2 and required by Parts 4 and 5 of BS 7671.

BS HD 60364-8-1 provides guidance on ensuring that efficiency measures for equipment and circuits are considered and appropriately selected as part of the design to use the optimum amount of energy for the task required of them. The focus is on:

a) motors;

b) lighting; and

c) heating, ventilation and air conditioning.

These are considered the primary loads within non-domestic buildings. The move to decarbonisation will mean the electrification of space heating and water heating. The introduction of technologies such as heat pumps in commercial, industrial and domestic properties will mean more consideration of the efficiencies of low voltage equipment, the associated controls and their operational profiles.

The type and efficiency of individual items of individual electrical equipment connected to the installation will be under increasing scrutiny at the design stage of a project. For example, in England, Approved Document Part L of the Building Regulations already places guidance on minimum efficiency of lighting. For Scotland, the documents to refer to are the Scottish Government Building Standards Division Technical Handbooks for Domestic and for Non-Domestic installations.

Automated controls are another example of reducing load demands. It is worth noting that BS HD 60364-8-1 itemises lighting controls as an example of this, including the deployment of absence and presence detectors, dimming facilities and daylighting controls.

4 Electrical safety

IET *Guidance Note 2: Isolation & Switching* to BS 7671 notes that:

> *"The Electricity at Work Regulations 1989 (EAWR) are general in their application and refer throughout to 'danger' and 'injury'. Danger is defined as risk of 'injury' and injury is defined in terms of certain classes of potential harm to persons. Injury is stated to mean death or injury to persons from:*
>
> *a) electric shock;*

b) electric burn;

c) electrical explosion or arcing; or

d) fire or explosion initiated by electrical energy."

EAWR imposes duties on employers, employees and the self-employed to ensure safety requirements of electrical installations and maintenance activities.

EAWR Regulation 4 states:

"1. All systems shall at all times be of such construction as to prevent, so far as is reasonably practicable, danger.

2. As may be necessary to prevent danger, all systems shall be maintained so as to prevent, so far as is reasonably practicable, such danger.

3. Every work activity, including operation, use and maintenance of a system and work near a system, shall be carried out in such a manner as not to give rise, so far as is reasonably practicable, to danger.

4. Any equipment provided under these Regulations for the purpose of protecting persons at work on or near electrical equipment shall be suitable for the use for which it is provided, be maintained in a condition suitable for that use, and be properly used."

EAWR Regulation 11 discusses protection from excess current:

"Efficient means, suitably located, shall be provided for protecting from excess of current every part of a system as may be necessary to prevent danger."

EAWR Regulation 12 highlights the requirements for isolation and switching:

"1. Subject to paragraph (3), where necessary to prevent danger, suitable means (including, where appropriate, methods of identifying circuits) shall be available for–

(a) cutting off the supply of electrical energy to any electrical equipment; and

(b) the isolation of any electrical equipment.

2. In paragraph (1), "isolation" means the disconnection and separation of the electrical equipment from every source of electrical energy in such a way that this disconnection and separation is secure.

3. Paragraph (1) shall not apply to electrical equipment which is itself a source of electrical energy but, in such a case as is necessary, precautions shall be taken to prevent, so far as is reasonably practicable, danger."

The requirements of EAWR Regulation 12 Paragraph 3 regarding sources of electrical energy are interesting to note and were compiled when the proliferation of on-site energy sources, which are likely to be working in synchronicity with the mains grid, was perhaps not foreseen. The requirements of BS 7671 Regulation 826.1.1.4 clearly state that "where an installation is supplied from more than one source, a main switch suitable for isolation (e.g. switch disconnector) shall be provided for each source of supply". This reinforces the requirements of Regulation 12 Paragraph 2. It also provides a more robust approach to the risks of multiple sources of energy than required in Paragraph 3.

There are operational risks in all electrical installations for maintenance work. This is more complicated in a PEI, which has multiple sources of supply. Appropriate mitigation measures against those risks are a necessary part of electrical installation, as is made clear in EAWR Regulation 13 'Precautions for work on equipment made dead':

"Adequate precautions shall be taken to prevent electrical equipment, which has been made dead in order to prevent danger while work is carried out on or near that equipment, from becoming electrically charged during that work if danger may thereby arise."

According to BS 7671 Regulation 131.1 that for all electrical installations the fundamental principles of electrical safety:

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"are intended to provide for the safety of persons, livestock and property against dangers and damage which may arise in the reasonable use of electrical installations…".

The two main principles regarding electrical safety are:

e) how the installation reacts under fault conditions to protect persons, livestock and property through the combined use of protective devices to automatically disconnect supplies and augmented by earthing and bonding connections; and

f) how the installation can be controlled, isolated and switched to allow safe operations in use and safe systems of work for maintenance requirements and replacement of electrical equipment.

The principal guidance within BS 7671 can be found in Part 4 and particularly in Chapter 41 for protection against electric shock and Chapter 46 for isolation and switching. Section 537 provides information on the functional aspects of switching and isolation, types of devices and their capacity for isolation, emergency switching off or functional switching.

Section 411 deals with requirements for automatic disconnection of supply as a key protective measure. There are also requirements to deal with maximum disconnection times and earth loop impedance for various installation arrangements. Of interest to PEI are arrangements for TN and TT installations.

For PEI these fundamental electrical safety principles are reinforced in BS 7671, Regulation 822.2:

"The implementation of the requirements provided shall not impair the safety of the PEI. In case of change of any energy supply configuration (e.g. from network supply to local power supplies) all protective measures shall continue to be operational or shall be automatically replaced by other protective measures providing an equivalent level of safety."

Regulation groups 551.1 and 551.2 discuss the scope and general requirements respectively of low voltage generating sets. These sets include:

g) combustion engines;

h) turbines;

i) electric motors;

j) photovoltaic cells;

k) batteries; and

l) other suitable sources.

The requirements include consideration of short circuit currents when the generating sets are connected to an installation that is connected to the grid, the stability of the voltage and frequency of the generating sets and the dangers of damage to equipment if these parameters are not met by connection of the local generation

Electrical safety in PEI will need a satisfactory combination of:

m) earth connections to suit all operating modes;

n) protective devices capable of reacting automatically in a timely manner to the particular fault currents in those varying operating modes; and

o) protective devices and equipment that operate correctly under bi-directional energy flow conditions (direct, reverse and island).

The framework for electrical safety in PEI is based on robust design, comprehensive commissioning and regular operational maintenance. A new installation in a new building will have its own challenges, but there should be an opportunity to address issues and mitigate risks to achieve successful outcomes.

A significant portion of the PEI market will be in retro-fit situations where on-site generation, battery energy storage systems, smart meters and EEMS are installed on top of an existing electrical installation. Integration of old and new will be crucial, and careful consideration of risks and non-compliances will be

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important.

A dilapidation survey, or a periodic inspection and testing in accordance with Part 6 of BS 7671, is recommended to establish the current status of the existing installation and its suitability to install PEI equipment. Clear communication with the installation owners on these issues is key to good working relationships and ensuring that electrical safety is not compromised.

Non-compliances should be highlighted and may necessitate additional earthing requirements and replacement of obsolete protective devices and consumer units, and upgrading of cabling and circuit protective conductors (cpc).

When completed, the PEI should also ensure that requirements for operational safe systems of work are met. As well as automatic disconnection of supplies under emergency conditions there should be systems in place for manual isolation and locking off of all electrical systems. This includes grid connected AC and all site-based AC and DC generating systems.

Further information is available on the design and implementation of particular components in a PEI in these IET publications:

p) *Code of Practice for Grid-Connected Solar Photovoltaic Systems*;

q) *Code of Practice for Electrical Energy Storage Systems*; and

r) *Code of Practice for Electric Vehicle Charging Equipment Installation*.

4.1 Earthing

The purpose of earthing, as decribed in Section 1.3 of IET *Guidance Note 8: Earthing & Bonding*, is to mitigate risks of live conductors (with respect to earth) rising to a potential value that is above their insulation rating, causing a short circuit and loss of supply. In an installation the function of earthing provides a low impedance path to allow operation of a protective device within a specified time during fault conditions. Automatic disconnection of supply (ADS) in this manner gives a measure of control over fault conditions and prevents excessive harm to people and damage to property.

An electricity supply company may provide an earth at the point of connection but its primary function is protection of the network upstream from the installation. Under the requirements of the Electricity Supply Quality and Continuity Regulations (ESQCR), the consumer is responsible for ensuring that the installation is satisfactorily earthed.

Regulations 26(1) and 26(2) of the ESQCR require the consumer's installation to be:

> *"...so constructed, installed, protected and used or arranged for use so as to prevent, so far as is reasonably practicable, danger or interference with the distributor's network or with supplies to others."*

4.1.1 Operating modes and earthing

Regulation 826.1.1.1 reiterates that PEI will change operating mode and that "protection of persons and properties shall be provided in all operating modes".

Where automatic disconnection of supply is used the system earthing used may differ and vary according to the operating mode in use at that point in time.

a) For direct feed and reverse feed modes the PEI is connected to the public distribution network and earthing of the PEI is the same as the public distribution network.

b) In island mode, when the PEI is disconnected from the public distribution network, the system earthing arrangements of the PEI may differ from the public distribution network whilst island mode is operational.

4.1.2 Changes to earthing arrangements

For simple electrical installations, earthing arrangements are static and are only amended if the actual installation is altered. BS 7671 generally prohibits any form of switching in the circuit protective conductors of the installation to ensure that there is a continuous path to earth under normal and emergency operating conditions. The different operating modes of a PEI provide particular challenges and to mitigate this a special safety case needs to be implemented. BS 7671 Regulation 537.1.5 permits a switching device in the earthing arrangements where there is more than one source of supply providing certain conditions are met:

> *"...a switching device may be inserted in the connection between the neutral point and the means of earthing, provided that the device is:*
>
> *(i) a multipole, linked switching device arranged to disconnect and connect the earthing conductor for the appropriate source at substantially the same time as the related live conductors, or*
>
> *(ii) a switching device interlocked with a multipole, linked switching device inserted in the related live conductors such that the earthing conductor for the appropriate source shall not be interrupted before the related live conductors and shall be re-established not later than when the live conductors are reconnected."*

Earthing arrangements need to be assessed carefully at the design stage and each mode considered in turn with mechanisms to change earthing arrangements if the mode of operation changes. These mechanisms need to be reversible, as stated in Regulation 826.1.1.2.1 :

> *"Any change of type of system earthing for island mode shall be reversible as operation in this mode can be temporary, and the PEI can then be operated again in connected mode."*

4.1.3 Earth electrodes

For island mode, connection to an earth electrode will be necessary. Regulation 542.2.2 provides a list of the types of acceptable earth electrodes which includes earth rods, earth tapes and earth plates. Connections to underground structural metalwork within the foundations of a building are also permitted.

Where an electric vehicle charging point is connected to a PEI, but physically located outside the building premises, the installation of an earth electrode for that part of the installation may be required.

Regulation 722.411.4.1 describes the design issues and potential solutions. Further information is available in Section 5 of the IET *Code of Practice for Electric Vehicle Charging Equipment Installation*.

4.1.4 System referencing relays

The following Regulations in Chapter 82 of BS 7671 define arrangements for transition to island mode:

a) 826.1.1.2.1 Earthing arrangement;

b) 826.1.1.2.2 Neutral conductor; and

c) 826.1.1.2.3 Connection to the local earthing arrangement.

Regulation 826.1.1.2.1 discusses the earthing arrangement required for operating in island mode. A suitable earth electrode should be installed within the PEI. There is no requirement to disconnect any earthing that is originally derived from the public distribution network e.g. TN-S or TN-C-S (see Figure 4.1).

It is important to note that operation modes are temporary and capable of changing. Earthing should be appropriate to whichever operation mode is active at that moment in time and shall be capable of reversing back to its previous state when the operating mode changes again, for example from direct feed to island mode and back again.

Any change of type of system earthing for island mode shall be reversible as operation in this mode can be temporary, and the PEI can then be operated again in connected mode.

Regulation 826.1.1.2.2 determines that all live conductors shall be disconnected from the DNO supply including the neutral conductor when the PEI operates in island mode.

Following the 'break before make' philosophy, the neutral and earth of the PEI shall be connected. This is done to prevent incorrect operation of residual current devices (RCDs), but is not done until after the double-pole island mode isolator has opened.

Regulation 826.1.1.2.3 describes the connection to the local earthing arrangement using a transfer switching device to facilitate the connection to the earthing arrangement of the local star/mid-point or the local exposed conductive parts.

Section 10.7.2 of the IET *Code of Practice for Electric Vehicle Charging Equipment Installations* states:

> *"An island-mode isolator and system referencing relay (previously known as N-E bond relay) arrangement is required that simultaneously performs the following functions:*
>
> *(e) the island mode isolator disconnects the grid supply from circuits that continue to be energized in island mode, as the installation moves from parallel operation to island-mode operation; and*
>
> *(f) the system referencing relay establishes a neutral-earth bond (if required) just after, but at substantially the same time as, the grid supply is isolated, so that in island mode the system voltages are correctly referenced to Earth and a return path for Earth fault currents is available."*

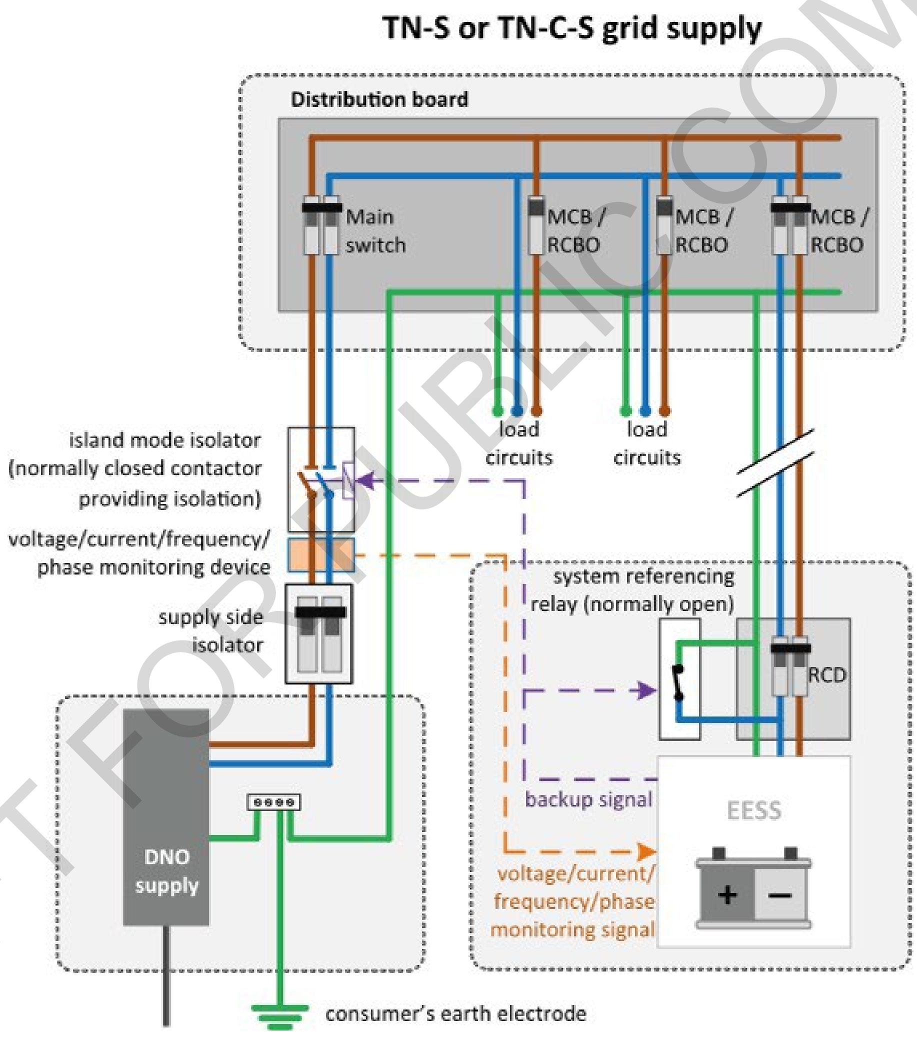


Figure 4.1 — TN-C-S/TN-S Single phase example of system referencing relay (Figure 9.7 from IET *Code of Practice for Electrical Energy Storage Systems*)

4.1.5 Additional devices

4.1.5.1 Residual current devices

It should be noted that measures such as local earth electrodes may still need to be augmented by the provision of appropriately rated residual current devices (RCDs) in accordance with the requirements of Section 411 and Regulation 411.5 in particular.

The location of the RCD should be carefully considered. Figure 4.2 shows this at the output connections for the energy storage, for example, and the neutral-earth bond is between that and the ESSS equipment in a TN-C-S or TN-S installation. A similar arrangement will be used for TT installations.

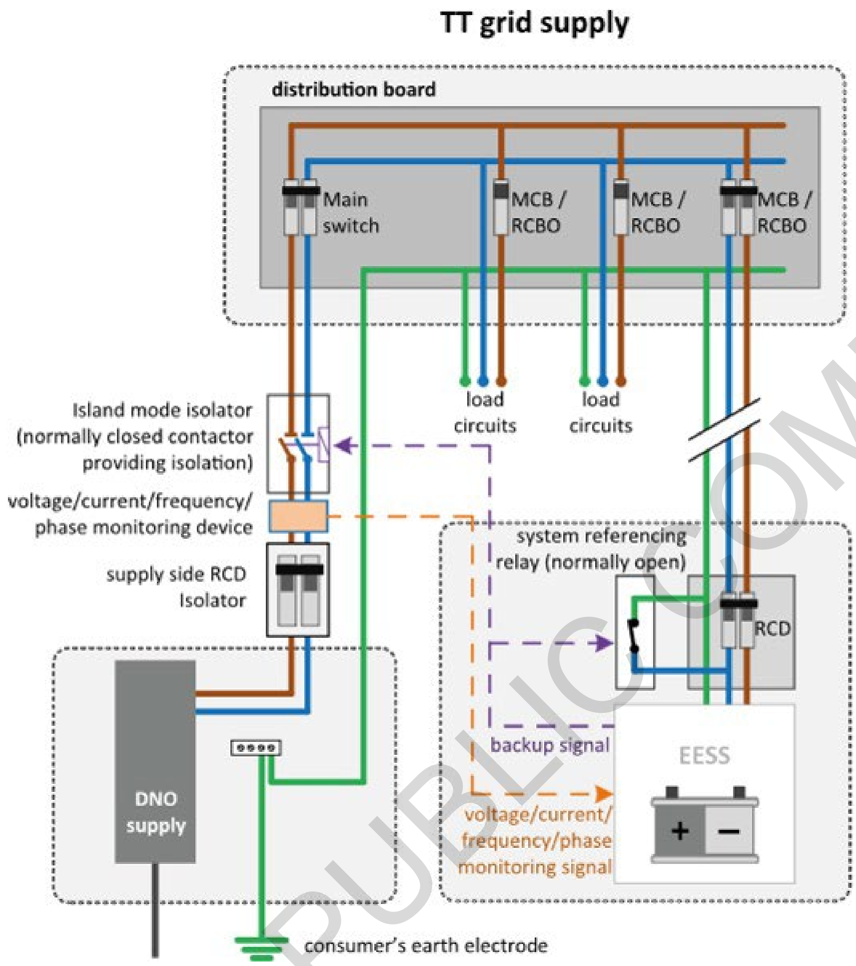


Figure 4.2 —

<num></num>

<num></num>

TT Single phase example of system referencing relay (Figure 9.7 from IET *Code of Practice for Electrical Energy Storage Systems*)

4.1.5.2 Open PEN detection devices

The IET *Code of Practice for Electric Vehicle Charging Equipment Installation* also gives information on the possible circumstances of additional installation-monitoring devices to assist with earthing arrangements. One concern is a break in the return circuit or neutral conductor and the inadvertent path then created by the vehicle and anyone touching it.

The safety risks, requirements and implementation of open protective earth and neutral (PEN) detection devices (OPDDs) are described in Section 5 of the Code of Practice. Reference should also be made to IET 01:2024, Open combined protective and neutral (PEN) conductor detection devices (OPDDs).

The standard provides definitions, requirements and tests for open PEN detection devices (OPDDs). During a protective earth neutral (PEN) fault, hazardous touch-voltages may occur at exposed conductive-parts, including metallic parts of an electric vehicle, connected to the supply PEN conductor by installation and equipment protective conductors.

OPDDs are intended to detect conditions during a PEN conductor fault in a distribution network supplying the installation in which the OPDD is installed. They provide co-ordinated disconnection of live conductors and the protective conductor associated with electric vehicles connected via electric vehicle supply equipment. OPDDs to this standard may be standalone, or incorporated into other products or assemblies, such as electric vehicle supply equipment (EVSE) or switchgear and controlgear assemblies.

4.1.6 Overload and short circuit currents

The general requirements to correctly assess prospective short circuit current and prospective earth fault current in installations that incorporate a low voltage generating set are highlighted in BS 7671.

Regulation 551.2.2 describes the requirements for independent and combined supply sources, emphasising the need to assess short circuit and earth fault current values for a variety of PEI operating modes. The rating of protective devices must not be exceeded for any of the assessed values.

Regulation 826.1.1.3 reinforces the need for all protective devices to operate in accordance with the maximum disconnection times. It also states that the minimum value of earth fault current needs to be considered and that value may vary according to the operating mode.

There is a need to pay attention to overload and short circuit currents wherever a protective device is installed in a PEI, according to Regulation 826.1.2.1:

> *"(i) for all possible configurations of each type of PEI, and*
>
> *(ii) for situations corresponding to the minimum and maximum current magnitudes.*
>
> *In all cases, compliance with Chapter 43 shall be fulfilled.*
>
> *The selection of overcurrent protective devices shall consider:*
>
> *(iii) the maximum short-circuit current (e.g. connected mode) for the selection of breaking capacity, and*
>
> *(iv) the minimum short-circuit current (e.g. island mode) for the setting of the tripping characteristics of the short-circuit protective device."*

The location of overcurrent protective devices (OCPD) is a critical consideration in any electrical installation, as is selectivity of devices within the infrastructure to minimise automatic disconnection of supply to other sub-circuits.

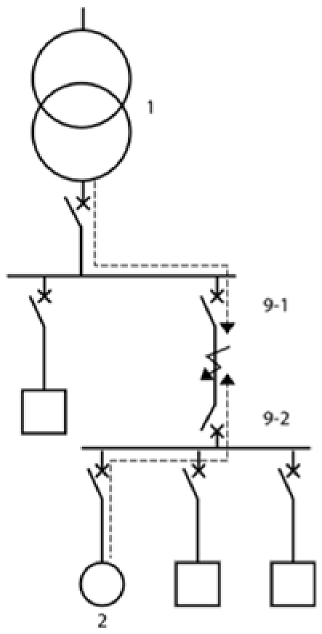
An OCPD is placed at the origin, whether that is at the mains intake, local supply or sub-circuit serving a particular service, e.g. lighting, socket-outlets, heating and so on. For local power supplies and local energy storage there should be an OCPD at the point of connection to the wider electrical installation.

Regulation 826.1.2.2. advises that for a PEI it is recommended that all local power supplies and local storage are connected directly to the main distribution board (or domestic installation consumer unit). Each connection will have its own OCPD and the possibility of accumulated short circuit currents is reduced.

In a PEI, where the operating mode can vary, it is important that OCPDs are designed to cope with all possible directions of current flow. The most obvious example of this is the part of the installation that energy storage facilities are connected to, given that at times it will be a load instead of a local supply.

For grid connected PEIs, the OPCDs upstream of the main distribution (or consumer unit) will also have varying current flow to facilitate both import and export of electrical energy.

Fig 82.10 – Example of double short-circuit protection for the same circuit



Key

1 Public network
2 Power supplies
9-1 Overcurrent protection device (OCPD 1)
9-2 Overcurrent protection device (OCPD 2)

Figure 4.3 — Location of OCPDs and possible short circuits

Protection of the installation against short circuits is made more complex by the integration of local power supplies and electrical energy storage.

Regulation 826.1.2.3 highlights that designers need to take into account the risks of combined short circuit currents where more than one source of supply can feed the same fault. The actual magnitude of any short circuit current will depend on the operation mode of the PEI at the time of the fault. Protective devices used in a PEI will need to cope with a range of short circuit currents.

Coordination between devices is necessary to minimise unnecessary disconnection of supply under emergency conditions in an adjacent part of the installation.

To ensure any particular protective device operates in a timely manner the designer needs to think about all PEI operating scenarios and take account of:

a) the location of the fault;

b) the combinations of PEI power supplies and hence the magnitude of the likely short circuit;

c) currents; and

d) the operating modes of the PEI.

4.2 Functional safety – isolation and switching

In a simple electrical installation, complete and safe isolation of the electrical supply takes place at the main switch located at the intake. Interrupting the supply at that point only, with appropriate locks and notices, is sufficient for safe systems of work to be initiated across the entire installation.

BS 7671 Regulation 462.1.201 stipulates that any main linked switch or linked circuit breaker should be placed at the origin of every installation or as near as practicable.

The purpose of such a main switch is to provide a means of switching the supply on load and as a means of isolation. A main switch shall interrupt both live conductors of a single-phase supply (and 4 poles in a three phase installation) and should be capable of being operated safely by ordinary persons as defined in BS 7671, as well as those trained in electrical safety issues.

A PEI has multiple points of electrical supply and a more holistic approach is necessary. Each point of supply should be considered carefully during the design stage to facilitate safe systems of work during the construction and operational phases of the installation's life span.

A PEI will change operating modes from time to time, through:

a) deliberate planning and controls; or

b) loss of mains power in unforeseen situations.

To ensure electrical safety, whatever those circumstances are, a PEI must continue to provide satisfactory protection of people and property at all times, irrespective of the operational mode at that time or the current status of any isolators, switches or interlocks.

The effect of isolation of any point of supply, and the potential for back feed from another point of supply, must be risk assessed and additional safety measures should be provided where necessary. For this purpose Regulation 826.1.1.4 states that:

> *"Where an installation is supplied from more than one source, a main switch suitable for isolation (e.g. switch disconnector) shall be provided for each source of supply."*

Other requirements include the use of a durable warning notice adjacent to each of these main switches to warn of the need to operate all such switches to achieve complete isolation of the installation.

Regulation 537.1.2 reinforces this message:

> *"Where an installation or an item of equipment or enclosure contains live parts connected to more than one supply, a durable warning notice shall be placed in such a position that any person, before gaining access to live parts, will be warned of the need to isolate those parts from the various supplies unless an interlocking arrangement is provided to isolate all the circuits concerned."*

Regulation 826.1.1.4 also states that a suitable interlock system can be provided as an alternative. The logic behind such an interlock would be to prevent access to live parts and facilitate isolation from all sources of supply where necessary. Safe systems of work may include key exchange systems and a planned sequence of isolation works to prove the status of the electrical system.

Figure 4 4 — Warning signs (Figure 11E from BS 7671 Appendix 11)

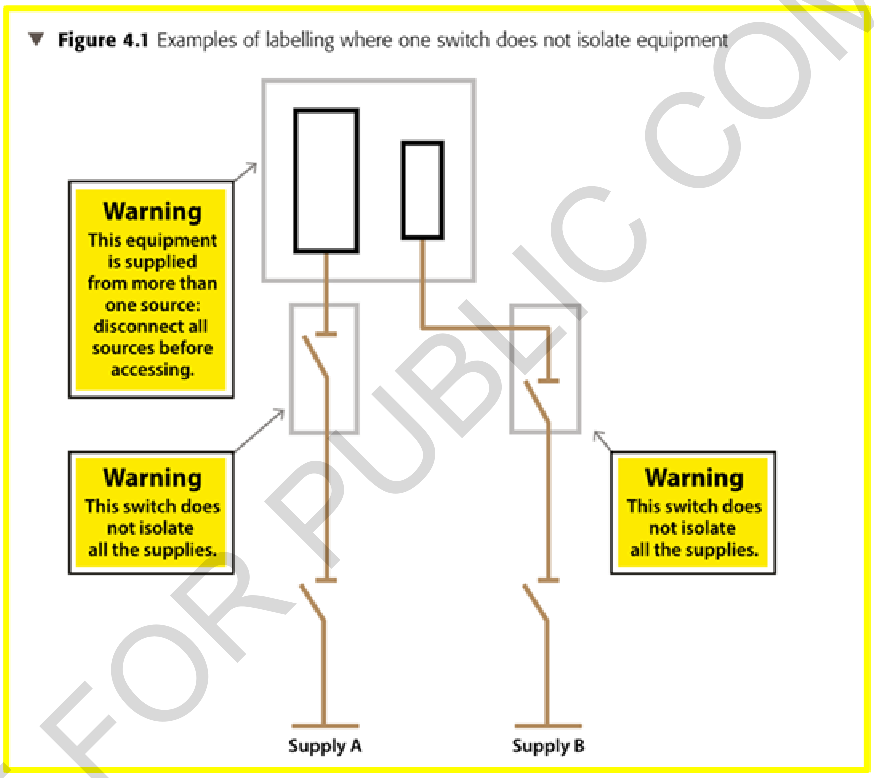


Figure 4.5 — Example of warning locations – multiple supplies (Figure 4.1 of IET *Guidance Note 2: Isolation and Switching*)

4.2.1 Isolators

Electrical isolators should be incorporated as necessary throughout any electrical installation to assist with safe working practices. Ideally they should also have facilities to be locked off to ensure re-energisation is only possible under controlled situations.

Table 537.4 of BS 7671 provides information on types of isolation devices and electrical connections. The table determines whether they can be used for emergency switching or functional switching and correlates that against relevant standards.

Simply switching off the grid connected intake mains isolator in a PEI, for maintenance purposes, may change the operational status to island mode. The installation will then be supplied from the EESS and/or on-site generation and would still be live. Electrical safety will be compromised, putting maintenance operatives at risk.

A cautious approach should be made to any activity on any electrical installation that incorporates low carbon technology including PV generation and energy storage. Regulation 712.410.101 reminds us that:

> *"Electrical equipment on the DC side shall be considered to be energized, even when the AC side is disconnected from the grid or when the inverter is disconnected from the DC side."*

A planned sequence of isolations and local lock offs will be required to ensure all forms of electrical energy supply are correctly isolated and the installation is safe to work on without risk of electric shock.

The IET *Code of Practice for Electrical Safety Management* outlines safe working practices and processes for isolating electrical installations. These include input at the design stage to:

a) clearly identify all forms of supply;

b) understand which loads will be impacted by any isolation; and

c) plan all necessary isolations including lock off points and voltage test points.

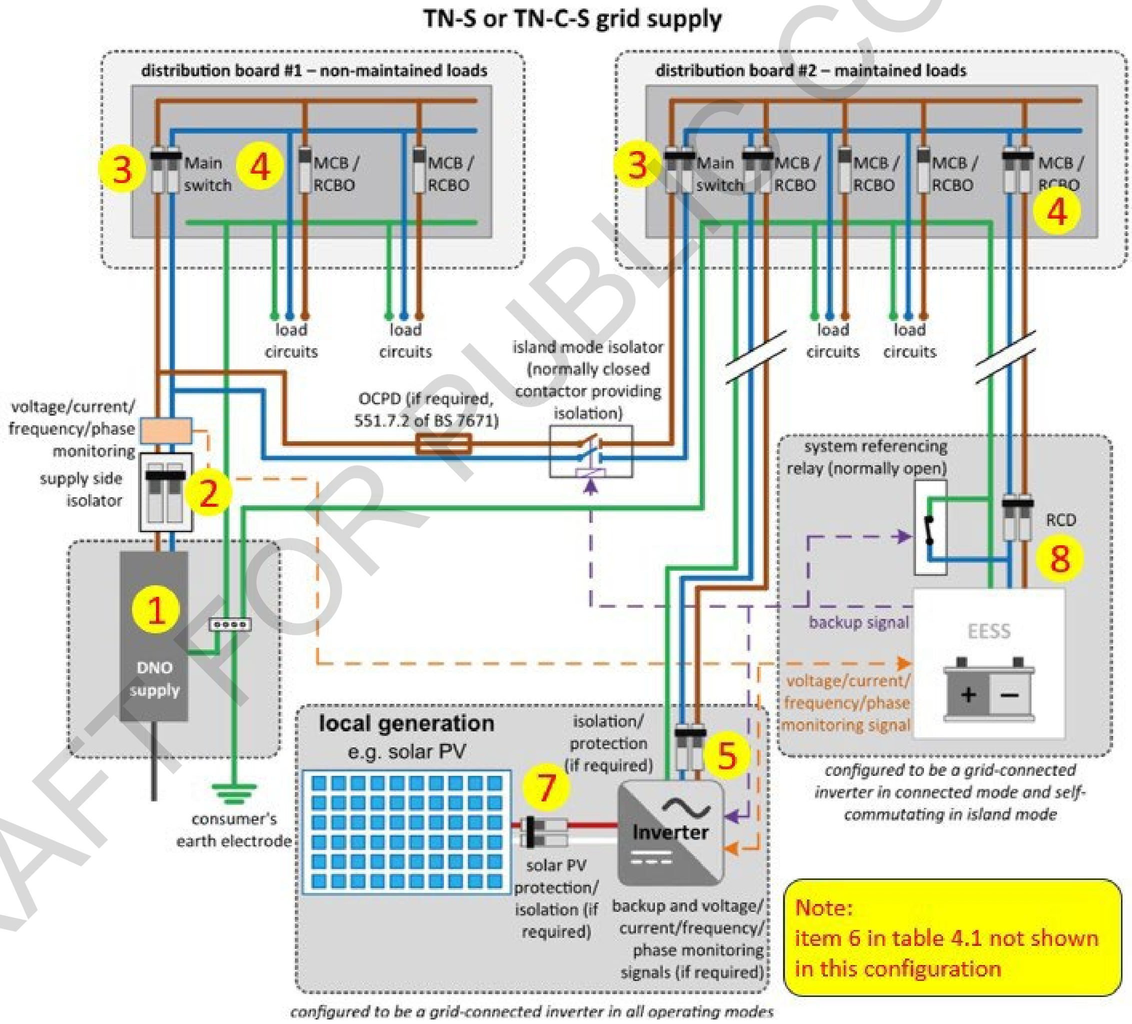


Figure 4.6 — Typical points of isolation in PEI

Adapted from Figure G.3 IET *Code of Practice for Electrcial Energy Storage Systems*

Table 4.1 — Typical points of isolation in PEI

Ref	**AC/DC**	**Item**	**Commentary**
1	AC	Intake fuse	Sealed fuses at cable head When fuses are removed will isolate live connections only. However, DNO seals will need to be broken to allow this and regulatory conditions will apply to reinstatement of the seals.
2	AC	Mains intake isolator	Recommended switching to control whole installation Should include switched neutral as well as live connections (2 pole or 4 pole according to number of phases) A mains intake isolator remains under the control of the installation end user
3	AC	Consumer unit/ distribution board	Integral mains isolator on consumer unit or distribution board Will include switched neutral as well as live connections (2 pole or 4 pole according to number of phases)
4	AC	Protective device	Could be AFDD/ RCBO/MCB according to circuit requirements and housed within consumer unit/distribution board: — MCBs will be single pole (or three pole on DBs) — RCBOs will be double pole in single phase consumer unit and may also be 4 pole in three phase DBs (includes neutral isolation) — AFDDs will be double pole in

Table 4.1 — Typical points of isolation in PEI *(continued)*

Ref	AC/DC	Item	Commentary
			consumer unit (includes neutral isolation) — Separate protective devices (and sub-circuits) will be required for each form of generation or electrical energy storage that is connected to the PEI. — Protective devices shall be appropriately rated and capable of coping with bi-directional energy flow as required. — Lock off kits are available for protective devices to allow individual circuits to be worked on
5	AC	PEI supply Isolator (local generation e.g. PV)	All grid-connected local generator systems (e.g. PV) shall include a main isolation switch downstream of any generation meter that: — isolates AC output from the connection point of the local generation to the main electrical installation — isolates all phase and neutral cables of the outgoing cables — can be locked in an isolated state to assist safe systems of work and prevent back feed in either direction during maintenance operations

Table 4.1 — Typical points of isolation in PEI *(continued)*

Ref	AC/DC	Item	Commentary
6	AC	PEI Inverter Isolator (local generation e.g. .PV)	All local generator systems (e.g. PV) shall include an isolation switch downstream of any inverter and upstream of the generation meter that: — isolates AC output from all of the system inverters; — isolates all phase and neutral cables of the outgoing cables (3 phase or 1 phase) — can be locked in an isolated state to assist safe systems of work and allow replacement of the meter
7	DC	PV array Isolator	For local generation from a PV string or array (depending on system design) a DC rated switch disconnector shall be installed prior to connection to the system inverter A safe system of work for replacement of PV system isolators would be isolation and lock off of both the PV array isolator, the DC input, and the PEI (PV) inverter isolator, the AC output. This isolates both AC and DC infrastructure Refer to *Code of Practice for Grid Connected Solar PV systems*, Section 5 for further details on DC design
8	AC	PEI supply Isolator (local storage e.g. EESS)	All local storage systems (e.g. EESS) shall include a main isolation that: — isolates AC output from the connection

Table 4.1 — Typical points of isolation in PEI *(continued)*

Ref	AC/DC	Item	Commentary
			point of the EESS to the main electrical installation — isolates all phase and neutral cables of the outgoing cables (3 phase or 1 phase) — can be locked in an isolated state to assist safe systems of work on cabling infrastructure and prevent back feed in either direction during maintenance operations — can be locked in an isolated state to assist safe systems of work and allow replacement of the EESS
10	DC	Integral Isolators	EESS may include integral battery isolators to allow intrusive maintenance activities. These should isolate both live cores

4.2.2 Functional switching

IET *Guidance Note 2: Isolation & Switching*, Section 7.2 advises that:

> *"Functional switching devices must be suitable for the most onerous duty that they will need to perform within the particular design constraints."*

Those design constraints need to consider the switching device's suitability:

a) to switch the type of load, including the ability to withstand start up currents; and

b) to operate for the necessary number of operations, including frequent use if required.

IET *Guidance Note 2: Isolation & Switching*, Section 7.2 also reiterates the general requirements of Regulation 537 that devices must comply with the requirements of the function it is intended for and, where it may be used for more than one function, each of the requirements must be adhered to. There can be no compromise in electrical safety for multifunctional devices. This includes the requirements appropriate to:

c) protection;

d) isolation;

e) switching;

f) control; and

g) monitoring.

It should be noted that whilst some circuit breakers, arc fault detection devices (AFDDs) and residual current devices (RCDs) are capable of functional switching, they are primarily circuit protective devices and not intended for frequent load switching. Appropriate devices will be needed for that and reference to Table 537.4 of BS 7671 should be made to assist with correct selection of the device required at any particular point in the PEI.

IET *Guidance Note 2: Isolation & Switching*, Section 10 is focused on PEIs and provides more guiance on the particular requirements for switching and isolation of a PEI under normal operating conditions.

4.2.3 Break before make

The transition from direct feed to island mode, and back again, needs careful consideration of the design risks and equipment that is required.

System earthing in direct feed and reverse feed modes will be different to island mode. Disconnection of the grid connected earth will be necessary when the PEI operates in island mode and this requires that an adequate local earth is connected to coordinate with protective devices.

Switching from one power source to another must include all live conductors (live phases and neutral) and the appropriate connection of earthing depending on the PEI mode of operation. Regulation 826.1.1.2.2 clearly states that there should be no overlap of connection of the neutral in PEI island mode and in direct feed (grid connected).

The type of installation earthing (TN-S, TN-C-S, TT etc.) under normal operating conditions should also be considered and will influence the PEI design for island mode conditions.

Unless the installation is designated as critical and has appropriate synchronising systems in place, the typical switching arrangement for PEI will be 'break before make'. There will be a momentary loss of power supply as the installation changes from one PEI mode to another.

Figure 4.7 demonstrates the change from direct feed to island mode and back again.

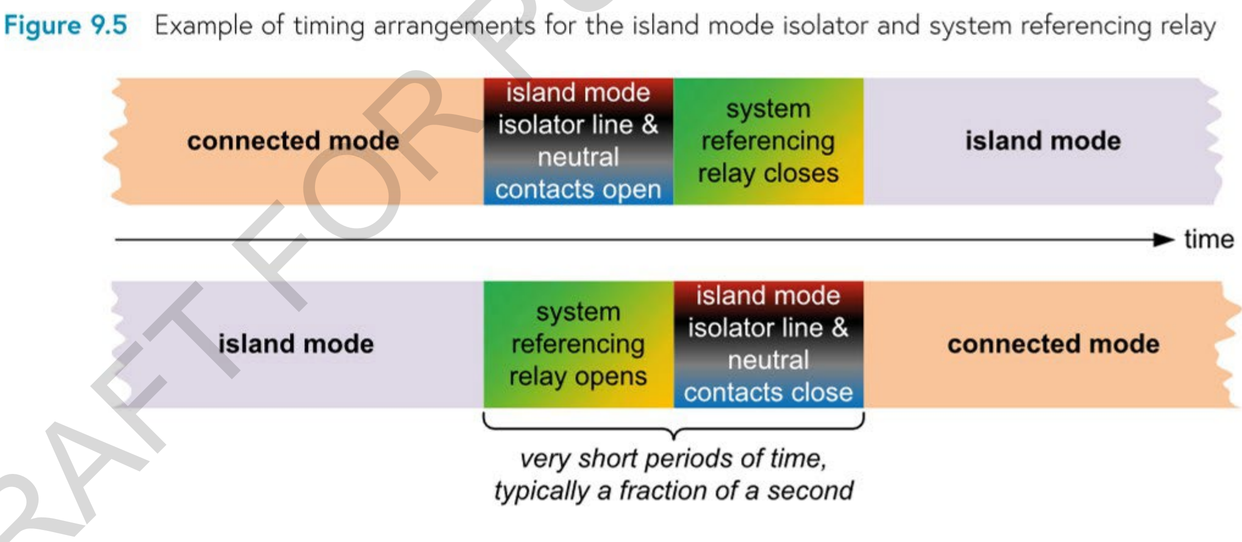


Figure 4.7 — Break before make

When the loss of mains power is detected, all live conductors must be disconnected (4 pole for three phase installations and 2 pole for single phase). The electrical loads will be without power for a short period. The neutral earthing bond relay system engages and the electrical safety of the installation is now reliant on the local earthing system.

The electrical loads are reconnected to the local power source including on-site generation and energy storage. Real time assessment of the total loads may be required by the EEMS and some load shedding of non-critical loads may be necessary to ensure the local power sources are not overloaded.

On reinstatement of the supply this process will be reversed, again with a short interruption of supply to all loads, before the neutral earthing bond relay system changes state, the local earth is disengaged and the installation is now reliant on grid-based earth systems.

The electrical loads will then reconnect to the mains grid supply. Any non-critical loads that may have been shed can be reconnected to the mains supply. It is advisable that the EEMS reinstates the loads in sequence to prevent unnecessary tripping due to simultaneous inrush currents.

4.2.4 Emergency switching

Where emergency switching is deployed in the fixed wiring of a PEI the provisions of BS 7671 Regulation 537.3.3 should apply.

It should be noted that emergency stops on machinery are covered by the requirements of BS EN 60204, Safety of machinery. Electrical equipment of machine.

Additional references on the general installation requirements of emergency switching can be found in Section 6 of IET *Guidance Note 2: Isolation & Switching*.

Emergency switches will need to be rated correctly for all scenarios. BS 7671 Regulation 537.3.3.2 states that:

> *"The devices for emergency switching off shall be capable of breaking the full load current of the relevant parts of the installation taking into account stalled motor currents where appropriate."*

A risk assessment approach should be used to confirm that emergency switching is necessary. The actual location of emergency switching within the PEI infrastructure needs to be considered carefully to ensure they are actually fulfilling their primary role and there are no unexpected consequences in terms of operation or electrical safety.

Distribution boards, or consumer units, are typical common points of connection for all forms of supply (e.g. grid, PV, EESS etc.) within a PEI. Downstream of the distribution board (DB) or consumer unit (CU), individual emergency switching connected into sub-circuits can interrupt electrical supplies to particular loads without necessarily affecting other parts of the installation.

Upstream of the DB or CU, careful assessment of the purpose of the emergency switching needs to be carried out to ensure it fulfils its function without giving rise to other dangers. For instance, interrupting the supply under emergency conditions to the on-site generation or EESS may isolate that particular supply.

Interrupting the mains supply could cause the PEI to automatically change over to island mode, supported by the local generation or EESS. In this scenario people could inadvertently attempt to work in systems that were thought to be off. Another consequence could be that pre-existing electrical faults can be fed from another source.

It is advisable to ensure that emergency switching cannot be automatically reinstated. All resets to the system should be carried out in a controlled manner under the direction of a person competent to assess the situation and conduct remedial activities to restore the full normal operation of the PEI.

Emergency switching should be clearly and concisely labelled to indicate which part of the installation it controls.

4.3 Outage of the public network

A PEI will typically connect to the DNO infrastructure and that grid connection will be maintained for export of surplus energy, and import of electrical energy when the load exceeds on-site generation and storage capacity.

From time to time the grid connection will be lost. It is important to understand how the PEI will react on loss of power.

As noted in BS 7671 Annex B82, when the installation is designed for island mode operation factors such as voltage disturbance and interruptions in supply need to be considered.

It is also important to understand what adverse influences a PEI or several adjacent PEIs may have on the grid connection and to avoid the associated electrical risks accordingly.

4.3.1 PEI response to outage

Regulation 826.1.3 highlights two courses of action for a PEI on loss of the main grid connection: either revert to island mode and operate independently of the grid; or disconnect from all local power supplies.

Utilising the PEI's electrical energy management system (EEMS), an automated response to operate in island mode in this situation will be governed by factors such as:

a) Capacity - how much real time on-site generation is immediately available from renewable sources and how much capacity is available in any EESS?

b) Load matching - How much load is actually being used and can any of it be switched off to ensure the combined output of the renewable energy source and EESS are not overloaded?

c) Load shedding - Priority loads will need to be recognised and maintained in operation or reduced, whilst less essential loads are perhaps set back or switched off.

4.3.2 PEI switching frequency

In a traditional, more passive electrical installation any connected control devices and protective devices will operate either under controlled conditions or under specific fault conditions. The frequency of these operations is relatively low and there are likely to be considerable time gaps between switching events. Manufacturers will design components to a level of robustness to satisfy this likely frequency of operation.

It should be noted that a PEI, operating on networks that are increasingly in need of grid reinforcement, may be subjected to more frequent loss of power without notice, or may be asked as part of the connection contract to operate off grid for a while to reduce overall demand.

The frequency of switching operations will increase in these scenarios and it is important that more robust control devices and protective devices are selected, with enhanced duty requirements, to cope with the increase in changes between modes of operation.

4.3.3 PEI quality issues

Section 10 of IET *Guidance Note 2: Isolation & Switching* notes that:

> *"consideration be given to the inrush current and other capabilities of local energy storage in the design of the system, especially when switching between operating modes. Isolation and switching devices should be appropriately selected."*

The consequences of outage of the public network will potentially make things worse if the devices are subjected to frequent in-rush currents from on-site electrical loads and other issues are not considered properly.

4.3.4 PEI influence on grid

Individual smaller scale domestic PEI will not necessarily have a large influence on the day to day running of the grid. Application for connection should be made to the respective local DNO, but the associated risks can be mitigated.

BS 7671 Annex C82.1, which is classed as informative, notes that:

> *"... high numbers of PEIs connected to the same public network could cause instability of these public networks resulting in the disconnection of some lines (distribution or transmission)."*

This could be true for a number of independent individual PEIs in close vicinity to each other and for large scale collective PEI operating across a new housing development or industrial estate.

To reduce the risks of grid outage being caused by prosumer electrical installations, the commentary in Annex C82.1 notes that:

> *"PEIs should be designed in such a way that their dynamical influence on the stability of public networks is reduced or, even better, that they improve the dynamic stability of these public networks."*

4.4 Selectivity

Selectivity describes the coordination of the operating characteristics of protective devices at various points within the electrical infrastructure. The purpose is that protective devices operate in a coordinated fashion in the event of an electrical fault.

Only the device nearest the fault should operate in the time required, isolating the fault and preventing the next device upstream from operating as well. BS 7671 Regulation 536.4 provides general information on the requirements for selectivity such as for:

a) overload conditions;

b) short circuit conditions;

c) between residual current devices (RCDs); and

d) between overcurrent protective devices (OCPDs).

Selectivity of devices should be verified and Section 536 suggests checks by one of the following methods:

e) desk study;

f) appropriate software tools;

g) tests using applicable product standards; or

h) manufacturer's declaration.

For PEIs, Regulation 826.6 provides additional requirements on the selectivity between protective devices. In particular, Regulation 826.1.2.3 focuses on the effects of combined short circuit protection.

Consideration should be given on all various PEI operational scenarios to account for any possible fault currents including:

i) location of fault within the PEI infrastructure and the reaction of the protective devices adjacent to that fault;

j) various possible combination of power supplies connected to the PEI at any one time and hence potentially feeding the fault; and

k) various operating modes including:

  — understanding when the PEI is grid connected or in island mode;

  — whether the PEI is importing or exporting at the time of fault; and

  — earthing arrangement at the time of the fault including the status of neutral-earth links.

Like a conventional passive electrical installation, selectivity in a PEI will include the following:

l) overload protective device;

m) short-circuit protective device; and

n) residual current device.

Design engineers and contractors will typically use software tools to model these outcomes before the installation is tendered or constructed. To ensure full selectivity it is important the model comprehensively demonstrates satisfactory outcomes for all PEI operating models and combinations of singular or parallel electrical supplies and also for maximum demands.

The schematic shown in Figure 4 8 illustrates a simple single phase PEI set up with a TN-S or TN-C-S grid connection, local solar PV supply, EESS and an electric vehicle charging point (EVCP).

The installation has a local earth electrode that is permanently linked to the incoming grid supply earth.

When in island mode the neutral earth link on any energy storage facility will change over to provide a supply earth reference for the installation whilst it is operating in island mode.

Items A to G on Figure 4 8 are discussed in this section (below Figure 4 9).

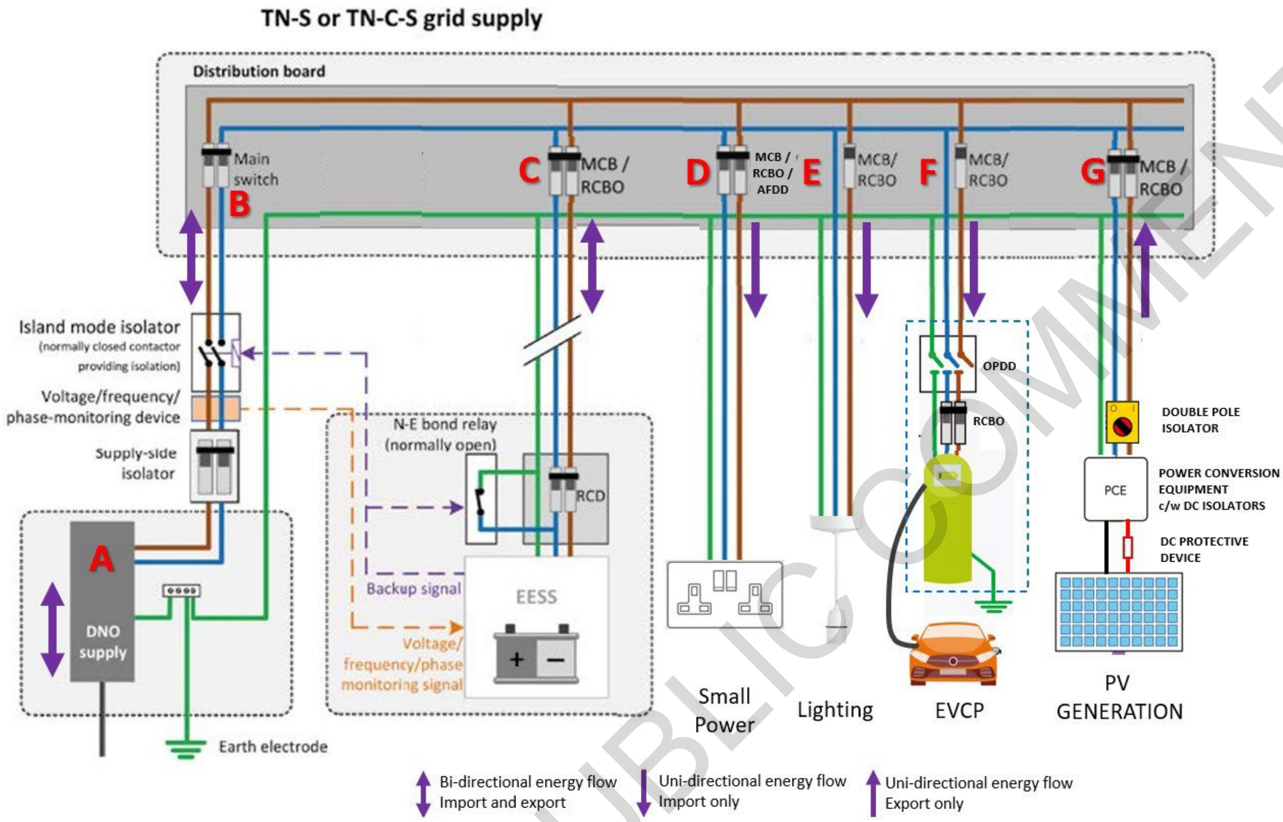


Figure 4.8 — Selectivity of devices in a PEI (TN-S or TN-C-S) (Adapted from Figure 9.7 in the IET *Code of Practice for Electrical Energy Storage Systems*)

The schematic shown in Figure 4 9 illustrates a simple single phase PEI set up with an alternative TT grid connection, local solar PV supply, EESS and EVCP.

The TT installation has a local earth electrode that is independent and not linked to the incoming grid supply in any way. The incoming supply has an RCD mains isolator for enhanced level of protection.

When in island mode the neutral earth link on any energy storage facility will change over to provide a supply earth reference for the installation whilst it is operating in island mode.

Items A1, A2 and B to G on Figure 4 8 are discussed in this section below Figure 4 9.

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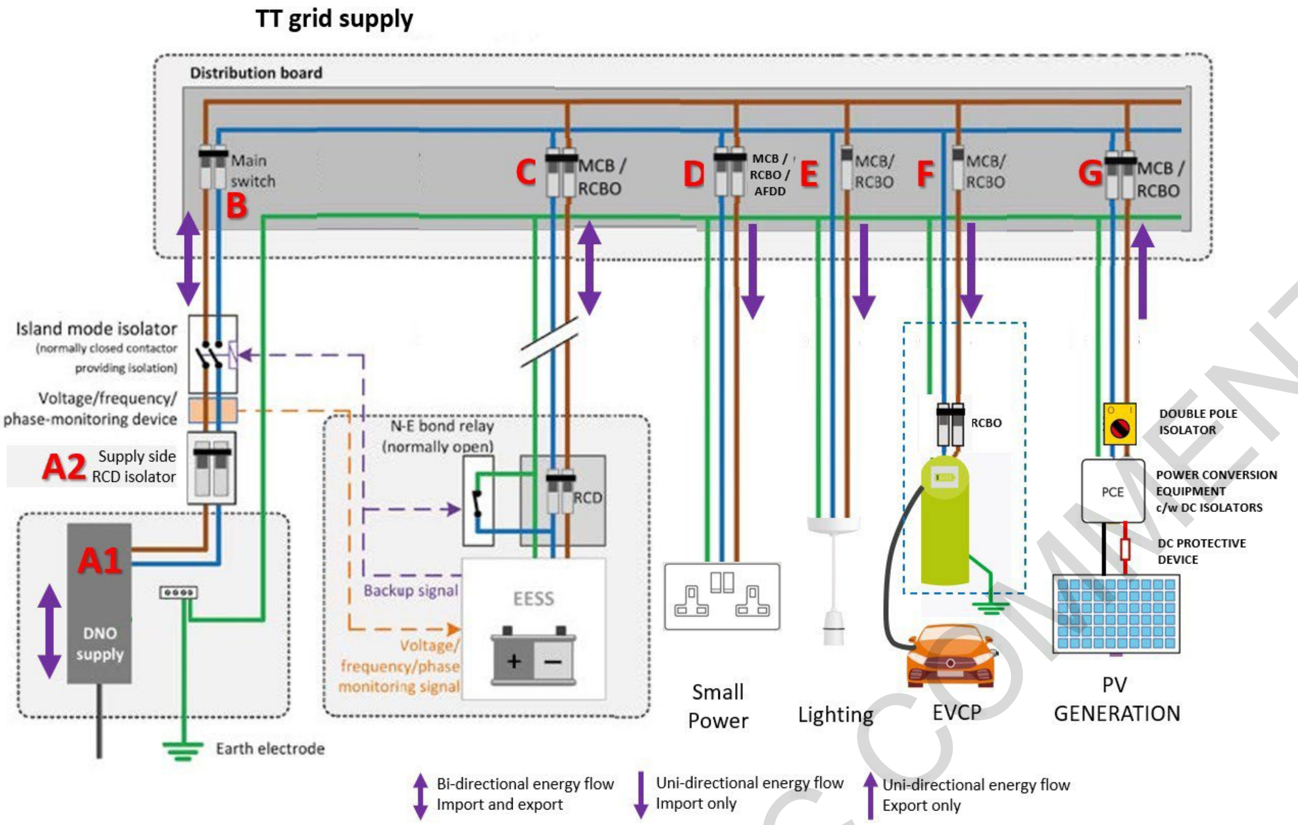

Figure 4.9 — Selectivity of devices in a PEI (TT) (Adapted from Figure 9.7 in the IET *Code of Practice for Electrical Energy Storage Systems*)

A (TN-S or TN-C-S)

The DNO supply cable head will contain protective devices in the line conductor that are typically sealed to avoid tampering. Cartridge fuses compliant with BS 1361 are used for this purpose and the common rating for smaller single phase installations is 80 A (18.4 kW). Three phase domestic installations may be rated at 60 A per phase (41.4 kW) and commercial installations at 80 A (55.2 kW) or 100 A (69 kW).

Fiscal electrical energy metering has been omitted from Figure 4 8 for clarity. A whole current meter will sit between the DNO supply and the main isolator for smaller installations of less than 100 A per phase.

To take full advantage of the functionality of a PEI it is expected that the meter will be a new generation smart meter.

The installation can be contracted to a suitable flexible tariff with a smart meter, allowing it to take advantage of lower tariffs at specific times of the day. The installation will also be able to respond to calls to shift loads to off-peak times, via control interfaces, and also to operate in island mode where applicable.

Simpler TN-S or TN-C-S installations may not always have a separate isolator adjacent to the cable head. Some installations will connect from the DNO supply (complete with sealed fuse protection) and meter directly to the integral mains isolator of the installation's consumer unit.

The technical complexity of integrating a neutral earth link into a PEI means that an additional isolator between the intake supply and the remainder of the installation is recommended to assist with safe systems of work and any necessary isolations of the installation.

A1 and A2 (TT)

For TT installations A1 in Figure 4 9will again contain the DNO supply fuses and the diagram also omits metering.

Instead of an integral mains isolator at the installation's consumer unit, the TT installation requires a local earth electrode and a suitable RCD to reinforce electrical safety requirements to the whole installation for fault protection purposes (BS 7671 Regulations 415.5.2 and 415.5.3).

B – Consumer mains isolator

The isolator is not considered under any selectivity solution but it must be rated satisfactorily to ensure it can switch the full load of the installation from off to on and back again. Ratings of 100 A are typical, even if the maximum protective device at the intake (e.g. DNO fuse) is rated at 80 A. The device is usually integral to any consumer unit or distribution board and should be capable of isolating all live cores simultaneously including the neutral conductors - 4 pole for three phase installations and double pole for single phase installations.

C – EESS

The EESS represented in both Figure 4 8 and Figure 4 9 is connected via a radial circuit. The origin of that sub-circuit is at the protective device, within the consumer unit in both diagrams.

Local to the EESS is a double pole RCD which should coordinate with any protective device at the mains intake. In the case of the TT installation these devices are likely to be RCDs and the mains intake RCD should either operate at a higher threshold or on a longer time delay. Any protective devices within the EESS sub-circuit should be capable of operating satisfactorily under varying energy flows, i.e. bi-directional depending on whether the system is charging for future use or export .

For installations under 100 A per phase and total EESS not exceeding 6 kVA, the IET *Code of Practice for Electrical Energy Storage Systems* notes the following:

> *"Selectivity issues are more likely to occur with higher prospective fault currents and lower external earth fault loop impedances, such as installations close to a distribution transformer.*
>
> *Where the protective devices within the installation are MCBs to the BS EN 60898 series, RCBOs to the BS EN 61009 series, or cartridge fuses, a fault that operates the supplier's cut-out first will be of such a magnitude that the supplier's cut-out operates in a relatively negligible time. Once the system switches to island mode, the available fault current is far lower.*
>
> *Any remaining fault will be detected either by the PC''s internal overcurrent protection or the RCD at the PCE output, and the impact of switching over is likely to be minimal in terms of clearing the fault within safe parameters."*

For various technical and performance reasons, the Code of Practice does not recommend the retro-fitting of an EESS to an existing installation using rewirable fuses to BS 3036, especially under island mode conditions. Rewirable fuse consumer units are also not recommended for PEI with full energy management systems where additional automated control philosophies need to be applied.

D – Small power final circuits

The small power final circuit represented in Figure 4 8 and Figure 4 9 is of a conventional 230 V 13 A BS 1363 twin socket-outlet, which could be configured as a radial circuit or as a ring final circuit. The origin of that final circuit is at protective device D in both diagrams.

The protective device is typically rated at 32 A for ring final circuits or 20 A for radial circuits for overcurrent protection purposes. Overcurrent selectivity is required between this device and the main intake DNO supply fuses (A on Figure 4 8 and A1 in Figure 4 9) and Regulation 536.4.1.3 applies.

In older single phase installations where the intake supply fuse may be restricted to 60 A, care should be taken over selectivity issues with 32 A residual current breakers (RCBOs) or AFDDs. If the intake fuses cannot be upgraded by arrangement with the DNO it may be necessary to configure all socket-outlet circuits as radials and all protective devices as 20 A. This may mean more outgoing final circuits and a larger consumer unit.

In retro-fit installation projects, existing small power circuits may be protected by Type A RCBOs. The residual current rating is likely to be 30 mA and in TT installations the main intake will also be protected by a suitable RCD. However, this will need to be coordinated so that the intake RCD operates either at a higher residual current threshold or is on a time delay.

Socket-outlets in some new installations should have an AFDD protective device (as of BS 7671:2018+A2:2022). There is a recommendation for their use in other installations too.

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Load shifting is an important operating tool for PEIs and requires the delay in operation of some loads to off-peak hours. Using large domestic eletrical appliances (so called 'white goods') overnight and unattended is not recommended, but is in essence load shifting. BS 7671 recommends the use of AFDDs to protect electrical small power circuits containing such appliances and this may provide a level of mitigation.

Small power circuits could also be radial circuits for specific items of equipment such as heating or hot water. Allowances for disconnection times will vary for plug top equipment connected to sockets compared to fixed equipment connected via dedicated circuits.

E – Lighting final circuits

Lighting is represented here as a pendant drop but could be proprietary LED luminaires, other type of luminaire, exterior lighting or other mains connected lighting circuits. Protective devices for lighting final circuits are likely to be rated significantly lower than small power circuits, for instance 6 A or 10 A, however some risks remain that could affect selectivity.

Within domestic settings, lighting circuits within bathrooms and shower rooms should be protected by RCBOs. To successfully coordinate the mains intake, the RCD, where deployed, should operate so that the intake RCD operates either at a higher residual current threshold or is on a time delay.

Some forms of lighting, for example high frequency fluorescent luminaires and LED luminaires, can emanate residual currents under normal operation. The individual level of these is very low but they can be cumulative in the circuit protective conductors. There will be a maximum number of luminaires that can be connected to any RCBO before inadvertently tripping the device.

Manufacturers can provide advice on what this quantity of luminaires might be, but checks should be made by the designer or installer. If the number of luminaires is exceeded and the RCD devices are not specified correctly then unwanted tripping may occur when lights are switched on.

F – Electric vehicle charge points

The EVCP represented here is a simple plug and socket-outlet arrangement on a radial circuit from the consumer unit and is connected as a load only. Where the EVCP arrangement is mode 1 or 2 the electrical load may not be any larger than 3 kW and selectivity of protective devices may be fairly straightforward.

For installations required to comply with Building Regulations in the UK, such as Approved Document S or Section 7.2 of the Scottish Government Technical Handbook, mode 3 charging outlet capable of 7 kW is required. For single phase loads, that requires a protective device of 40 A. Selectivity against an intake protective device of around 80 A may be a challenge; it will probably not work against a 60 A supply fuse.

Referring to the protective devices in Figure 4 8 and Figure 4 9, Table 4.2 describes some of the considerations that are necessary to ensure appropriate selectivity of protective devices. To comply with BS 7671 (particularly Sections 722.4, 722.826.3.201 and 825.1) these include:

o) local RCD protection at the point of use;

p) additional earthing at external charge points;

q) circuit safety status monitoring; and

r) facilities to isolate all live conductors and earth in the event of a fault.

G – On-site generators

The on-site generation represented in Figure 4 8 and Figure 4 9 is for local photovoltaic (PV) solar panels. It is likely that this will be the most common form of on-site generation but other sources may also be connected.

Where systems include the use of an inverter to convert DC generation to AC there are a series of potential faults to be considered to ensure appropriate protective devices are used to safely integrate the energy source into the electrical infrastructure.

Further reference should be made to Section 712 of BS 7671 and to the IET *Code of Practice for Grid-Connected Solar Photovoltaic Systems*.

Table 4.2

Fault protection issues and mitigation

Fault type	Issue	Mitigation
DC to DC faults	There should be DC overcurrent protection to protect the DC infrastructure and generation system on the DC side of the inverter. For instance, there should be separate protection in each PV string.	Refer to BS 7671 Regulation 713.43 Protection against overcurrent for specific DC overcurrent protection measures and criteria.
DC to AC faults	An inverter without simple separation ('transformer-less inverte') could feed a DC fault current into the AC side.	A DC fault current may inhibit the normal operation of an RCD. The mitigation is use of a Type B RCD that detects both AC and DC residual currents. Refer to BS7671 regulation 712.531.3.5.1.
AC to AC faults	Inverters in a grid-connected PV system shall have an overcurrent protective device located at the consumer unit. The overcurrent protective device shall be selected and erected according to the requirements of BS 7671.	Overcurrent protective device should meet the requirements of BS 7671 and with guidance from the inverter manufacturer. If there are multiple inverters then the device should be acceptable to all connected inverters.

For the protection of PV AC supply cable, further advice is provided in BS 7671 Regulation 712.433.104:

> *"When defining the rated current of the overcurrent protective device for the AC supply cable, the design current of the inverter shall be taken into account. The inverter design current is either the maximum AC current given by the inverter manufacturer or, if not available, 1.1 times its rated AC current".*

Further informative guidance on protective devices generally and selectivity in particular can also be found in BS 7671 Chapter 53, Annex A53, Device functions and coordination.

5 Functional requirements

For decades the paradigm has been for electrical loads to be connected to an installation that is marshalled via a consumer unit or distribution board. The installation is in turn connected, via an energy meter, to the grid. Other installations in the vicinity are also connected to the grid and can be linked to the same transformer.

Stability of electrical supply, as the loads individually vary through the day, has traditionally been the remit of the generation and distribution companies. Fluctuating loads in individual installations, or on the wider grid, can have an immediate impact on voltage and frequency. Peak-time increases in load demand will affect the supply capacity of the grid and increase requirements for additional generating plant.

Under Section 27 of the Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR), for a single phase installation the declared voltage is 230 V and the frequency is 50 Hz. The voltage is permitted to vary by not more than 10 % above and 6 % below. The frequency is permitted to vary by ± 1 %.

In practice, the response time required to adjust grid generation to improve the frequency to required limits can be considerable. Operationally, the working tolerance range is often taken as being between 49.8 H and 50.2 Hz. Action can be taken to adjust generation output to bring the frequency back to the optimum 50 Hz.

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Table 5.1 — Frequency and voltage stability

Supply	Demand	Frequency / Voltage	
Low	Low	Stable	If demand is low across the grid generation capacity is reduced to make the overall system more efficient.
Low	High	Lowers	If demand rises significantly and is unexpected then any spare generating capacity can be quickly used and frequency and voltage can drop. More generating capacity is required to meet the load and stabilise voltage and frequency outputs.
High	Low	Rises	If supply capacity is too high, when compared to the demand at that time, then the frequency and voltage can rise. Less generating capacity is required to match the load, with some spare capacity, to stabilise voltage and frequency outputs.
High	High	Stable	As the demand rises the generating capacity is increased to match the load and stabilise the voltage and frequency. The system must be monitored constantly to ensure it remains balanced and operating satisfactorily.

Understanding how loads can vary, and balancing the requirements of frequency and voltage, is a constant challenge for electricity supply companies. The connection of PEI will make this situation more complex by introducing supplies to the grid that are not necessarily under the direct control of the supply companies.

BS 7671 Regulation 822.3 references the requirements of proper functioning of a PEI and its potential risk to the grid:

> *"It is essential for the operation of the smart grid that the electrical installation remains reliable and available for the maximum possible time while the power quality parameters are also maximized by using appropriate protection measures and other good installation practices."*

The frequency and installation output of a PEI must match the requirements of the grid connection. The parameters for this are illustrated in ENA ERECs G98 and G99.

It is also important to note that even in island mode a PEI should have sufficient controls and monitoring to ensure it can operate within prescribed parameters. Regulation 822.3 points out that:

> *"It is essential for the PEI to comply with similar requirements on stability, availability and quality in island mode as for the connected mode."*

5.1 PEI systems and design considerations

Each individual PEI must follow the stipulated electrical supply and electrical safety requirements. The following sub-sections outline some of the key requirements for one PEI.

Section 6.7 of this guide advises on further implications for multiple PEIs in the same vicinity.

5.1.1 Supply characteristics of electrical supplies

Grid connection

For low voltage connections Regulations 27 and 28 of ESCQR 2002 require that the distributor provides details of the supply including:

a) number of phases;

b) frequency;

c) voltage;

d) maximum prospective short circuit current at the supply terminals;

e) maximum earth loop impedance of the earth fault path outside the installation;

f) type and rating of the distributor's protective device or devices nearest to the supply terminals; and

g) type of earthing system applicable to the connection.

It is important that these details are recorded on relevant certification. Certification should be based on the models given in Appendix 4 of BS 7671. Copies should be provided to key stakeholders for the installation including owners and occupiers/users.

The full capacity of the supply should be reconciled against the installation load requirements. This will be determined by the installation designers and must take into account the maximum demand of all loads including diversity where applicable. (See Section 5.1.2 of this Guide.)

On-site generation

Details of supply characteristics should be provided by the manufacturer of the generating equipment.

The power output of low carbon generating technologies will vary due to a number of factors but there should be consistency of voltage and frequency from the generator when exporting to the installation or the grid in accordance with the parameters set out in EREC documents G98 and G99. Likewise, any harmonics and flicker issues should be minimised within the proscribed limits.

For many generators, such as PV, an inverter to convert DC generation to AC output is necessary. This may also provide other functionality such as:

h) synchronizing the output voltage and frequency with the grid;

i) monitoring the grid and disconnecting the generator system if its output voltage or frequency exceed the permitted tolerance levels;

j) monitoring the grid if there is a loss of main supply: for a PEI the generator may need to be disconnected while loads requirements are assessed and prioritised in island mode. Earthing systems

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may also need adjusting; and

k) monitoring the generator (and inverter) output to ensure that the waveform remains within specified harmonic and flicker limits.

Electrical energy storage system (EESS)

Details of the storage system characteristics should be provided by the manufacturer of the battery equipment and for a PEI should include:

l) battery type and size;

m) charge and discharge rate;

n) optimum operating temperature;

o) state of health of the battery; and

p) number of charge and discharge cycles.

The power output of a battery will vary due to a number of factors, but there should be consistency when exporting to the installation while still connected to the grid or exporting direct to the grid in accordance with the parameters set out in EREC documents G98 and G99.

For an EESS to operate correctly as part of PEI power conversion equipment (PCE), complete with inverters to convert DC energy to AC energy and vice versa, it is necessary for the EESS to provide functionality such as:

q) synchronizing the output voltage and frequency with the grid;

r) monitoring the grid and disconnecting the battery system if its output voltage or frequency exceed the permitted tolerance levels;

s) monitoring the grid if there is a loss of main supply while the PEI operates in island mode; and

t) monitoring the inverter output to ensure that the waveform remains within specified harmonic and flicker limits.

The PCE should incorporate a battery management system that should:

u) monitor the real time capacity of the EESS;

v) initiate charging of the EESS when necessary for emergency purposes or when the tariffs are low for most efficiency; and

w) initiate discharging for:

- local energy use when tariffs are high to reduce import costs to the installation; and
- exporting if surplus energy is available providing revenue.

Supply characteristics for the EESS for a PEI operating in island mode must be assessed. For unplanned disconnection of the grid, or for installations that are permanently off grid, assessment of loads in real time is necessary under varying conditions and matched against the remaining capacity of the EESS. Controls will be necessary to assist with automatic load shedding to retain power to priority sub-circuits.

A PEI operating in island mode will have a system referencing relay and the EESS earthing systems should automatically adjust during this operation mode (refer to Figure 4.1 and Figure 4.2 of this guide).

5.1.2 Maximum demand and load diversity

BS 7671 Regulation 311.1 refers to maximum demand and diversity and states that:

> *"For economic and reliable design of an installation within thermal limits and admissible voltage drop, the maximum demand shall be determined. In determining the maximum demand of an installation or part thereof, diversity may be taken into account."*

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Providing an electrical installation that is designed to accommodate all loads operating simultaneously at their maximum loads is not a realistic reflection of how the loads will be operated. For this the electrical installation would be overspecified and cables and busbars overrated. Materials used in the installation will be underutilised, and hence wasted – copper is expensive and protective devices would be oversized, especially at the main intake.

There may also be financial implications for billing if installation intakes are larger than they need to be, especially in commercial installations where there may be a charge based on reserved capacity.

For any installation, understanding the load profile of individual circuits, and of the installation as a whole entity, is key to ensuring that the requirements of electrical safety and needs of energy efficiency are both met satisfactorily.

Maximum demand is a calculated value based on a baseline of the summation of all loads in the electrical installation and the likelihood of them actually being used simultaneously. The ratio between the actual load and potential full load is the load diversity.

Traditional installation methods for assessing maximum demand and permissible levels of load diversity have been based on fairly simple changes in load throughout a 24-hour period and with a static supply limit. IET *Guidance Note 1: Selection & Erection* for BS 7671 refers to this methodology in Section 6.2 and Appendix H. The document provides guidance on individual final circuits and equipment and gives diversity values for various examples.

A PEI will have multiple energy sources to support the electrical loads that can operate in various combinations. The output from any on-site generation can be intermittent and the available EESS capacity will vary for a number of reasons. In island mode especially, the PEI may not have the same capacity for supporting the full electrical load in the way that the grid supply should.

Maximum demand in a PEI will need to be assessed for each supply scenario and the electrical loads should be assigned with priorities to ensure the supplies are not overloaded.

Automated controls will be beneficial to dynamically monitor loads and match them against the available supply capacities. The control system can then adhere to predetermined load planning and shed some of the loads whilst maintaining supplies to priority loads.

The principal energy loads in most buildings are space heating and hot water heating. Decarbonisation will become an increasingly important factor in the delivery of energy to buildings in the coming years and electrification of heat will become increasingly prevalent. Electrified heat and the addition of local charge points for electric vehicles will also impose loads on electrical infrastructure that were not envisaged when Appendix H of IET *Guidance Note 1: Selection & Erection* was originally written.

For domestic installations, and the development of new housing, DNOs use the metric of after diversity maximum demand (ADMD). This is a kW rating to account for the likely use of electricity within one property. However it should be recognised that this is an average. The context is for just one property amongst an estate of many. At any one time some will be drawing no electrical power while others will be drawing more than the average for a short period.

It should be noted that, historically, most ADMD values have been determined for properties that use another energy vector for heating and hot water, such as gas and oil. This means that typical estimations of electrical ADMD are low. DNOs are conducting studies to understand the impact of electrification of heat and addition of EV charge points with a view to updating the ADMD estimates.

Table 5.2 and Table 5.3 illustrate an approach to assessing maximum demand and load diversity. Sample calculations for domestic installations can be found in Annex D.

By assessing each load and final circuit on a case-by-case basis, and updating that for each PEI operating mode, the load demands over the whole installation can be assessed more dynamically to ensure satisfactory operation of the PEI under all circumstances and make the installation operate more efficiently.

The examples here are for domestic-related PEIs. Similar assessments, for grid connected mode and island mode operations, could be done for other installation types such as commercial, retail and light industrial. The examples can be viewed as subjective to a certain extent. It is recommended that an assessment for each installation is undertaken for each final circuit, and the loads attached to them, to ascertain particular

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priorities when in island mode.

Table 5.2 — Load diversity - domestic example

Priority	Commentary of load diversity
High	The diversity range for high priority loads could be e.g. 0.8 to 1.0. Diversity will typically be 1.0 for final circuits supplying control systems, life safety systems and communications, which ensures continuous control and energy reporting.
Medium	The diversity range for medium priority loads could be e.g. 0.5 to 0.7. It will be important to evaluate loads under grid and island mode supply scenarios. Many loads could be less of a priority in island mode and diversity ratios will lower.
Low	The diversity range for low priority loads could be e.g. 0.1 to 0.4. It will be important to evaluate loads under grid and island mode supply scenarios. A degree of caution is necessary as some loads could be more critical in island mode. These will have greater priority in island mode and diversity ratios for those loads may need to raise.

Table 5.3 — Equipment loads - domestic example

Ref	Description	Grid priority	Island priority	Commentary
1	Cooker circuit	Medium	Low	In grid connected mode cookers used intermittently with more frequent use possible during peak tariff periods. In island mode use may need to be curtailed by control or user behaviour.
2	Kitchen socket-outlets	High	Medium	In grid connected mode kitchen sockets-outlets may be used frequently and some appliances will be on constantly (freezers, fridges etc.). In island mode use of appliances, except freezers, fridges etc., should be curtailed by control or user behaviour.
3	Reception room sockets 1	Medium	Low	In grid connected mode some reception room sockets may be used intermittently and some appliances will be on constantly (PCs, home entertainment etc.). In island mode use of appliances should be curtailed by control or user behaviour.
4	Reception room sockets 2	Medium	Low	As above, but also noting that internet linked energy controls/ management may need an individual backup supply.
5	Bedroom sockets	Low	Low	In grid connected mode bedroom

Table 5.3 — Equipment loads - domestic example *(continued)*

Ref	Description	Grid priority	Island priority	Commentary
				sockets may be used intermittently. In island mode use of appliances should be curtailed by control or user behaviour.
6	Utility room sockets	Medium	Low	In grid connected mode utility sockets may be used daily e.g. washing machines, dryers. In island mode use of appliances, should be curtailed by control or user behaviour.
7	Showers	Medium	Low	In grid connected mode electric showers will impose a high load for a short time. In island mode use of showers should be curtailed by control or user behaviour.
8	Heating controls	High	High	In grid connected mode heating controls will be a small load but required constantly. In island mode it may be necessary to continue support for heating controls.
9	Heat pump	Medium	Low	In grid connected mode the heat pump and thermal storage will need planning to suit need and tariff. In island mode heat pumps might be curtailed by control (temperature setbacks) or

Table 5.3 — Equipment loads - domestic example *(continued)*

Ref	Description	Grid priority	Island priority	Commentary
				switched off to reduce demand.
10	Backup water heating	Low	Medium	In grid connected mode unlikely to be used. In island mode more likely to be used as it imposes less load on the EESS or on-site generation supply than the heat pump.
11	Internal lighting 1	Medium	Medium	In grid connected mode lighting in circulation areas may be operating more often. Operation in other areas may be more intermittent. In island mode use may be similar to ensure safety and comfort of users especially after dark. Lesser used areas may be curtailed by user behaviour.
12	Internal lighting 2	Medium	Medium	As above
13	External lighting	Medium	Low	In grid connected mode external lighting is likely to be used overnight only. Lux level controls and presence detection can reduce energy use. In island mode external lighting becomes a low priority.
14	Electric vehicle charging	Medium	Low	In grid connected mode electric vehicles will charge intermittently and some tariffs will encourage off-peak use.

Table 5.3 — Equipment loads - domestic example *(continued)*

Ref	Description	Grid priority	Island priority	Commentary
				In island mode use of appliances should be curtailed by control or user behaviour.
15	Garage supply	Medium	Low	In grid connected mode requirements for small power in the garage may be intermittent. In island mode general use of small power the garage should be curtailed by control or user behaviour.
16	Garden room supply	Medium	Low	In grid connected mode requirements for small power in a garden room may be intermittent where used as a work from home space or home gym. In island mode general use of small power in a garden room should be curtailed by control or user behaviour.
17	Electrical energy storage system	Medium	N/A	In grid connected mode EESS becomes a load in certain periods and some tariffs will encourage off-peak use. In island mode EESS becomes the supply source.
The use case for Electric Vehicle Charging in this table (item 14) is specifically for vehicles as a load on the installation. The development of Vehicle to Grid and Vehicle to Home applications will see energy passing back form the vehicle to the installation or on to the grid.				

Whilst controls will be necessary to ensure loads are prioritised, it may be advantageous to provide separate, but electrically linked, consumer units or distribution boards for high priority island mode loads and for the rest of the installation. This is a similar concept to the essential/non-essential arrangements used in installations such as hospitals and data centres to determine which loads will be supported by standby supplies in the event of mains power failure.

The IET *Code of Practice for Electrical Energy Storage Systems* provides example schematics of these possible arrangements.

Figure 9.9 Alternative arrangement, island mode isolation and earthing, where only maintained loads are supplied in island mode

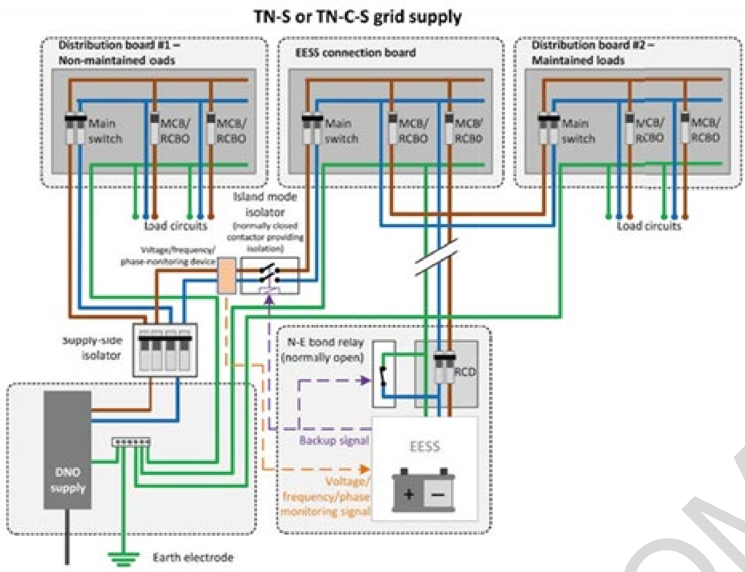

Figure 5.1 — Maintained and non-maintained loads *(Placeholder)*

5.1.3 Earthing systems

Chapter 41 of BS 7671 describes the purpose and requirements of installation earthing as a protective measure from the dangers of electrical shock. Section 411 provides details concerned with automatic disconnection of supply as a protective measure.

Regulation 411.1 states that:

> *"Automatic disconnection of supply is a protective measure in which:*
>
> — *basic protection is provided by basic insulation of live parts or by barriers or enclosures, in accordance with Section 416, and*
>
> — *fault protection is provided by protective earthing, protective equipotential bonding and automatic disconnection in case of a fault, in accordance with Regulations 411.3 to 411.6."*

Section 312 of BS 7671 describes various earthing system types. The primary systems are:

a) TN, where the earth connection for an installation is derived for the main electrical distribution system; and

b) TT, where the earth connection is via a local means of earthing i.e. earth electrode.

DNOs do not guarantee an earth connection from the grid when providing new installations with electrical supplies. BS 7671 Regulation 114.1 states:

> *"For a supply given in accordance with the Electricity Safety, Quality and Continuity Regulations, it shall be deemed that the connection with Earth of the neutral of the supply is permanent."*

To mitigate this for TN installations BS 7671 Regulation 411.4.2 recommends:

> *"that an additional connection to Earth, by means of an earth electrode in accordance with Chapter 54, is made to the main earthing terminal."*

For automatic disconnection of supply, Chapter 82 cross references to Regulation 551.4.3.2.1:

> *"Protection by automatic disconnection of supply shall not rely upon the connection to the earthed point of the system for distribution of electricity to the public when the generator is operating as a switched alternative to a TN system.*
>
> *A suitable means of earthing shall be provided."*

For PEIs the implementation of an earth electrode is crucial to ensure that there is an adequate earth path irrespective of the operational mode at the time as required by Regulation 826.1.1.1.

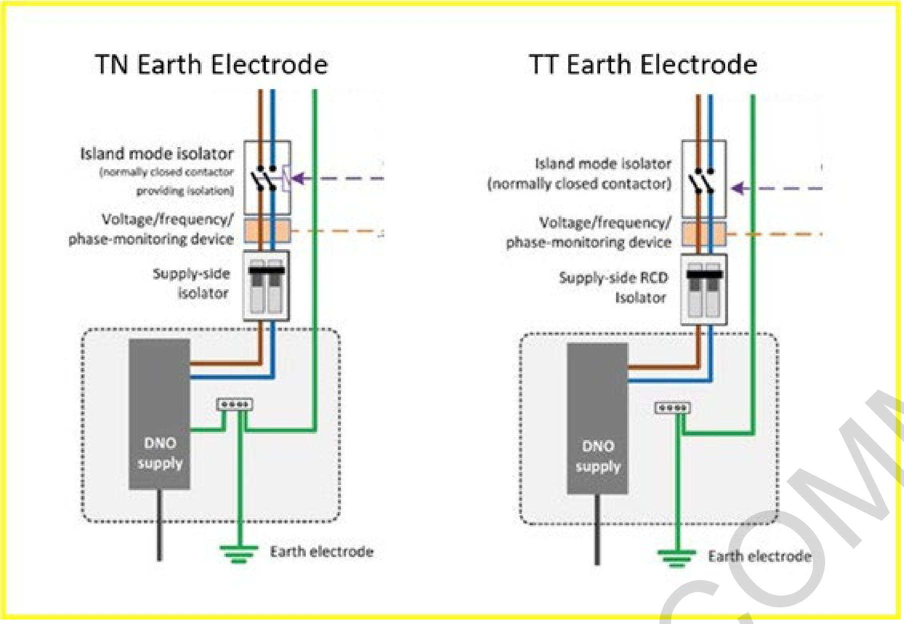

Figure 5.2 — PEI earth electrode arrangements

(Adapated from Figure 9.7, IET *Code of Practice for Electrcial Energy Storage Systems*, 3rd Edition)

When connected to the grid the PEI maintains a consistent connection to the public distribution network and the system earthing of the PEI is directly linked.

When operating in island mode the PEI is independent and isolated from the public distribution network and the system earthing arrangement of the PEI is altered.

The IET *Code of Practice for Electrical Energy Storage Systems* states that:

> *"For TN systems, EESS operating in island mode cannot rely on the suppliers means of earthing.*
>
> *For TT grid-supply arrangements, an existing consumer's earth electrode with high earth electrode resistance (Z_{EE}) may be unsuitable for an EESS in island mode operation."*

Other issues to consider that are raised by the IET *Code of Practice for Electrical Energy Storage Systems* include:

c) earth electrodes should comply with the requirements of BS 7671 and BS 7430;

d) use of lightning protection earth electrodes to support PEI earthing arrangements is not recommended;

e) the resistance value of an earth electrode (ZEE) should be as low as practicable, and should not exceed 200 Ω;

f) Earth electrode resistances significantly higher than 200 Ω are likely to be unstable and are therefore unsuitable for EESS and PEI;

g) the effect that soil drying and freezing may have on the resistance value of an earth electrode. The electrode type and its embedded depth should be sufficient to overcome these seasonal variations; and

h) galvanic degradation of the electrode over time should also be considered. Analysis of soil types and treatment when the electrode is installed may be necessary.

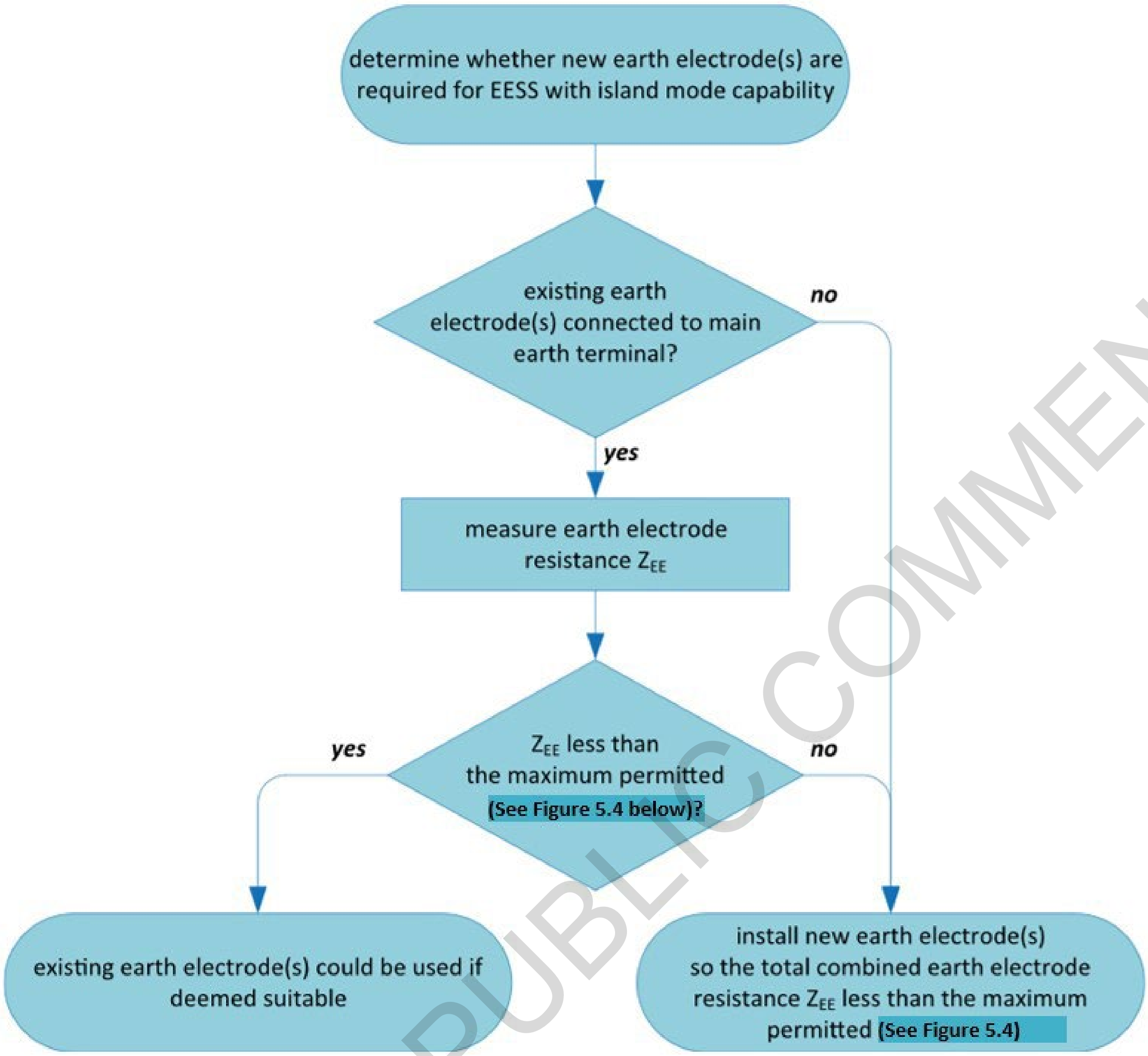

Figure 5.3 — Island mode earth electrode selection: criteria for installation of new electrodes determine

Section 9, IET *Code of Practice Electrical Energy Storage Systems, 3rd Edition*

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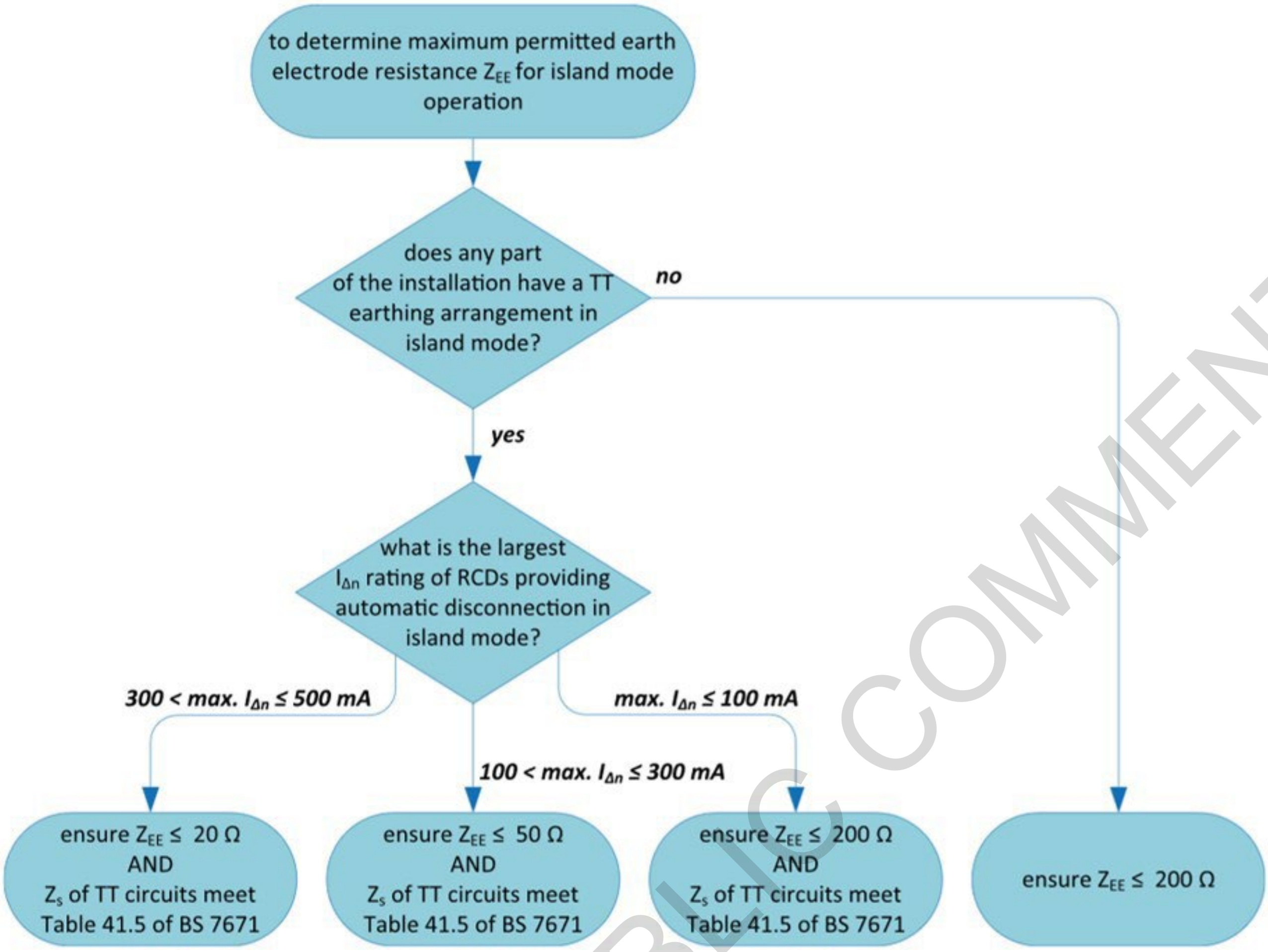

Figure 5.4 — Island mode earth electrode selection: maximum values of earth electrode resistance

Section 9, IET *Code of Practice Electrical Energy Storage Systems, 3rd Edition*

IET *Guidance Note 8: Earthing & Bonding* provides more details and explanations of particular types of systems.

The most common types for configuration of PEIs are TN-C-S and TT. Care should be taken to assess the existing installation type and the condition of any pre-existing earth electrode, especially where PEI is retro-fitted:

i) where earth electrodes are absent the addition of a new earth electrode for island mode operation is critical as discussed previously; and

j) where existing electrodes are in a poor state then a replacement should be installed and it would be prudent to check ground conditions to understand why it has deteriorated for future reference.

Figure 5 5 and Figure 5 6, originally from IET *Guidance Note 8: Earthing & Bonding*, show pictorial examples of simple single phase installations typical of many domestic properties.

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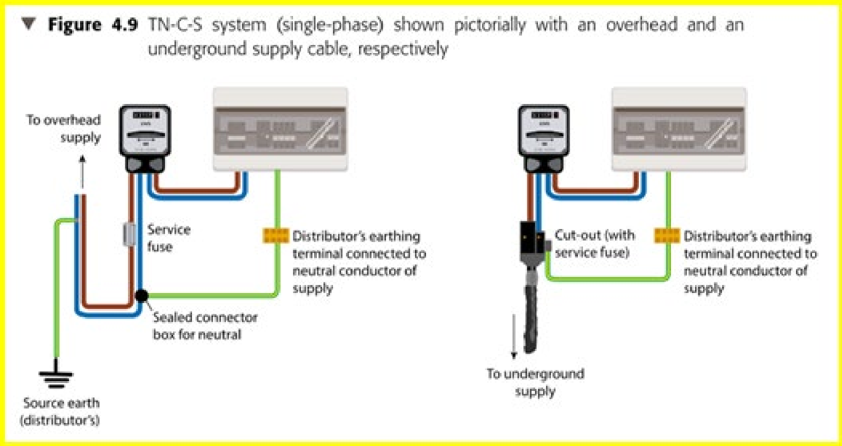

Figure 5.5 — TN-C-S earth connection arrangements *Source Figure 4.9 IET Guidance Note 8*

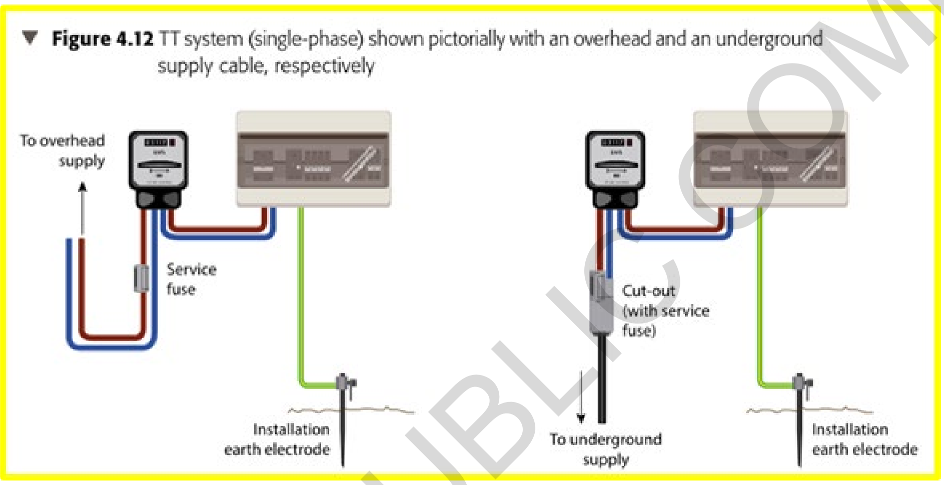

Figure 5.6 — Figure 5.6 TT earth connection arrangements *Source Figure 4.12 IET Guidance Note 8*

The IET *Code of Practice for Electrical Energy Storage Systems* provides guidance on earthing in Section 9 and covers DC earthing, AC systems and neutral-earth bonds. It also discusses arrangements for grid connected mode and island mode.

5.1.4 Fault current magnitudes

Prospective fault currents should be assessed in any electrical installation at the origin and at other relevant points in the installation, for example within distribution boards or at the point of use (lighting points, sockets and other equipment). This is a requirement of BS 7671 Regulation 643.7.3.201.

The Regulation also requires that where there are installations with multiple sources of supply:

"... measures should be taken to determine prospective fault current for all combinations of supply arrangements, so that the contribution made by any privately controlled embedded generation or uninterrupted supply arrangements is included."

This is reiterated in Chapter 82 where Regulation 826.1.2.1 requires that overload and short-circuit currents:

"...shall be determined at every point of the PEI where a protective device is installed:

(i) for all possible configurations of each type of PEI, and

(ii) for situations corresponding to the minimum and maximum current magnitudes."

For any electrical installation the careful assessment of fault currents is necessary to ensure the correct selection of overcurrent protective devices. For PEI additional consideration for the maximum and minimum cases will be required to ensure all potential operating scenarios are considered.

The maximum short-circuit current occurs when the grid supply is also active (connected mode) and will influence the selection of the overcurrent protective device's breaking capacity

The minimum short-circuit current will influence the setting of the tripping characteristics of the short-circuit protective device.

Figure 5 7 is based on Figure 82.9 of BS 7671 and illustrates the minimum fault currents based on a fault to earth on a sub-circuit in both connected mode and island mode.

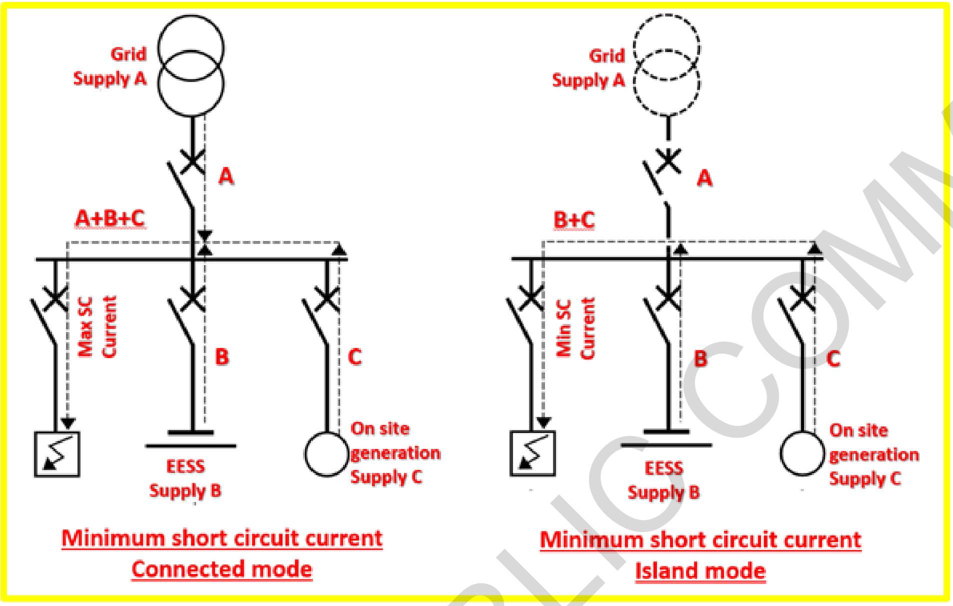

Figure 5.7 — Fault current magnitudes

5.2 Installation infrastructure

The configuration of distribution boards or consumer units in PEIs and their final circuits should be considered carefully. Circuit types for particular loads and the specification of appropriate overcurrent protective devices will need attention. BS 7671 Section 314 discusses the design philosophy for the division of the installation into separate final circuits including:

a) avoiding danger and reducing inconvenience across the installation by mitigating hazards from the failure of one circuit;

b) assisting safe systems of work for inspection, testing and maintenance purposes;

c) reducing the cumulative effects of excessive protective conductor currents and prevent unwanted tripping from RCDs.

In modern electrical installations there is a design philosophy that multiple final circuits are typically configured as radials. This can include 230 V 13 A socket-outlets final circuits, although the ring final circuit arrangement can still be used. BS 7671 Appendix 15 provides guidance on ring and radial circuit arrangments for socket-outlet circuits.

PEIs provide particular challenges in distribution boards and consumer units with regards to the direction of currents, both to load circuits and from generating circuits. There is a need to check that overcurrent protective devices are rated appropriately and capable of accepting:

d) uni-directional import current flow for equipment loads;

e) uni-directional export current flow for generation from DC/AC inverters such as PV and wind turbines;

f) bi-directional current flow for EESS to charge the batteries and release energy as required; and

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g) bi-directional current flow at the main intake where an overcurrent protective device is deployed to control the whole installation (e.g. TT installations).

Operating temperature in electrical installation enclosures, such as consumer units, is also a concern and Section 2.8.2 of IET *Guidance Note 6: Protection Against Overcurrent* states that:

> *"When current passes through an overcurrent protective device, its temperature increases regardless of which way the current is flowing through the device. Where one or more generating sets are connected through a LV assembly, the contribution of the generating set must be taken into account alongside the demand of the loads supplied by the assembly."*

BS 7671 Regulation 551.7.2 outlines the current contribution of on-site generation when operating in parallel with mains supplies. Any assembly, including distribution boards and consumer units:

> *"... shall be selected such that:* $I_{nA} \geq I_n + I_{g(s)}$
>
> *where:*
>
> I_{nA} *is the rated current of the assembly*
>
> I_n *is the rated current or current setting of the incoming circuit overcurrent protective device either incorporated within the low voltage switchgear and controlgear assembly or upstream of it*
>
> $I_{g(s)}$ *is the rated output current of the generating set or sets."*

This means that the consumer unit busbar must be capable of supporting the combined current output of the mains supply, any EESS and any local generation such as PV.

BS 7671 Regulation 551.7.2 also describes the point of connection for generating sets in consumer units and requirements for final circuit conductor sizing.

Another consideration for protective devices in PEIs is the difference between the likely prospective fault current and earth fault loop impedance values, first in connected mode and second in island mode. It should be noted that in island mode the prospective fault current is likely to be less and earth fault loop impedance will be proportionally more.

It is important that the manufacturer's details are checked for these potential operating characteristics and the correct selections are made as part of the design and installation.

5.2.1 Types of residual current devices

Deployment of RCDs will often be necessary to provide an additional measure of protection, however it should be understood that there are different types of RCD and one size does not fit all. The characteristics of the loads that are to be connected to the final circuit should be assessed so that an appropriate RCD can be selected. Some equipment is designed to emit a small leakage current. Other equipment may feed back DC or high frequency signals back down the circuit cables.

It is also important to note that these leakage currents can be cumulative on a circuit, for example, from multiple switch mode power supplies from IT equipment. Several circuits each serving fewer socket outlets may be necessary.

BS 7671 Regulation 531.3.3 lists four main types of RCD – AC, A, F and B. Table 5.4 provides some notes on the tripping characteristics for single phase circuits and the type of loads that are suited to them.

It should be noted that Regulation 531.3.3 states that RCD Type AC shall only be used to serve fixed equipment where it is known that the load current contains no DC components.

An advisory note here is a caution about any possible confusion between the nomenclature of a Type B RCD and a Type B MCB (typically used in a domestic installation). The two protective devices have different operating characteristics. If additional protective measures are required on a circuit an RCD should be provided and a Type B MCB is not an adequate substitute.

The purposes of RCCB and RCBO are different:

a) an RCCB is a residual current operated circuit-breaker without integral overcurrent protection conforming to BS EN 61008 series; and

b) an RCBO is a residual current operated circuit-breaker with integral overcurrent protection conforming to BS EN 61009 series.

RCCBs operate when the residual current reaches the level specified. They do not protect against overcurrent or short circuits. They should always be used in conjunction with an overcurrent protective device such as a fuse or circuit-breaker.

RCBOs also operate when the residual current reaches the level specified. Additional functionality is designed to protect against overcurrent and short circuits. RCBOs are installed independently of any other overcurrent protective devices. As with MCBs, checks should be made to ensure that the installation design is within its rated short circuit capacity (kA).

It is important to check that the manufacturer's details carefully when using RCBOs in a PEI especially where double pole isolation is a requirement. Some RCBOs have solid neutrals and are by default single pole RCBO devices. The neutral remains connected. RCBOs configured as single module when fitting in a distribution board or consumer unit are often a problem here. These will be described as 1P+N, when the preference would be for 2P or double pole.

It may be necessary to allow space for a double module to ensure that the device can isolate both poles simultaneously in a fault, particularly where more than one energy source is involved and back feeds could become a risk – mains intake, EESS or on-site generation.

Table 5.4 — RCD characteristics and PEI

Adapted from BEAMA *Guide to Selection and Application of RCDs* (Aug 2022)

Type	Symbols	Principal RCD tripping characteristics	Typical loads and impact of PEI
AC		**Trips on what:** alternating sinusoidal residual current **Trips when:** suddenly applied or smoothly increasing	Suited to simpler single phase load characteristics such as resistive, capacitive and inductive loads without any electronic components. Typical examples include: — Immersion heater — Oven/Hob with resistive heating elements — Electric shower — Tungsten & halogen lighting
A		**Trips on what:** — alternating sinusoidal residual current — residual pulsating direct current **Trips when:** suddenly applied or smoothly increasing	Suited to all Type AC applications plus single phase loads with electronic components. Typical examples include: — USB socket outlets — Single phase invertors — Class 1 IT and Multimedia equipment — Class 2 equipment power supplies — appliances without frequency control, like d.c. or universal motor, e.g. washing machine — lighting controls such as a dimmer switch — home and building electronic systems

Table 5.4 — RCD characteristics and PEI *(continued)*

Adapted from BEAMA *Guide to Selection and Application of RCDs* (Aug 2022)

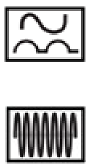
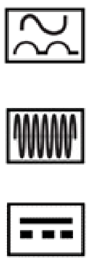
Type	Symbols	Principal RCD tripping characteristics	Typical loads and impact of PEI
			— LED lighting drivers — induction hobs — electric vehicle charging where any smooth DC fault current is less than 6 mA
F		**Trips on what:** — alternating sinusoidal residual current — residual pulsating direct current — for composite residual currents, **Trips when:** — suddenly applied or slowly rising — intended for circuit supplied between phase and neutral or phase and earthed middle conductor — for residual pulsating direct currents superimposed on smooth direct current	Suited to all Type A and AC applications plus single phase loads with frequency control Typical examples include: — washing machines, dishwashers and driers e.g. containing synchronous motors — some air conditioning controllers using variable frequency speed drives
B		**Trips on what and when:** — residual sinusoidal AC up to 1 kHz; — residual AC superimposed on a smooth DC — residual pulsating DC superimposed on a smooth DC	Suited to all Type F, A and AC applications plus various PEI and other low carbon electrical loads. Typical examples include: — Heat Pumps (air and ground source) with inverter driven compressors

Table 5.4 — RCD characteristics and PEI *(continued)*

Adapted from BEAMA *Guide to Selection and Application of RCDs* (Aug 2022)

Type	Symbols	Principal RCD tripping characteristics	Typical loads and impact of PEI
		— residual pulsating rectified DC which results from two or more phases — residual smooth DC whether suddenly applied or slowly increased independent of polarity	— electric vehicle charging — photovoltaic — EESS

5.2.2 Uni-directional & bi-directional protective devices

Within PEIs the current flow in certain parts of the installation will be in more than one direction. For instance, within an EESS final circuit the distribution board or consumer unit busbar, and at the main intake as imports and exports of energy take place.

To ensure electrical safety at all times under fault conditions the protective device for these parts of the installation must be suitable for a supply to be connected to either or both sets of connection terminals. It should be able to react to current flows, and faults, in both directions: the devices need bi-directional functionality.

Other final circuits will typically be connected to loads and will be uni-directional, similar to traditional installations.

On-site generation will also be uni-directional but the current flow, at the distribution board or consumer unit point of connection, will be in the opposite direction. Electrical energy storage systems, though, can alternate from a generation unit to a energy load and back again as required. The current flow will alter and hence the need for bi-directional protective devices to protect that part of the installation under all circumstances.

The 2024 publication of Amendment 3 of BS 7671:2018 provides further clarity on defintions of uni-directional and bi-directional protective devices.

All uni-directional protective devices should be clearly marked with load and line, or in and out. Arrows should indicate the direction of current flow.

It is important to procure and install the correct protective device for each final circuit within a PEI. Devices for parallel energy sources including EESS and on-site generation will need careful selection. The same approach is also necessary for any double pole device for protection of the main intake (e.g. in TT installations).

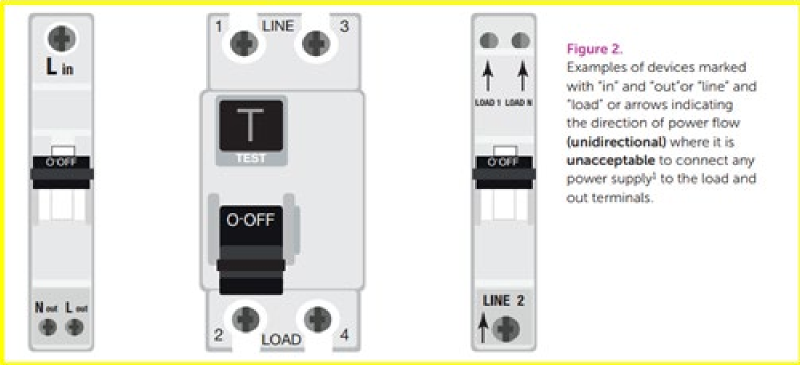


Figure 5.8 — Directional protective devices *(Placeholder)*

Further guidance is available in the August 2023 BEAMA Technical Bulletin 'Connection of Unidirectional and Bidirectional RCDs and MCBs'.

5.2.3 Arc fault detection devices

BS 7671 Regulation 421.1.7 requires the use of arc fault detection devices (AFDDs) for final circuits that supply socket-outlets rated up to 32 A in certain installation environments, including accommodation for students, care homes, homes of multiple occupancy (HMO) and residential buildings over 18m in height.

For other installations, including those that incorporate PEI components, it is a recommendation to use AFDDs on final circuits with socket-outlets.

5.2.4 Protective device examples and commentary

Each installation is different, especially in refurbished properties where the installation will have been added to over the years.

Table 5.5 illustrates the issues for particular circuits and enhancements that could be provided to ensure compliance with BS 7671 for protective device types and additional commentary for PEI where appropriate. It is a guide and should be developed for each individual installation as appropriate.

To benefit fully from the potential operational efficiencies of a PEI, not just from the local storage and generation, it may be necessary to upgrade the installation with a replacement distribution board or consumer unit. This may be a necessity in an existing installation where the PEI components are being retro-fitted.

Table 5.5 — Equipment loads - domestic example

Ref	Circuit	Device type	PEI island priority	Commentary
1	Cooker circuit	MCB	Low	Circuits for cooking appliances will vary, from one connection for a complete cooker unit to various connection points for individual ovens, hobs and other devices. Individual radial circuits for each appliance are preferred with defined protective devices, permanent connection and accessible labelled wall switches for the end user. Consider load characteristics for rating of the device and for deployment of an RCBO as an additional protection measure. May need to be load shed under island mode.
2	Kitchen sockets	AFDD	Medium	A separate circuit for the kitchen socket outlets is preferred. It is recommended that sockets should be protected by an AFDD in new installations (see BS 7671 Regulation 421.7). Devices should be checked for operational requirements under grid connected mode and island mode.

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Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
				Refrigeration appliances may be required in island mode and could benefit from a separate circuit.
3	Reception room sockets 1	AFDD	Low	Multiple final circuits may be required for general purpose sockets in reception rooms/ bedrooms depending on the layout of the installation. It is recommended that sockets should be protected by an AFDD in new installations (see BS 7671 Regulation 421.7). Devices should be checked for operational requirements under grid connected mode and island mode.
4	Reception room sockets 2	AFDD	Low	As above
5	Bedroom sockets	AFDD	Low	As above
6	Utility room sockets	AFDD	Low	As above
7	Showers	MCB	Low	Circuits for electric showers should be connected to radial circuits, adequately sized and rated. Power showers will require particular attention to current ratings. It is recommended that electric showers are not used in island mode unless there is adequate backup supply.

Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
8	Heating controls	MCB	High	During the heating season the heating controls will be a priority load in connected mode and could need backup in island mode, even if the heating is off. A dedicated circuit is recommended rather than a spur from a socket circuit.
9	Heat pump	MCB	Low	Care should be taken with heat pump designs to check the full load demands at minimum coefficient of performance plus requirements for auxiliary equipment (pumps etc.). In winter a 12kW heat pump with a coefficient of performance (CoP) of 2 may need 6 kW of electrical input. Protective devices should be rated to cope with minimum CoP demands. Manufacturers' data sheets should be checked.
10	Backup water heating	MCB	Medium	Backup water heating is likely to be resistive in nature. Manufacturers' details should be checked. A typical requirement will be a radial circuit supporting a 3 kW load.

Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
11	Internal lighting 1	MCB or RCBO	Medium	Domestic internal lighting in new installations will typically be LED. Some older installations may have traditional lamp sources. Consideration of cumulative starting currents for LED drivers will be necessary. Lighting circuits will typically be 6 A or 10 A rating and should be radials. Lighting circuits in bathrooms may need additional protection by an RCBO (see BS 7671 Regulation 701.411.3.3).
12	Internal lighting 2	MCB or RCBO	Medium	As above
13	External lighting	MCB or RCBO	Low	Domestic external lighting in new installations will typically be LED. Older installations may have traditional lamp sources. Lighting circuits will typically be 6 A or 10 A rating and should be separate radials. External lighting circuits may benefit from additional protection by RCBO (see BS 7671 Regulation 701.411.3.3).
14	Electric vehicle charging	RCBO (230 V double pole)	Low	Provisions of electric vehicle charging shall comply with

Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
				requirements of BS 7671 Section 722. Also refer to the IET *Code of Practice for Electric Vehicle Charging Equipment Installation* Section 6 for guidance on protective devices. Where vehicles are also used as additional storage (vehicle to grid etc.) bi-directional protective devices in consumer units will be required to facilitate import and export of electrical energy. Additional measures will be required in the final circuits such as — local RCD protection at the point of use, — additional earthing at external charge points, — circuit safety status monitoring and — facilities to isolate all live conductors and earth in the event of a fault. Needs clear labelling, and lock off facilities to aid safe systems of

Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
				work are recommended. For PEI installations the rating of EVCP loads may have a significant impact on island mode operations. Controls to load shed the EVCP may be necessary in island mode.
15	Garage supply	RCBO	Low	Where a garage is detached from a property there may be a sub-distribution cable and local consumer unit/distribution board with socket and lighting final circuits. It is recommended that RCBOs are provided to ensure additional protective measures are in place. Double pole protective devices are recommended for detached outbuildings.
16	Garden room supply	RCBO	Low	Where a garden room is detached from a property there may be a sub-distribution cable and local consumer unit/distribution board with socket and lighting final circuits. It is recommended that RCBO devices are provided to ensure additional protective

Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
				measures are in place. Double pole protective devices are recommended for detached outbuildings.
17	Electrical energy storage system	RCBO	NA	Main isolation for EESS, capable of supplying installation in island mode (part or full load). Careful selection of a bi-directional protective device is required, and also for circuit conductor sizing. In grid connected mode an EESS will typically import in certain periods. Import may also come simultaneous from on-site generation. The final circuit infrastructure should take into account all potential current magnitudes. In island mode EESS becomes the supply source and exports. It may also be able to import from on-site generation (PV etc.). Facilities to isolate all live conductors and earth in the event of a fault. Needs clear labelling and lock off facilities to aid safe systems of

Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
				work are recommended. Neutral-earth link in circuit required and connection to local TT earth for island mode operation.
18	On-site generation	RCBO	NA	Main isolation for on-site generation, capable of supplying installation in island mode (part or full load). Careful selection of a reverse uni-directional protective device is required to allow for energy export. Final circuit should be dedicated radial for generation with no other equipment connected. Facilities to isolate all live conductors and earth in the event of a fault. Needs clear labelling and lock off facilities to aid safe systems of work.
19	Surge protection	Surge protection device (SPD)	N/A	Type 1 or 2 or combined device Regular monitoring of operational status is recommended.
20	Main isolation	RCBO	NA	Main isolation for the grid connected supply. Assessment will be required on the type of supply e.g. TN-C-S or TT.

Table 5.5 — Equipment loads - domestic example *(continued)*

Ref	Circuit	Device type	PEI island priority	Commentary
				May require careful selection of a bi-directional protective device to allow protection of installation under grid connected export and import conditions.

5.3 Controls and measurement

Controls and measurement form a fundamental part of the PEI, whether it is operating in grid connected mode (either direct feed or reverse feed) or in island mode.

An electrical energy management system (EEMS) is critical to ensuring that a PEI is functioning correctly. Ideally the system should provide end-to-end status monitoring and energy management from all sources of supply and all final circuit loads.

BS 7671 Section 825.1 states that the objectives of the EEMS are to:

"i. control the connection of the PEI to the smart grid

ii. manage locally the electrical energy production

iii. manage locally the electrical energy consumption

iv. manage the electrical energy procurement from the DSO."

The sophistication of the controls and measurement system will depend on the type of installation specified and the budget available. BS 7671 Section 825.1 suggests some examples of functions that might be expected from an EEMS.

The EEMS may be installed as a separate item of equipment or be integrated within other equipment. However, features and requirements of an EEMS may include:

a) communication facility with installation smart meters;

b) load planning to optimise dynamic tariffs and even out maximum load demands (e.g. load shifting);

c) load shedding when required (e.g. to allow capacity for essential loads when supplies are constrained or the installation is in island mode); and

d) monitoring when:

— the installation is importing from the grid (e.g. direct feed);

— the installation is exporting to the grid (e.g. reverse feed);

— the EESS is charging from either the grid or the on-site generation;

— the EESS is discharging back to the installation or the grid; and

— the on-site generation is exporting to the grid or to the EESS.

Section 7.2 of this guide provides further commentary and examples of the design and implementation of an EEMS. The EEMS and its user interface provide the ability to monitor operational electrical characteristics such as voltage and frequency as well as energy use and efficiencies.

5.4 Design for installation and maintenance

The process of installing equipment to facilitate both production and consumption of electrical energy will necessitate satisfactory space planning in the early design stages of an installation. For an individual

PEI this means a greater amount of space compared to a traditional installation.

New domestic builds are often compact; providing more equipment will be a challenge. In retro-fit installations, there may be a need to upgrade critical parts of the existing installation, for instance a replacement duplex 18 way consumer unit may not fit in the space of the old 8-way consumer unit.

Finding internal space for the EESS will be a challenge too and the units, and any associated power conversion equipment, should be located in an area that has good ventilation. For some types of EESS, an external unit might be the only viable technical solution.

It is important at the design stage to ensure that adequate areas are allocated for the installation of all necessary equipment and that the basic requirements of electrical safety are complied with. Space allowance and access arrangements should consider the needs of those who install new equipment, maintain existing installations and replace failed equipment. The focus has to be on:

a) safe systems of work for electrical safety;

b) access to equipment and the associated fixings especially when working at height; and

c) handling heavy and/or bulky equipment where that is required.

Manufacturers' data should be consulted to confirm the clearances needed around each item of equipment, especially those that may be subjected to heat gain during normal operation and can be affected by adverse operating environments, e.g. EESS, inverters and adjacent equipment such as heating.

The operating environment should be considered as a whole and for individual components of a PEI. The ingress protection (IP) rating of any equipment should be checked for the location in which it is placed.

Ventilation around components needs to be checked. Use of mechanical ventilation and cooling should only be considered if necessary as this will detract from the overall operational efficiency of a PEI. Locating plant rooms adjacent to outside walls will allow natural ventilation methods to be considered.

As a source of stored chemical energy, batteries carry an inherent fire risk. It is recommended that BSI document PAS 63100 'Electrical installations. Protection against fire of battery energy storage systems for use in dwellings', is consulted. It provides a specification on protection of fire for EESS in domestic locations.

For other non-domestic premises a suitable and sufficient fire safety risk assessment for energy storage should be considered as part of general fire engineering design and operations. This will include safe operating environments for energy storage facilities and appropriate fire detection and alarms and fire supression where necessary.

The Fire Protection Association (FPA) and insurers group Risk Insight, Strategy and Control Authority (RISCAuthority) have issued advisory documents for other non-domestic fire risk assessments:

— RC59: Recommendations for fire safety when charging electric vehicles; and

— RC62: Recommendations for fire safety with PV panel installations.

For the end user, there must be clear line of sight to any control interfaces and adequate access to metering, even if that metering also communicates with smartphone apps or remote monitoring. Maintenance personnel may also need access to control interfaces. To assist this they possibly need cable connection to data and socket-outlets for laptops.

A robust Wi-Fi connection may help maintenance personnel within plant areas. A Wi-Fi connection could also be necessary for remote monitoring devices that are attached to PEI components and low carbon technologies such as heat pumps.

There should be clear access to all forms of electrical isolation throughout the installation. Labels should clearly indicate what their purpose is and what circuit they are connected to at the local DB or CU. The outgoing ways of the DBs or CUs should having matching descriptions.

Additional cable routes will be required for all equipment, which will need adequate support throughout their length and mechanical protection where necessary. Fire stopping and weatherproofing of cable routes should be provided where appropriate to ensure the energy performance of the building fabric and its associated fire integrity are not compromised by the PEI.

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The relative proximity of PEI equipment should be considered to minimise the materials used, such as reductions in cable lengths. This will help to optimise the efficiency of the overall system, in line with BS 7671, BS HD 60364-8-1 and good practice generally.

Use of a DC coupled installation provides opportunities to improve efficiencies on the energy harvesting and storage side of a PEI, and reduces the impact of harmonics on the AC side of the installation. Voltage drops in the DC installation may be an issue and locating equipment centrally reduces this impact.

5.5 Requirements for inspection and testing

The requirements for initial and periodic inspection and testing for a PEI should follow Part 6 of BS 7671 and the additional commentary in IET *Guidance Note 3: Inspection & Testing*.

Additional requirements for grid connections and the commissioning procedures required by the DNO/DSO, including export sign offs, can be found in Engineering Recommendations G98 and G99. Other guidance in this area is available on the ENA website - www.energynetworks.org.

The requirements of equipment manufacturers should also be carefully considered to avoid later disputes regarding warranties.

It is vital that safe systems of work are used throughout all inspection and testing processes, both for initial verification and commissioning and for subsequent periodic testing or recommissioning. This is true for any electrical installation, but constant observation should be made of the status of each PEI energy source to ensure that live energy sources are not a risk to personnel. Every isolation should be checked thoroughly to avoid risks of electric shock.

The full scope and sequence of inspection and testing should follow that detailed in BS 7671 Part 6, in particular:

a) Section 642 for inspection activities; and

b) Section 643 for testing activities.

Assessment of the PEI for each combination of energy sources should be made to ensure the correct operation of all protective devices and associated earthing arrangements depending on operational mode.

Further guidance is also available in Section 16 of the IET *Code of Practice for Grid-Connected Solar Photovoltaic Systems*, which provides details of:

c) commissioning processes for AC and DC systems; and

d) commissioning processes for EESS

For DC systems, both documents refer to BS EN 62446-1.

Commissioning of any electrical installation involves a defined inspection and testing process and also compliance checks against the original design criteria. This ensures adherence to the original design intent, and that the equipment installed meets the specification criteria and has been installed in a satisfactory manner.

Commissioning is the opportunity to check that the designer's requirements have been met, the end user's needs have been considered and that the installation is safe for all. Section 12 of the IET *Code of Practice for Electrical Energy Storage Systems* provides a checklist for the commissioning process: this has been adapted here, in Table 5.6, and is intended to supplement the requirements of BS 7671 and other standards.

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Table 5.6 — Inspection checklists

(Adapted from Table 12.1 CoP EESS)

	Requirements	Recommended Activity	
System design/equipment selection and connection **See BS 7671 Chapter 64**			
1	General check to confirm equipment complies with relevant standards	Y	
2	System installed in accordance with design	Y	Y
3	Equipment correctly selected and erected according to standards and manufacturer's instructions		Y
4	Equipment undamaged		Y
5	Conductors correctly connected, identified and routed		Y
6	Conductors suitably selected for voltage and current requirements	Y	Y
7	Switchgear and ancillary devices suitable for voltage and current requirements	Y	Y
8	Switchgear and ancillary devices correctly installed and connected		Y
9	Components selected and erected to suit the location and any external influences	Y	Y
Checks to design drawings and specifications			
Visual inspection of installation			

Table 5.7

	Requirements	Recommended Activity	
Protection against electric shock			
Basic protection (prevention of contact with live parts) See BS 7671 Section 416			
1	Protection by insulation of live parts (e.g. conductors) correctly applied and suitable		Y
2	Protection by the use of barriers or enclosures suitable and with an appropriate IP rating	Y	Y
Additional protection (additional protection measures) See BS 7671 Section 415			
3	Protection by the use of an RCD not exceeding 30 mA	Y	Y
4	Supplementary bonding	Y	Y
Other methods of protection See BS 7671 Section 414			
5	SELV (separated extra-low voltage)		Y
6	PELV (protected extra-low voltage)		Y
7	Double or reinforced insulation. (Class II or equivalent equipment and circuits)		Y
Automatic disconnection of supply See BS7671 section 411			
8	Suitable main earth provided	Y	Y
9	Earth connections suitably installed		Y
10	Main protective bonding suitably installed		Y
11	RCDs provided for fault protection	Y	Y
Checks to design drawings and specifications			
Visual inspection of installation			

Table 5.8 — General safety and maintenance issues

	Requirements	Recommended Activity	
General safety and maintenance issues			
1	Equipment and circuits deployed to prevent mutual detrimental influence See BS 7671 Regulation 132.11		Y
2	Equipment located to allow suitable access arrangements See BS 7671 Regulation 132.12	Y	Y
3	Labels and signs displayed and durable See BS 7671 Section 514		Y
		Checks to design drawings and specifications	
			Visual inspection of installation

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Table 5.9 — Systems that provide backup or island mode power supply

	Requirements	Recommended Activity	
Systems that provide backup or island mode power supply			
1	Isolation of grid supply current-carrying conductors See BS 7671 Chapter 53 and Regulation 826.1.1	Y	Y
2	Provision of consumer's earth electrode See BS 7671 Regulation 551.4.3.2.1	Y	Y
3	Additional protection by RCDs to supplement overcurrent protective devices to ensure adequate disconnection times are met See BS 7671 Regulation 411.4.5 and Regulation 419.2	Y	Y
4	Provision of surge protection devices See BS 7671 Regulation 826.1.4	Y	Y
	Staggered start and/or load-shedding on change-over See BS 7671 Regulation 826.4 and Annex C82.5	Y	Y
Checks to design drawings and specifications			
Visual inspection of installation			

Section 12.2.2 of the IET *Code of Practice for Electrical Energy Storage Systems* discusses how to verify earth fault loop impedance and prospective fault current, and notes that:

> *"earth fault loop impedance and prospective fault current measurements may be distorted by the presence of local inverters (from EESS, solar PV, and so on)."*

The Code of Practice recommends that:

> *"(a) external earth fault loop impedance and prospective fault current measurements are carried out at the origin, with inverters isolated*
>
> *(b) earth fault loop impedance and prospective fault current measurements for the remainder of the installation are not taken unless all the inverters in the system are isolated."*

Table 5.7 — Minimum electrical circuit tests to BS 7671

(based on table 12.2 IET Code of Practice for Electrical Energy Storage Systems)

Item	Requirement
Continuity of earthing and/or equipotential bonding conductors	Test continuity of earthing and/or protective equipotential bonding conductors (where installed). Verify connection to main earthing terminal. See BS 7671 Regulation 643.2.
Insulation resistance test	Test insulation resistance between live conductors, and between live conductors to protective conductor. Test to be undertaken on all site-installed circuits (AC and DC). See BS 7671 Regulation 643.3 NOTE 1 Devices that may influence, or be damaged, during insulation resistance testing (e.g. Surge protection devices) should be temporarily disconnected during testing.
Polarity test	Test to ensure that all conductors are correctly identified and connected to the correct terminals. See BS 7671 Regulation 643.6
Earth electrode resistance	Measure the resistance of the local earth electrode for the PEI. An additional electrode should be provided for TN installations and already fitted for TT installations. See BS 7671 643.7.2
Earth fault loop impedance	Determine the earth fault loop impedance of individual circuits. The determined value needs to be checked to ensure that it is low enough to allow the circuit protective device to clear a fault within the proscribed disconnection time for that circuit. See BS 7671 Regulation 643.7.2 generally and Regulation 826.1.1.2 for PEI specifically Additionally, the influence of connected inverters (on-site generators and EESS) during testing shall be mitigated. See BS 7671 Regulation 826.7
RCD test	Test to ensure proper function of any RCDs See BS7671 Regulation 643.8

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Table 5.7 — Minimum electrical circuit tests to BS 7671 *(continued)*

(based on table 12.2 IET Code of Practice for Electrical Energy Storage Systems)

Item	Requirement
	NOTE 2 The test should be carried out in connected mode and island mode to ensure that the earth fault return path is operational in both modes.
Functional tests	Tests to ensure that switchgear and other circuit devices operate correctly Tests to ensure correct functioning of island mode isolator in switching between all supported modes See BS 7671 Regulation 643.10

The outcome of all inspection and tests shall be recorded as described in BS 7671 Section 6 and Appendix 6. Associated certification should be handed over with the operations and maintenance documentation.

Periodic inspection and testing is an important function to ensure the longevity of any electrical installation. This is critical to a PEI and should be carried at regular intervals.

The installer, and subsequent maintainers, have a duty of care and a crucial role in determining the frequency of periodic inspections. Historical recommendations of every five or ten years for traditional installations may not be suitable for PEI. Such installations are much more complex and the frequency of inspection should vary as the installation ages and component parts start to deteriorate.

Different aspects of a PEI may need checks at different intervals. Cabling infrastructure will not necessarily need inspecting as frequently as the EESS, PV or other generation. A rolling programme over 12-month intervals with varying levels of inspection and testing tasks may be preferable.

The training level, experience and competence of the inspector carrying out electrcial installation inspection and testing on PEI equipment is also important. Spotting potential electrcial safety and fire safety snags and correctly interpreting test results are important to ensure continuity of service and safety for end users with all electrical installations and PEI in particular.

Among key considerations for more frequent check are:

e) regular checks on earth electrodes to ensure electrical safety devices can operate in a timely manner in grid connected and island connected mode;

f) correct operation of any neutral earth links;

g) correct operation of break before make switching;

h) correct operation of protective devices;

i) battery status in EESS;

j) sufficient space and ventilation air flow around equipment such as EESS to reduce heat gain risks; and

k) correct operation of EEMS equipment interfaces and user interfaces.

6 Operational types and modes of PEI

Regulation 824 of BS 7671 recognises three types of PEI:

a) individual - one installation that has all the essential components of a PEI and a single smart meter connection to the grid;
b) collective - acollection of installations located in the same vicinity, each with their own smart metered connection, and an external shared infrastructure of local energy generation and/or energy storage; and

c) shared - a number of adjacent PEIs, each having its own on-site energy generation and/or storage

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but which may aggregate their export connections to the grid and/or have agreements in place to share locally generated or stored energy with each other.

See also Sections 6.1, 6.2 and 6.3 of this guide.

Regulation 824 also notes three operating modes – direct feed, reverse feed and island mode. The modes and how they relate to each of the three types are explored in more detail in Annex B82:

d) direct feed - this describes a traditional grid connection to the installation and energy transfer from the grid via the meter to the sub-distribution system and electrical loads. The primary energy flow is importing;

e) reverse feed - this describes the transfer of energy from the PEI generation and energy storage via the meter back out to the grid. This will usually occur when the on-site loads have a low demand and there is surplus energy from on-site generation and/or energy storage. The primary energy flow is export; and

f) island mode - this describes the scenario of mains isolation from the grid connection and the installation relying purely on its own source of generation or on-site energy storage. Careful energy management will be necessary to ensure electrical loads do not exceed the supply capacity that is available from the on-site generation and/or storage. This mode can also describe a PEI that operates completely off-grid.

See also Sections 6.4, 6.5 and 6.6 of this guide.

For the collective and shared scenarios there are possible variants in the infrastructure set up. These are shown in Regulation 824 of BS 7671 Chapter 82.

6.1 Individual PEI

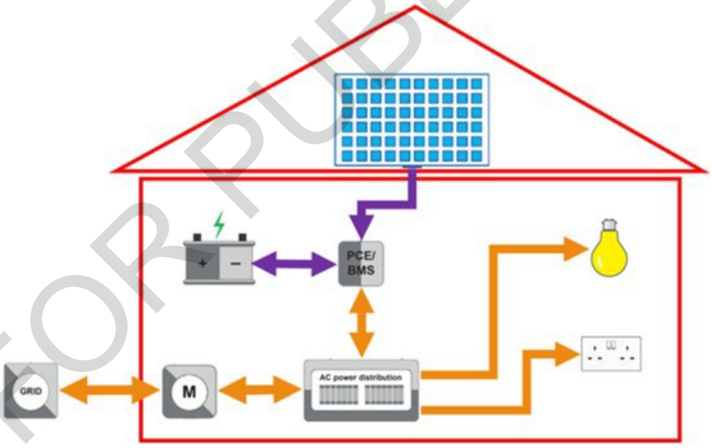

Figure 6.1 — Individual PEI installation

Figure 6.1 illustrates an individual PEI within a single property that has its own grid connection complete with smart meter to record energy exports and imports, its own on-site electrical generation and its own energy storage facility. It should be noted that some installations might not have both the on-site generation and the storage facility. However, by definition, as a PEI, they should at least have one of them.

The on-site generation example set out in this series of diagrams is photovoltaic. A PEI may have other forms of on-site generation as demonstrated in Figure 2.1 of this guide.

For clarity the EEMS has been omitted from the diagram but that will control electrical load usage through load planning, monitor exports and imports, monitor time of use tariffs, receive signals on network constraints and communicate with the grid.

It is worth noting the potential energy flow through the electrical installation which will vary throughout the day as the installation load profile varies compared to the on-site generation and the capacity of energy storage. The variations in energy flow include:

a) uni-directional flow to electrical loads;

b) uni-directional flow from on-site generation to distribution/consumer unit;

c) bi-directional flow to and from the local individual energy storage;

d) bi-directional flow to and from meter and distribution/consumer unit; and

e) bi-directional flow to and from meter and grid connection.

It is likely that an individual PEI installation will be the most common type used.

6.2 Collective PEI

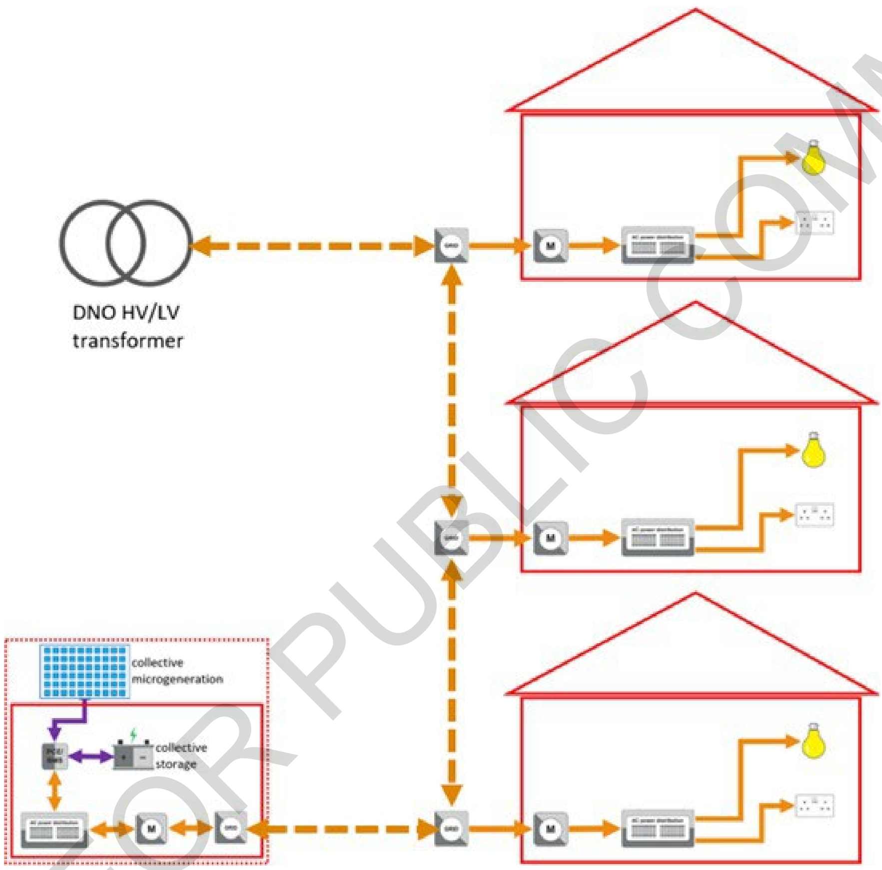

Figure 6.2 — A collective of PEI installations

Figure 6 2 illustrates the arrangement for collective type PEI, where multiple consumers, with electrical installations in relatively close proximity, each have a traditional type of installation. They all have their own meter connection, usual sub-distribution within the installation and sub-circuits providing energy to different electrical loads. From the meter, and downstream to the loads, the energy flow is conventional and uni-directional.

The external low-voltage (LV) infrastructure in this example will be common to all properties. There will be multiple sources of energy which may come from the grid or from a central, or collective, renewable source. For ease only a PV source has been illustrated here but the renewable source could be a wind turbine, or perhaps a water turbine near a river. Central energy storage could be used as part of this centralised low carbon supply to enhance a wider energy strategy.

A linked EEMS is omitted from the diagram but should provide communication and controls links between each of the installations, the grid supplies and the collective PEI supply. There should be coordination through the whole collective to assess and permit electrical load usage through load planning, monitor exports and imports, monitor time of use tariffs, receive signals on network constraints and communicate with the grid.

The network of communications should monitor in real time the individual demands in each of the properties and the combined demand on the local infrastructure. The EEMS will match the demand against the capacity of the local generation, local storage and grid connection. Any surplus energy can be stored in the collective energy storage unit or exported directly back to the grid.

The potential energy flow through the whole collective electrical installation will vary depending on the combined installation load profile, the output of the central on-site generation and the capacity of the associated energy storage. These variations in energy flow include:

a) A collective type PEI installation is likely to be less common in urban areas. However, it could be envisaged as a PV installation on a large roof area of a residential block. The electrical output may support the landlords' areas including stairwells and communal lighting.

b) Another example may be on an agricultural estate with several buildings that share a local PV installation or wind turbine.

Linking both of these examples to energy storage facilities will assist with intermittency of renewable energy supply. Lighting circuits would typically use the stored energy during darker hours when PV will not be able to generate.

Another form of collective PEI is described in Figure 82.5 of BS 7671. In this example the common production and storage element of the PEI also provides a separate infrastructure to each property. Each installation is considered a consumer. The common local generation and energy storage is considered a producer.

6.3 Shared PEI

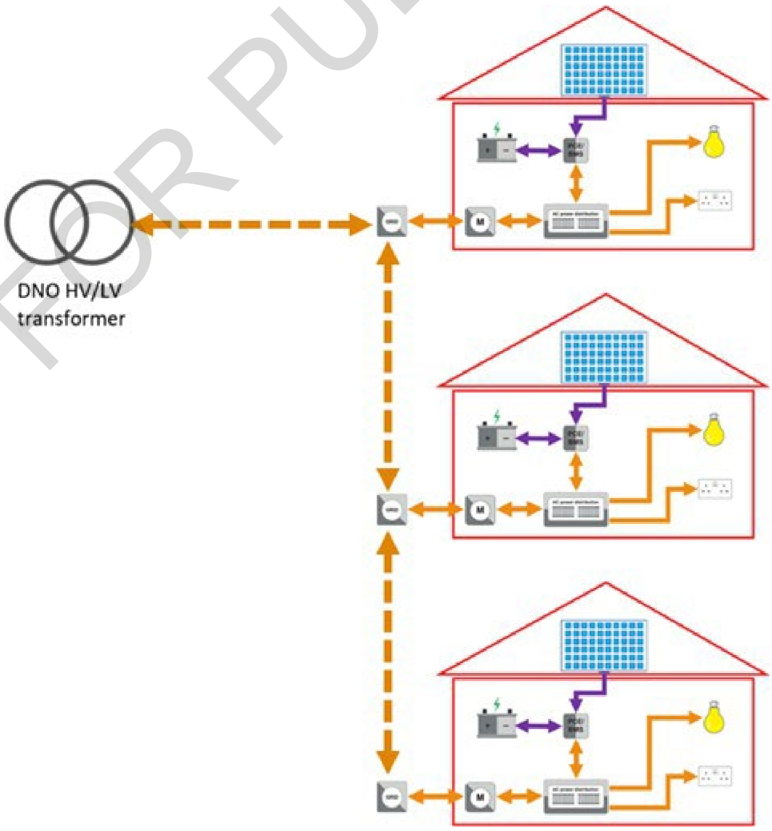

Figure 6.3 — A shared PEI installation infrastructure

[Figure 6 3](#) illustrates the arrangement for shared type PEI. For this arrangement there are a series of individual PEIs, linked to a common LV infrastructure. Each property has its own grid connection complete with smart meter, its own on-site electrical generation and its own energy storage facility.

The external infrastructure, typically LV, will be common to all properties. There will be multiple sources of energy which may come from the grid or from their own renewable source or from an adjacent property linked to them. Energy storage could be used as part of this shared low carbon supply to enhance a wider energy strategy.

The properties should have a linked EEMS that provides communication and controls links between each of the installations, the grid supplies and the collective PEI supply. There should be coordination through the whole shared estate to assess and permit electrical load usage through load planning, monitor exports and imports, monitor time of use tariffs, receive signals on network constraints and communicate with the grid.

It is worth noting the potential energy flow through the electrical installation which will vary throughout the day as the installation load profile varies compared to the on-site generation and the capacity of energy storage. The variations in energy flow within each PEI will be similar to the individual type and include:

a) uni-directional flow to electrical loads;

b) uni-directional flow from on-site generation to distribution/consumer unit;

c) bi-directional flow to and from the local individual energy storage;

d) bi-directional flow to and from meter and distribution/consumer unit; and

e) bi-directional flow to and from meter and grid connection.

The network of communications should monitor in real time the individual demands in each of the properties and the combined demand on the local infrastructure. The EEMS will match the demand against the capacity of the local generation, local storage and grid connection. Any surplus energy can be exported directly back to the grid or to adjacent properties where it may be used immediately or stored in the respective PEI energy storage unit.

A shared type PEI installation could be envisaged as a new housing estate where properties in a small cul de sac are each built with integral PEI but are linked to common street infrastructure with common export/import energy agreements in place with the local energy supplier and with each other.

The shared PEIs aggregate their assets and can support each other or export to the wider grid as required.

6.4 Connected mode direct feeding

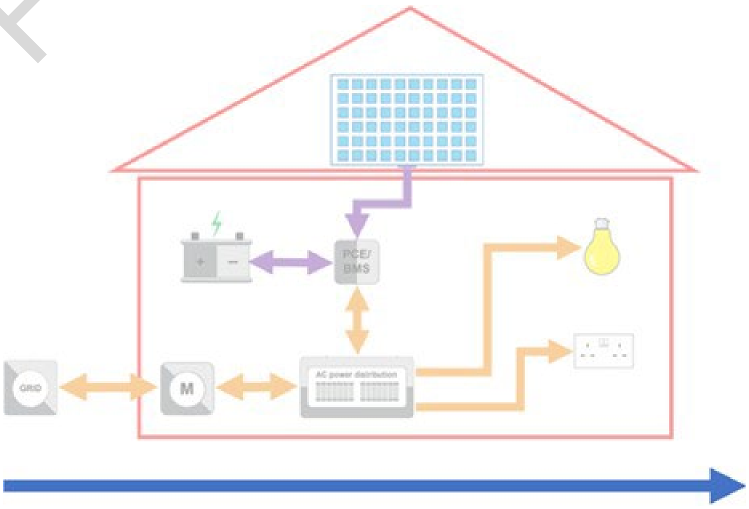

Figure 6.4 — Direct feed for individual PEI

For an individual PEI type, direct feeding mode demonstrates that the typical net energy flow is from the grid via the installation sub-distribution to the point of use, such as a light or socket. Figure 6 4 shows the energy flow as a blue arrow.

For prosumers with their own generation or storage facility there will be an opportunity to supplement electrical energy required for the electrical loads from the local source. This will reduce dependency on the grid connection and lower metered costs.

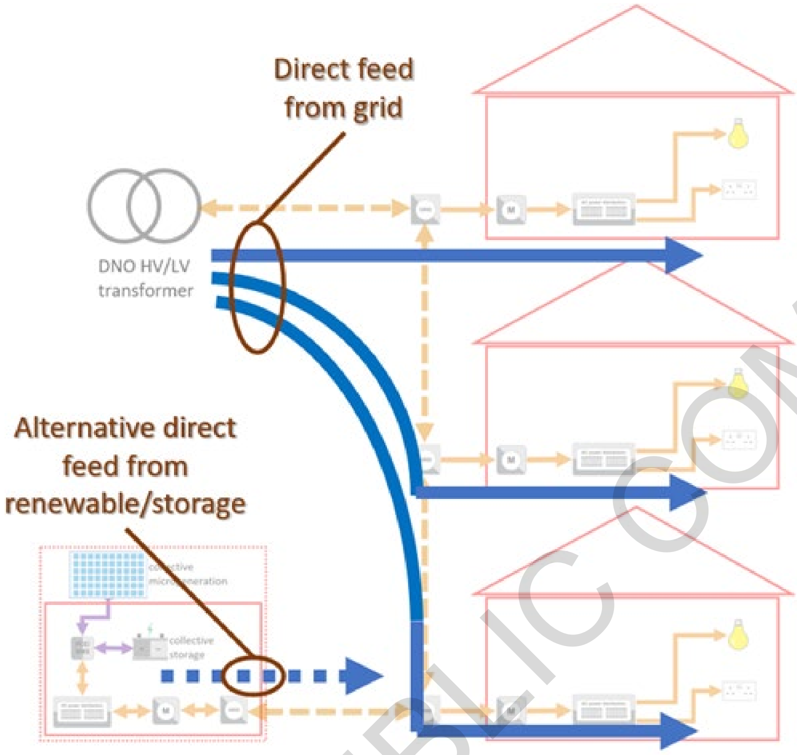

Figure 6.5 — Direct feed for collective PEI

For the collective type of PEI, direct feeding mode demonstrates that the typical energy flow is again from the grid via the installation sub-distribution to the point of use, such as a light or socket. Energy flow to various properties via a common infrastructure is shown in Figure 6 5 as a series of blue arrows.

The generation or storage facility is collective and housed separately from the principal users. The opportunity to supplement electrical energy from the local source is collective and reduced dependency on the grid connection, and lower metered costs can benefit some or all users depending on demand.

The grid connection may also be used to charge the collective energy storage.

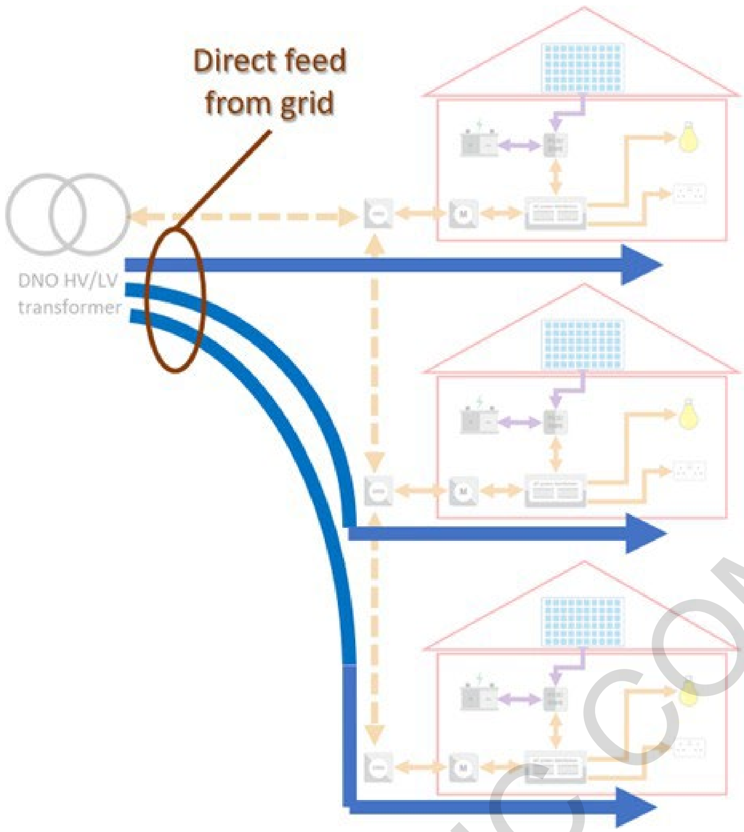

Figure 6.6 — Direct feed for shared PEI

The shared type of PEI, in the direct feeding mode, demonstrates a similar typical energy flow from the grid via the installation sub-distribution to the point of use, such as a light or socket. The diagram shows a collection of blue arrows to the various properties.

This example shows that the generation or storage facility is in each principal user installation. The opportunity to supplement electrical energy from the local source can be controlled collectively, through consolidation of each of the assets and their respective connections to the grid.

There is reduced dependency on the grid connection and lower metered costs, but using individual energy generation and storage assets that are pooled and shared. Within this arrangement one installation may be direct feeding (net import) whilst another is reverse feeding (net export) to support it.

6.5 Connected mode reverse feed

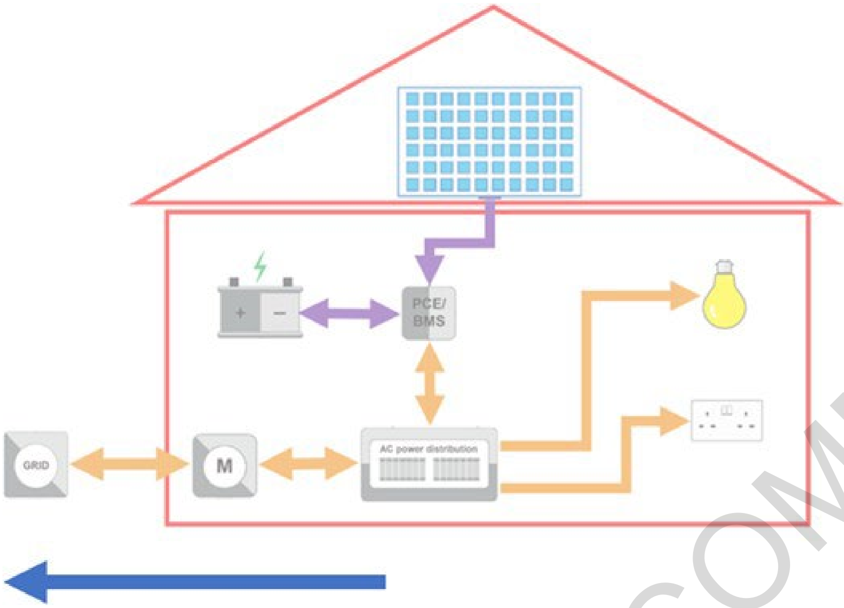

Figure 6.7 — Reverse feed for individual PEI

Reverse feeding mode for individual PEI is simply an export of surplus electrical energy from either the generation (e.g. PV) or the energy storage to the grid. The benefit of earning from the export is simply for the individual prosumer in this instance.

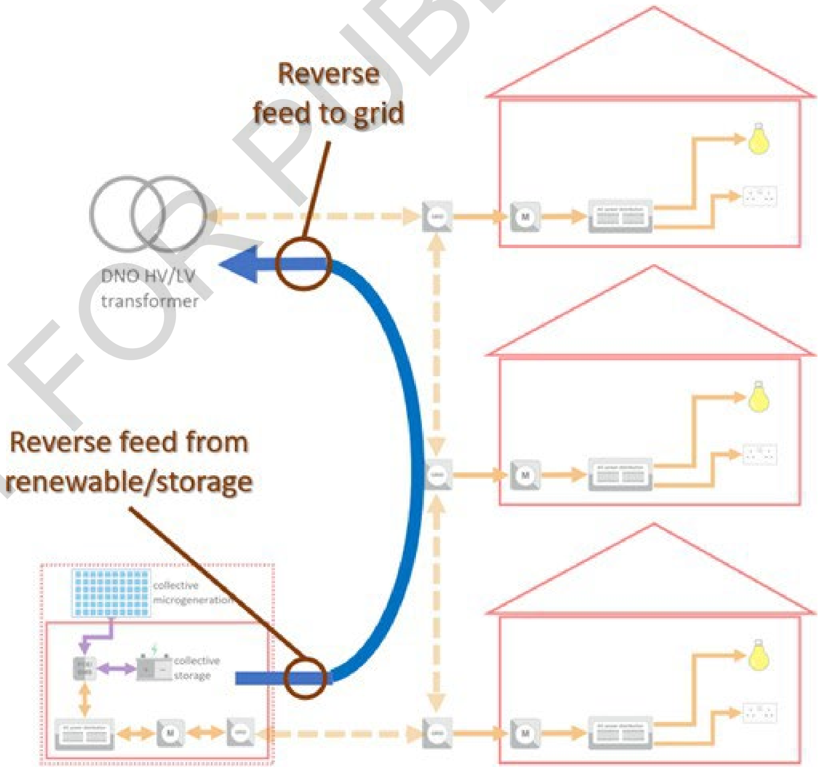

Figure 6.8 — Reverse feed for collective PEI

For a collective PEI the reverse feeding mode may not directly benefit the actual properties. Using the common infrastructure, the main energy flow is considered as exporting directly to the grid from the collective energy generation or energy storage facility.

It may also be feeding the properties at the same time and reducing dependency to the grid. Such exports are likely to be on a call-off arrangement when the grid reaches peak demand.

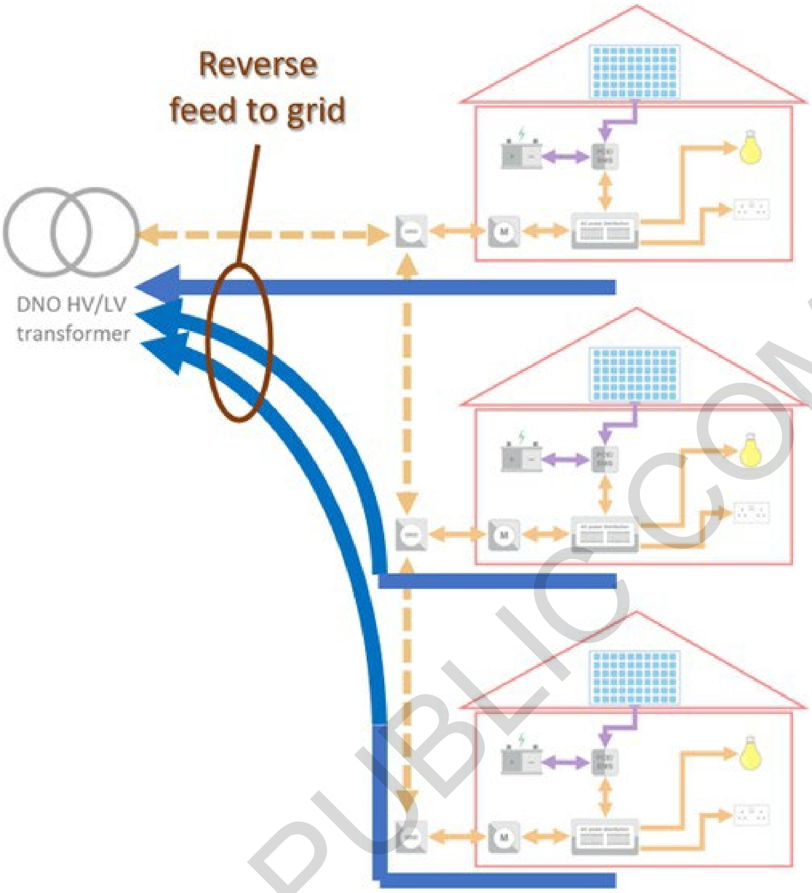

Figure 6.9 — Reverse feed for shared PEI

For the shared type of PEI, the reverse feed mode comes from each of the individual PEIs and is aggregated via the grid connections for each property.

It is feasible that whilst one or more of the properties in the shared scheme are exporting energy, others may be simultaneously importing to meet extra local demand.

6.6 Island Mode

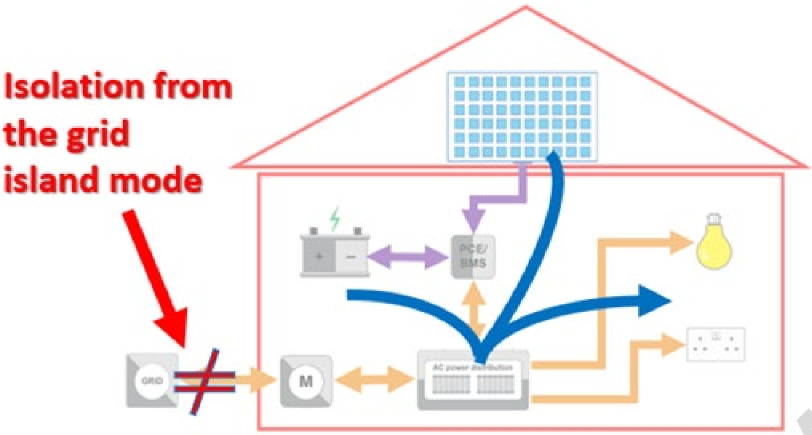

Figure 6.10 — Island mode for individual PEI

The main feature of island mode is that there is no connection to the grid and the prosumer is operating from local electrical generation. If the local generation is provided by PV or wind generation, the use of local energy storage is advisable to overcome intermittency of supply.

Island mode could be a temporary situation caused by a loss of grid connection due to faults in the wider electrical distribution system. Equally, the installation could be permanently off grid.

Additional design and operational measures are recommended to ensure energy efficiency in use and to maximise the time the installation can rely on energy storage.

For a PEI to operate in island mode, it is advisable that operational planning scenarios are assessed beforehand and the EEMS programmed appropriately to control the PEI satisfactorily. Depending on the capacity of the energy storage or output from the on-site generation, the planning will need to include load shedding strategies or load shift for non-essential loads to reduce overload issues.

Electrical safety issues are an important consideration. For example, earthing arrangements in island mode and the performance of protective devices both need to be addressed during the design stage, correctly commissioned and regularly checked during the operational stage.

The energy flow comes from the energy storage unit and from the local generation source to feed the circuits in the individual installation.

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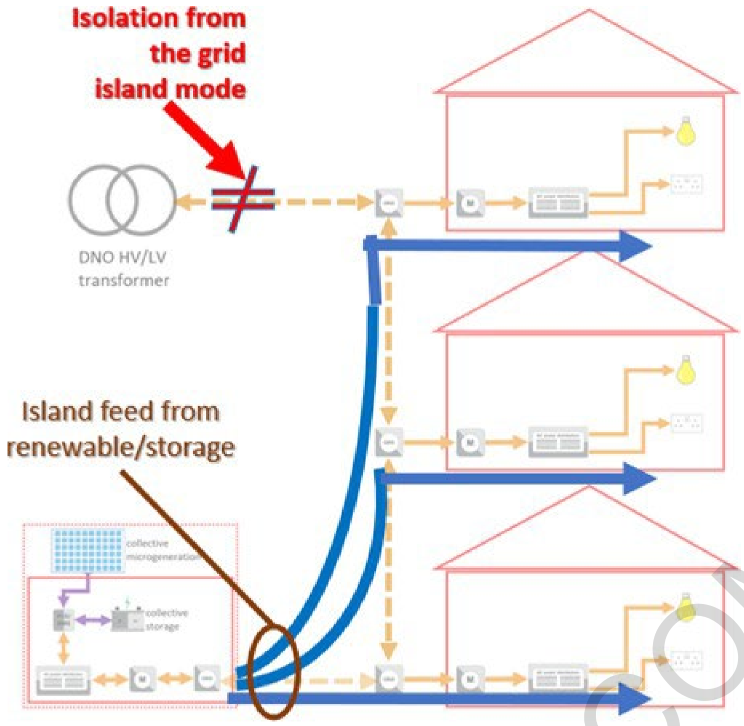

Figure 6.11 — Island mode for collective PEI

For island mode, there is no direct connection to the grid with a collective PEI. The individual consumers are operating from a common electrical supply infrastructure. The local generation (for instance, PV or wind generation) should be supported by the use of local energy storage to overcome intermittency of supply.

Island mode may be caused by a loss of grid connection due to faults in the wider electrical distribution system. Equally, the installation could be permanently off grid.

As there are more installations linked to the same source of supply, additional design and operational measures are essential to ensure energy efficiency in use and to maximise the time the installation can rely on energy storage.

For a collective PEI to operate in island mode, it is advisable that operational planning scenarios are assessed beforehand and the EEMS programmed appropriately to control the PEI satisfactorily.

The planning will need to include:

a) recognising the electrical load demands in all properties attached to the shared PEI;

b) understanding the capacity of the energy storage or output from the on-site generation; and

c) identifying priorities for load shedding strategies or load shift for non-essential loads to reduce overload issues.

All of these parameters will need to be monitored in real time and automatic control procedures may be required to optimise efficient running of the installation and prevent overloads on the PEI output during island mode operation.

Electrical safety issues across the whole installation will need to be addressed in each installation and across the whole island infrastructure. Nuances in earthing arrangements in island mode and the performance of protective devices in all properties must be risk assessed properly. This is also required at the shared PEI.

Mitigation measures should be identified during the design stage, correctly commissioned and regularly checked during the operational stage.

The typical energy flow is from the collective PEI (energy storage unit and local generation sources) through the common infrastructure to feed the circuits in each of the individual consumer installations.

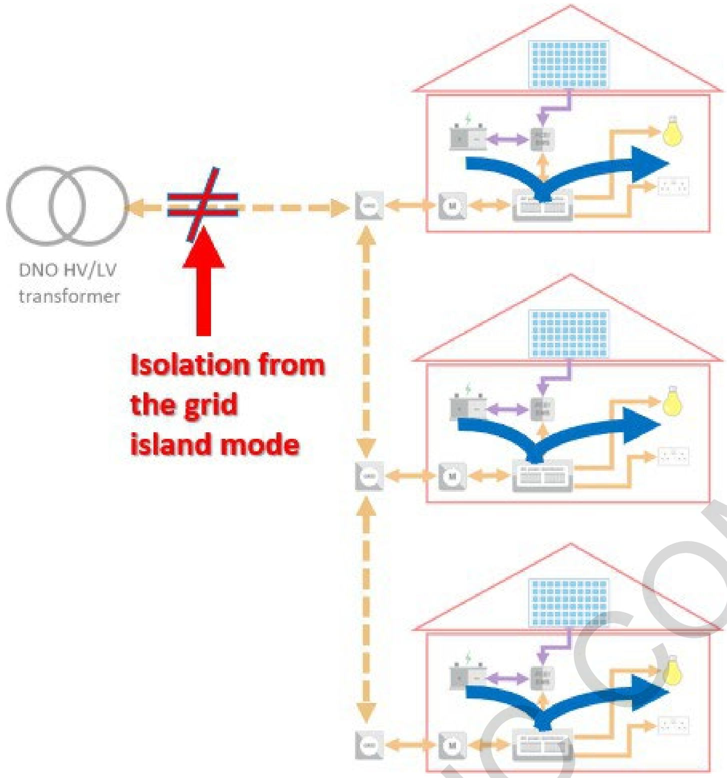

Figure 6.12 — Island mode for shared PEI

There is no direct connection to the grid with a shared PEI. The individual consumers are operating from their own PEI electrical supply infrastructure. The local generation (for instance PV or wind generation) should be supported by the use of local energy storage to overcome intermittency of supply.

Again, island mode may be caused by a loss of grid connection due to faults in the wider electrical distribution system. Equally, the installation could be permanently off grid.

The installations are still linked to a common infrastructure. Additional design and operational measures are essential to ensure energy efficiency in use within each installation and to maximise the time the installation can rely on energy storage. It is advisable that operational planning scenarios are assessed beforehand and the EEMS programmed appropriately to control the PEI satisfactorily.

The planning will need to include:

d) recognising the electrical load demands in each property attached to the common infrastructure;

e) understanding the capacity of the energy storage or output from the on-site generation in each installation;

f) identifying priorities for load shedding strategies or load shift for non-essential loads to reduce overload issue within each installation; and

g) notifying any spare capacity in an installation that could be exported via the common infrastructure to an adjacent installation on the same shared PEI network.

All of these parameters will need to be monitored in real time and automatic control procedures may be required to optimise efficient running of the installation and prevent overloads on the PEI output during island mode operation.

Electrical safety issues across the whole installation will need to be addressed in each installation and across the whole island infrastructure. Nuances in earthing arrangements in island mode and the performance of protective devices in all properties must be risk assessed properly. Mitigation measures should be identified during the design stage, correctly commissioned and regularly checked during the operational stage.

The typical energy flow is within each installation from the PEI energy storage unit and local generation sources to feed the circuits in each of the individual consumer installations. Where feasible, surplus energy may may be exported from one property through the common infrastructure and imported to support an adjacent property.

6.7 Distribution

When designing, installing and operating multiple PEI installations that are in close proximity from each other, or which jointly form part of a shared or collective scheme, it is recommended that a strategic approach is taken to ensure satisfactory outcomes for individual components and the wider installation.

The implementation of either shared or collective PEI systems will require additional considerations for merged controls, electrical safety and operational performance.

Another example is adjacent individual PEIs that may have issues with regards to earthing arrangements and proximity of earth electrodes.

Section 5.1 provides insights on design considerations for PEI systems with attention to electrical safety. It mainly focuses on PEIs in individual standalone situations, although the principles are true for all. Table 6.1 highlights some other design or operational considerations for sites with multiple PEIs.

Table 6.1 — Additional electrical safety considerations

Design considerations	Commentary
Supply characteristics of electrical systems	The supply characteristics of the grid connection, local generation and EESS for an individual PEI can be monitored and adjusted by one central EEMS within the individual PEI. Shared PEI arrangements are essentially individual PEIs with common facilities to export and import. It is critical that the individual EEMS can communicate with each other so that their combined exports, for instance, do not contravene regulations for supply voltage and frequency. Operating a shared PEI in island mode will also be critical. Communication between the various EEMS will be necessary to ensure installations can operate for as long as possible or resort to individual operation while the grid is disconnected. For collective PEI arrangements the main EEMS will be located with the central collective local generation and EESS, however satellite EEMS may be necessary within the actual installations to monitor and plan load, particularly load shedding under island mode or load shifting under smart tariffs.
Maximum demand of electrical supplies	Under normal operation, facilities to monitor and adjust maximum demand of electrical loads assist efficiency and hence costs. For collective and shared PEIs, continued operation under island mode is dependent on all installations minimising their maximum demand and implementing load shedding of non-essential circuits and appliances.
Earthing systems	Earthing systems for all PEI types should be considered carefully. For developments with multiple PEIs the integrity of individual earth electrodes within the installation and their relative position to adjacent properties needs careful design and positioning. The provision of other services, such as EV charging, may add further complication. An example is a new development of multi-storey terraced townhouses that are only 4.5 m wide and all provided with individual PEIs and EVCPs, Each property will require electrically separate earth electrodes for the EESS and EVCPs. The electrodes also need to be electrically separate from adjacent properties.
Fault current magnitudes	Taking steps to understanding the magnitude of fault currents throughout an electrical installation is a requirement of BS 7671 Regulation 643.7.3.201 and augmented for PEIs by Regulation 826.1.2.1.

Table 6.1 — Additional electrical safety considerations *(continued)*

Design considerations	Commentary
	For collective and shared PEIs there will be additional combinations of supply to consider over a wider installation area.

7 Energy storage and energy management

The use of on-site generation such as PV in traditional electrical installations has increased over the last couple of decades and is well established. Installations like these are simple: there is little control over the generation output and it is exported straight to the grid. Metering is used to acknowledge that export and offset it against the usual imports.

The operating parameters and requirements for parallel operation and export of energy have been governed by the DNOs for several years through documents such as G59 and G83.

The components that set PEI apart from traditional installations is the deployment of:

a) on-site energy storage systems (EESS) that can interact with the grid supply and the on-site generation; and

b) an electrical energy management system (EEMS) that monitors and controls, either automatically or manually, the supply import and export requirements and the load demands.

This gives the end user greater control and facilitates a more energy efficient electrical installation with potentially lower energy costs.

DNO requirements and documents have been updated to reflect recent advances in technology and a suite of documents are now available, including G98, G99 and G100. More information and links are discussed in Section Clause 8 of this guide.

7.1 Electrical energy storage systems

The role of an electrical energy storage system (EESS) in a PEI is to optimise consumption of electrical energy by improving the energy efficiency of the installation in real time and reducing costs on billing over defined periods.

The EESS can be used in a number of ways to assist with these outcomes:

a) diverting surplus energy from on-site generation and storing it locally instead of exporting it directly to the grid. This stored energy can be used later to reduce maximum demand during peak periods; and

b) allowing the harvesting and storage of cheaper tariff grid energy (typically overnight) for use later when tariffs are more expensive, known as arbitrage.

Another use of EESS is to support some of the installation loads in island mode, in the event of a loss of mains grid supply. This support may be time limited according to the loads connected and the remaining capacity of the EESS at the time of mains failure.

Section 7.4 of this guide discusses load shifting, load shedding and load planning. An appropriately rated EESS provides enough flexibility to the installation for these operations to take place.

Further reading and commentary on electrical energy storage is available in:

c) Section 4 of the IET *Code of Practice for Electrical Energy Storage Systems*;

d) Section 13 of the IET *Code of Practice for Grid-Connected Solar Photovoltaic Systems*; and

e) Section 10 of the IET *Code of Practice for Electric Vehicle Charging Equipment Installation*.

Figure 7.1 shows an idealised cycle of an electrical installation through a 24-hour period.

In the early hours the installation loads are entirely reliant on a grid connection and imported energy to operate (mode A).

As the day progresses, and PV self-generation is operating, the load uses the PV supply and the surplus energy is harvested by the EESS (mode B).

Later in the day when the PV no longer operates the energy stored in the EESS now supports the electrical load, displacing the grid connection. Once that discharges the installation is back to using the grid connection only once again (mode C).

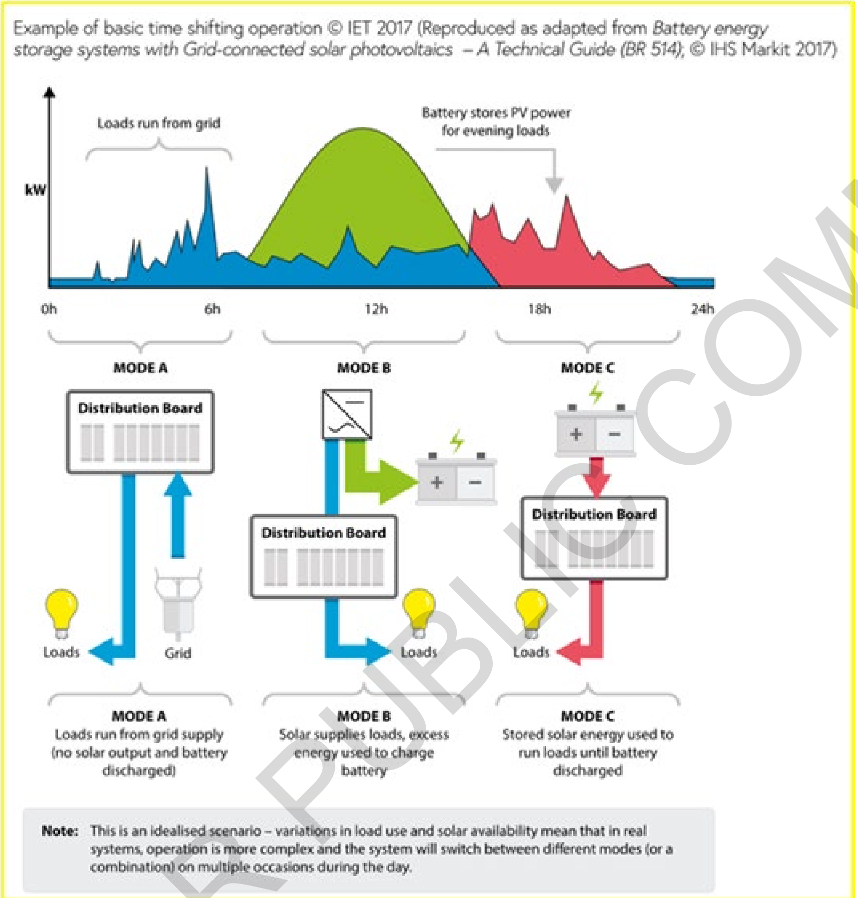

Figure 7.1 — Role of EESS (Source; Figure 4.1 of IET *Code of Practice for Electrical Energy Storage Systems*, 2nd Edition)

7.2 Electrical energy management system

7.2.1 EEMS objectives

An electrical energy management system (EEMS), as defined in BS 7671, is a form of building automation and control system (BACS).

BS EN 15232-1 provides guidance on how to use BACS to monitor and improve energy performance of buildings. The IET *Code of Practice for Building Automation and Control Systems* provides guidance on the design and operation of such systems and particularly on the integration of various components.

Directly relevant to PEI is the focus on:

a) energy use;

b) energy efficiency; and

c) energy consumption.

BS 7671 Regulation 825.1 sets out the agenda for a PEI EEMS, by stating that it shall:

"...monitor and control the operation of all power supplies, the load of the storage units and the

operation of loads.”

The primary objectives of a PEI EEMS are outlined as:

d) the control of the PEI connection to the smart grid;

e) local control and management of on-site electrical energy production;

f) local control and management of electrical energy consumption; and

g) communication and management of electrical energy procurement from the DSO.

7.2.2 EEMS architecture

BS 7671 Regulation 825.2 describes the architecture of an EEMS. A primary consideration is that an EEMS is not necessarily one central device that provides all control and communications for all other elements of the installation. Each element or component may well have its own controls but it is important that all elements can communicate and act together as one coherent EEMS. This may be straightforward to achieve in a new individual PEI with a common specification for EEMS architecture. For shared or collective systems, with multiple PEIs connected together, EEMS should be able to communicate with all installations.

To achieve this, BS 7671 Regulation 825.2 states that:

> *“... energy meters, performance measuring and monitoring devices (PMD) or other measuring equipment shall be installed in appropriate/required locations”.*

Energy management systems of any type or purpose should be designed to adhere to the main design priorities of BS 7671:

a) there should be no compromise to electrical safety with the introduction of an EEMS;

b) monitoring of the operational capacity of the electrical installation should be improved by an EEMS; and

c) likewise, energy efficiency of the electrical installation is a principal focus of an EEMS.

Resilience and recovery of the electrical installation during and after loss of mains grid connections should be assisted by the use of an EEMS, whilst maintaining a focus on safety and capacity.

7.2.3 EEMS control examples

The level of sophistication of the controls and measurement system will depend on the type of installation specified and the budget available. BS 7671 Regulation 825.1 suggests some examples of functions that might be expected from an EEMS. Table 7.1 provides some additional commentary on those examples.

Table 7.1 — EEMS control examples

Item	BS 7671 section 825.1 examples	Commentary
1	Power sources and loads management	At its simplest this will simply be status monitoring to check what supplies are simultaneously connected to the installation and what loads are operating. More advanced EEMS will monitor supply characteristics in real time, check synchronization requirements for grid parallel purposes and dynamically monitor load demands.
2	Multi-source connection management	Status monitoring of the grid and on-site supplies will be a necessary function, but an advanced EEMS will monitor the output of on-site generation and the real time capacity of energy storage. Exports to the grid may also be managed in accordance with supply agreements and on site capacity.
3	Propose load control (load shedding and load shifting)	Simpler systems may be able to monitor loads to allow informed decisions to be made by the user. Smart metering connections may assist with monitoring and provide information on dynamic tariff updates. Automatic controls and algorithms will determine the optimum time to operate particular loads including EVCP, heating, certain appliances and non-critical large electrical loads.
4	Bi-directional exchange of information with the DSO	Communication with the DSO is an essential part of a grid connected PEI. Two way flow of information to and from the EEMS is necessary. The DSO system should inform on capacity of the grids, real time tariffs including peak and off-peak rates, and periods when load shifting may be necessary. The PEI system should inform on capacity to act as a distributed generator back to the grid, energy used for billing purposes on a half-hourly basis, operating

Table 7.1 — EEMS control examples *(continued)*

Item	BS 7671 section 825.1 examples	Commentary
		parameters such as voltage, frequency and maximum demands.
5	Backup system management by means of electrical energy storage units and power sources	In situations where the grid is offline, or for PEIs permanently off grid, the EEMS is essential to manage the electrical sources still available and the loads connected to optimize efficient running of the installation.
6	Control the electrical energy flow from and to electrical energy storage units	The EESS is both a load and a supply source. The EEMS has an active role controlling when it: — charges from either the grid and the on-site generation facility; — discharges to support on site loads when the gird supply is off; and — discharges to export back to the grid.
7	Monitor the voltage quality	Ideally this will monitor more than just simple voltage parameters. With inverters connected and particular loads it will also be prudent to harmonics checked too, ensuring efficient operation and reducing unnecessary heat gain.
8	Provide an interface for the end user	A PEI is a considerable investment for the end user. A user interface needs to be carefully designed and through to ensure it is intuitive and an aid for the person operating it. Different users should be considered, including thecommissioning engineer, the maintenance engineer, the informed user and the casual user.

7.2.4 EEMS controls strategy

A PEI designed to the requirements of BS 7671 prioritises compliance with electrical safety and capacity of the various sources of supply.

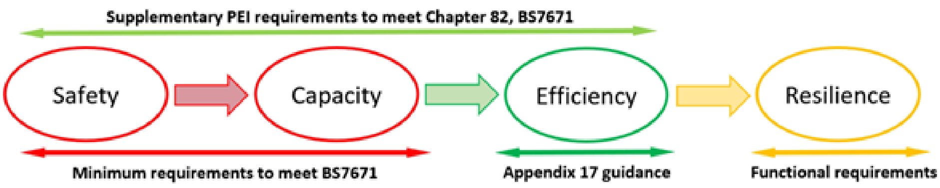

Figure 7.2 — BS 7671 headline design priorities and controls strategy

Efficiency in design and operation in accordance with BS HD 60364-8-1 is also to be considered. Installations in some sectors will also have resilience as a lower priority.

Controls interfaces for each of these design priorities should to be carefully considered as the design and installation develops. Figure 7 3 illustrates some of the key points and provides a framework for further design development of the controls needed for the EEMS depending on the sophistication and budget of the PEI.

Where the PEI is shared or collective then each installation may be considered individually first and then as a whole to provide an holistic solution to the wider scheme.

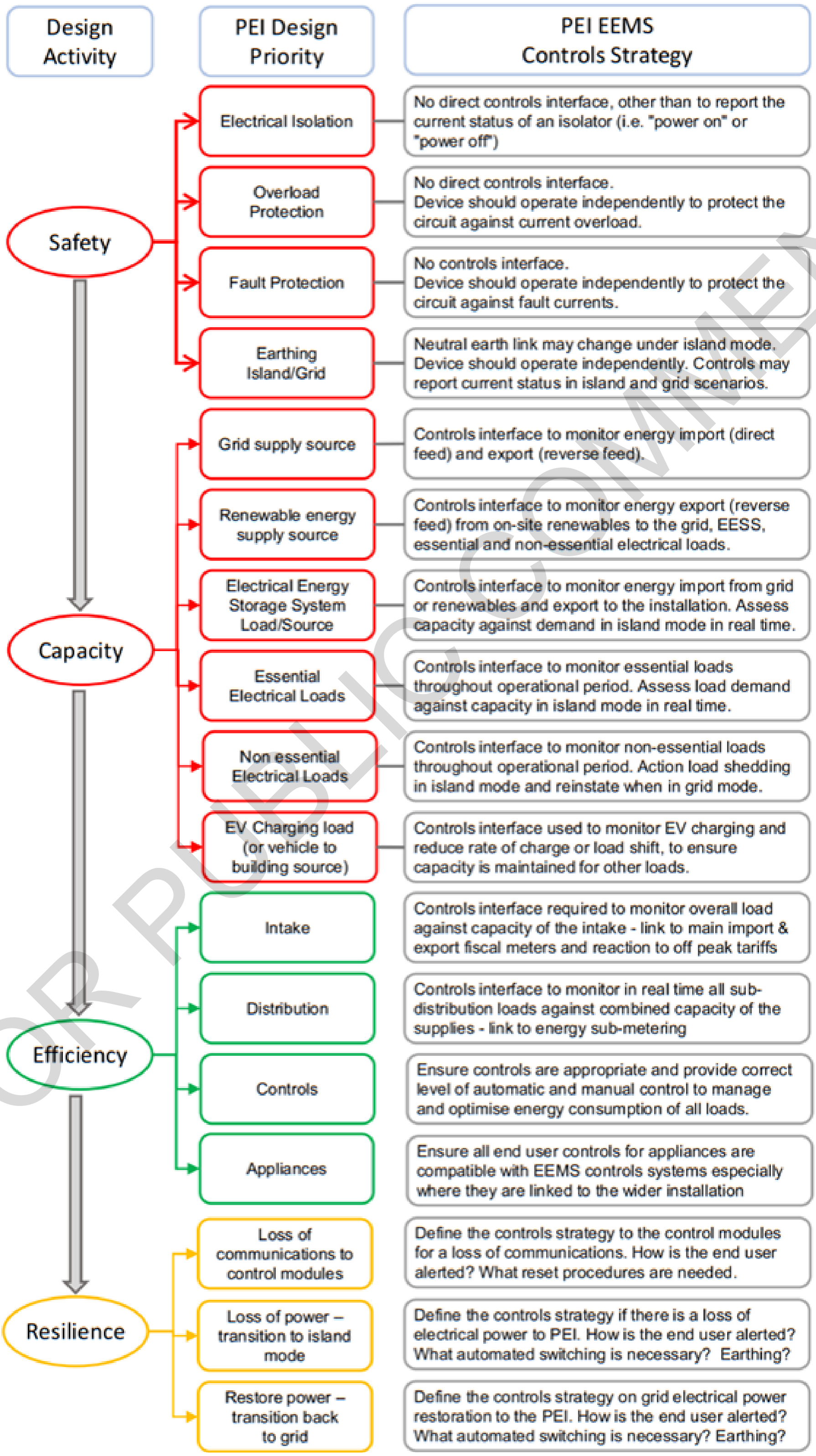

Figure 7.3 — PEI outline detail design priorities and controls strategy(Adapted from IET CoP EVCP Figure 12.10)

7.2.5 EEMS and PEI types

BS 7671 Annex D82 provides some example schematic diagrams of PEI architectures with a particular focus on the integration of EEMS in the installations. There is one for each of the individual, collective and shared types.

Figure 7 4 provides an insight into individual PEI types using an annotated version of BS 7671 Figure 82.1.

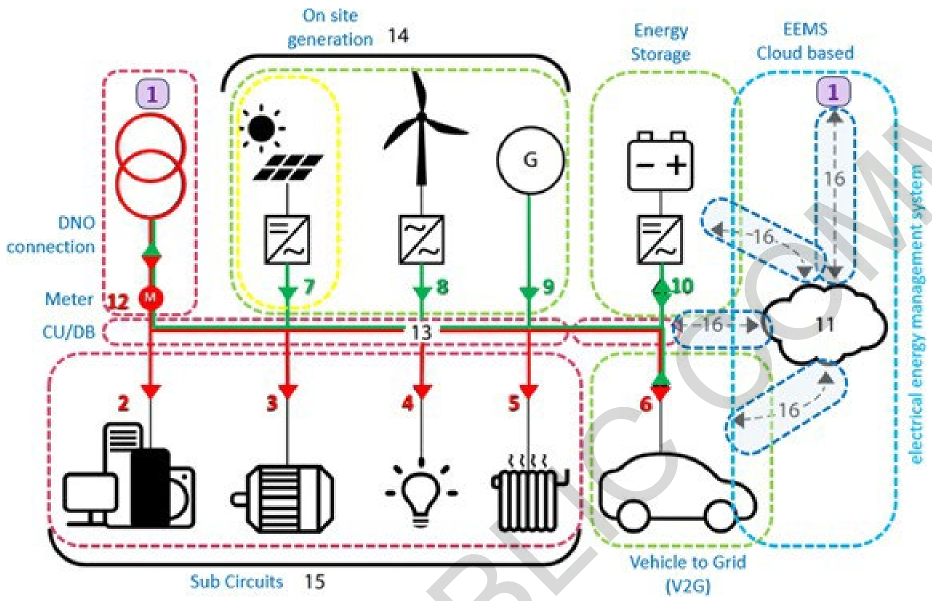

Figure 7.4 — PEI EEMS deployment – individual type (Adapted from BS 7671 Figure 82.1)

Figure 7 4 shows the electrical energy management system (EEMS) as an integral part of a PEI. The installation is actively managed through the EEMS and is responsive to demands both from within the installation and externally from the grid.

a) Item 16 shows EEMS signals to and from local generation, storage and individual loads via the on-site smart network. This could be one device with controls connections to all elements of the PEI or a series of devices, each controlling one discrete element, but networked and communicating together. The EEMS will also communicate directly with the grid to monitor intake, transition to island mode where required and to facilitate load planning in response to signals from the grid.

b) Item 1 shows the connection to and from public network via smart meters (item 12). The smart meter will need to be capable of recording and transmitting both import electrical energy consumption and exported electrical energy production.

c) The local distribution board, or consumer unit, is shown as item 13. This will include all appropriate protective devices and should make provision for double and single pole devices as necessary. Bi-directional protective devices will be required on some circuits.

d) The end circuits are grouped as Item 15 complete with home appliances and electronic devices (items 2, 3, 4 and 5). It is worth noting that some installation types will require sub-metering of load types to comply with regulations such as UK Approved Document Part L, for energy management purposes.

e) The on-site generation is grouped as Item 14 and could be comprised of solar, wind or local generation (items 7, 8 and 9).

f) Item 6, an EV, is typically another load, but with V2G technology could also become a source of energy for the installation.

g) Item 10, the EESS, is both a load and a source of supply.

For shared PEIs the communication network will extend to neighbouring PEIs with the interactions between them being determined by the designed control philosophy, e.g. exporting from one property to support loads in another.

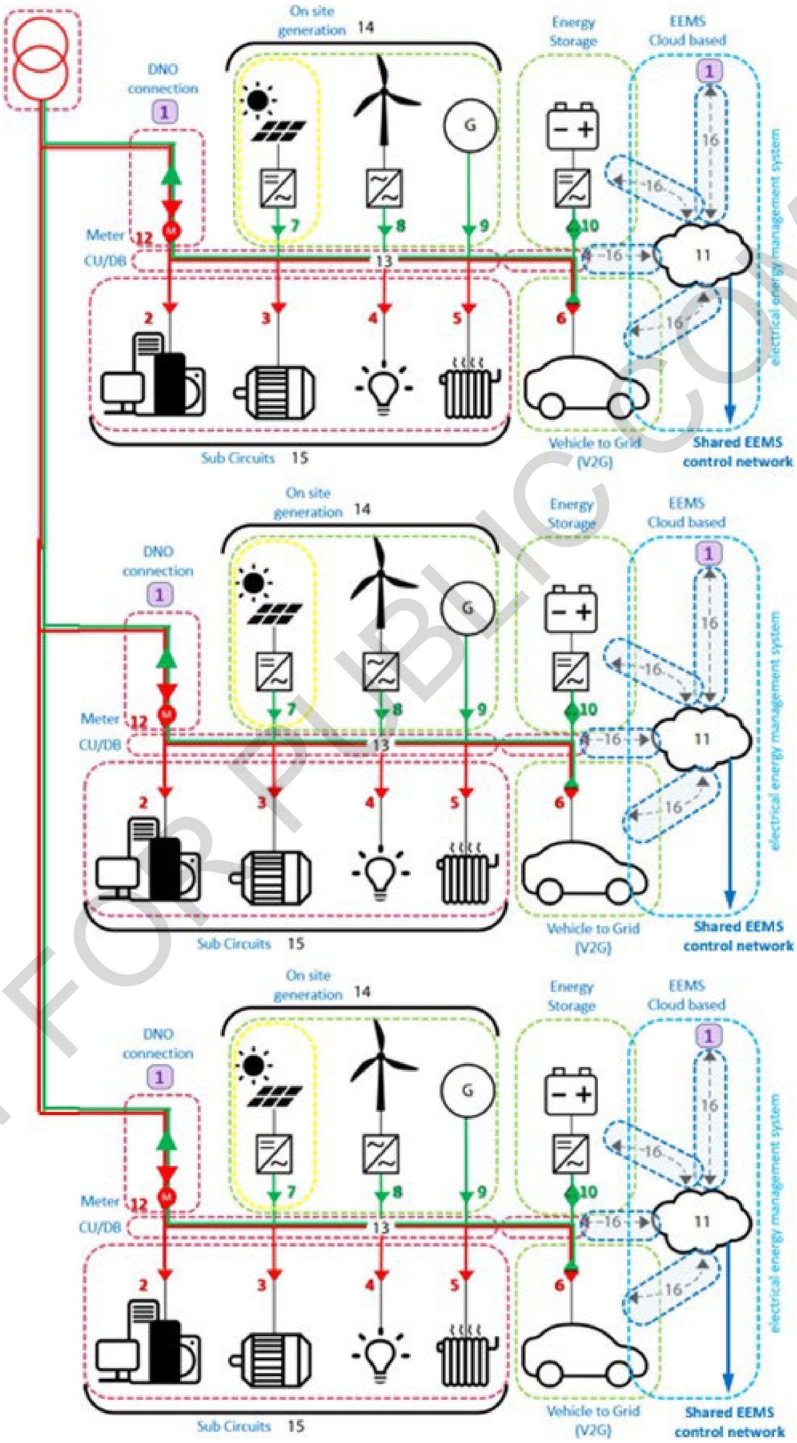

Figure 7.5 — PEI EEMS deployment – shared type

For collective PEIs the communication network will extend between the various properties and their combined EESS and renewable energy facilities.

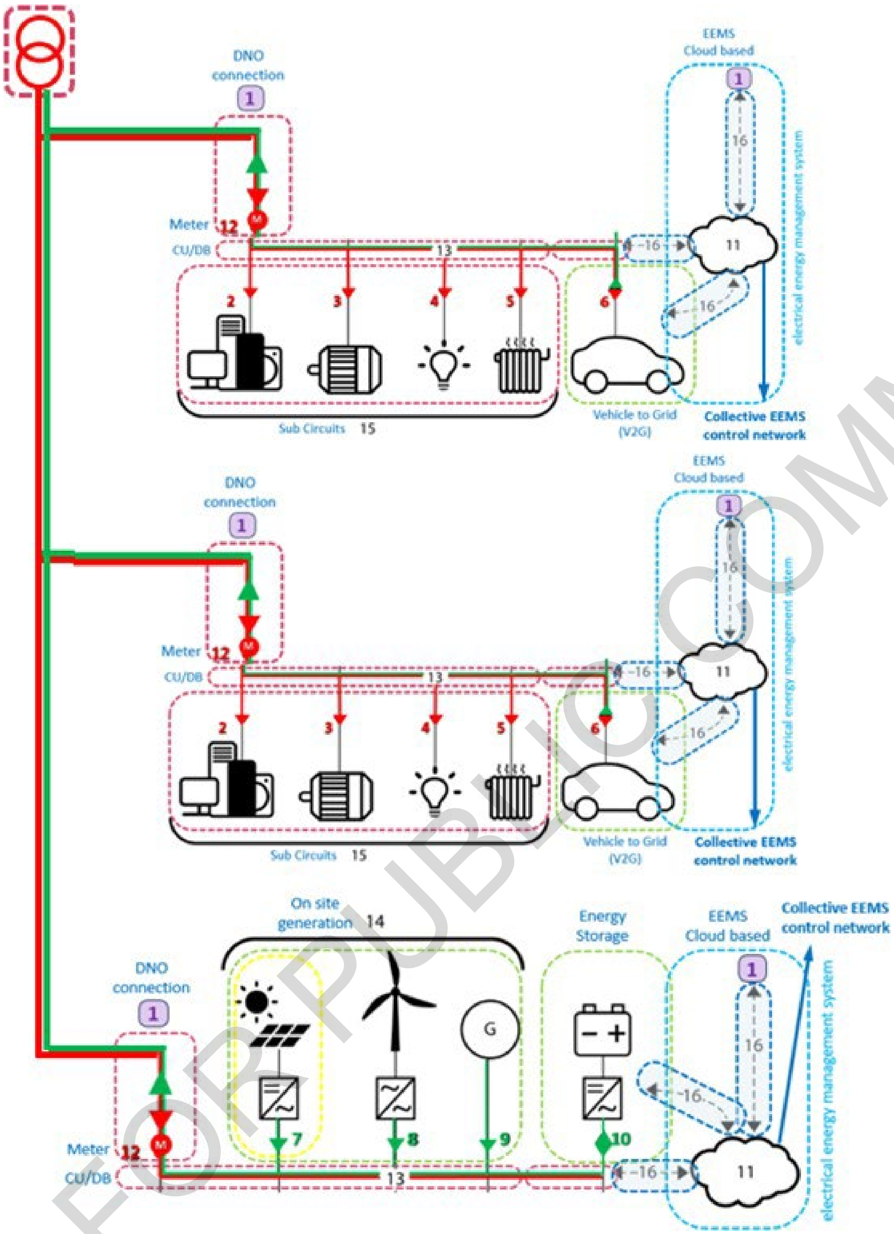

Figure 7.6 — PEI EEMS deployment – collective type

7.3 Active energy management

BS 7671 Annex A82 outlines the objectives and concepts of a PEI and states that:

> *"The end user should be able to permanently monitor and control their own electricity consumption and their own electricity production as a result of an active energy management system."*

There is a requirement to balance the availability of local energy generation and grid supplies with the needs of a dynamically changing load profile.

An operating condition of a PEI that is using an EEMS for active energy management will be continuous real time communication with the DSO for exchanging or receiving information. Examples may include receiving signals from the DSO:

a) when urgent electricity consumption reduction is needed to relieve pressure on grid capacity; and

b) when reverse feeds from energy storage may be required to locally augment supply capacity.

BS HD 60364-8-1 provides guidance on the design considerations, implementation and operational requirements of energy efficient electrical installations. As part of an energy efficient electrical installation, using an EEMS allows the user to:

c) monitor energy efficiency and consumption of connected loads;

d) monitor output of on-site generation and energy storage;

e) monitor availability of grid connections;

f) have a level of control when loads might operate to suit tariffs; and

g) override where more urgent needs arise.

A principal market for PEIs will be domestic orientated new builds and retro-fit installations. It is recommended that the principles of BS HD 60364-8-1 are used to guide and inform the design and installation of a PEI and its associated energy management following commissioning.

A schematic representation of the requirements of the integration of supply inputs, control inputs, load outputs and control feedback is provided in BS HD 60364-8-1. This has to be seen as a continuous process that provides a strong framework for the installation, commissioning and setting to work of the PEI. It should also provide a robust but intuitive interface that allows the end user to maximise their investment and optimise system efficiencies.

Figure 7 7 has been used in other IET publications on energy management and building automation and controls. In this guide, it illustrates the energy flow and control concepts for a PEI and shows the integration of a variety of energy sources and energy loads with various control mechanisms and outputs as part of a continuous improvement process of active energy management and energy efficiency.

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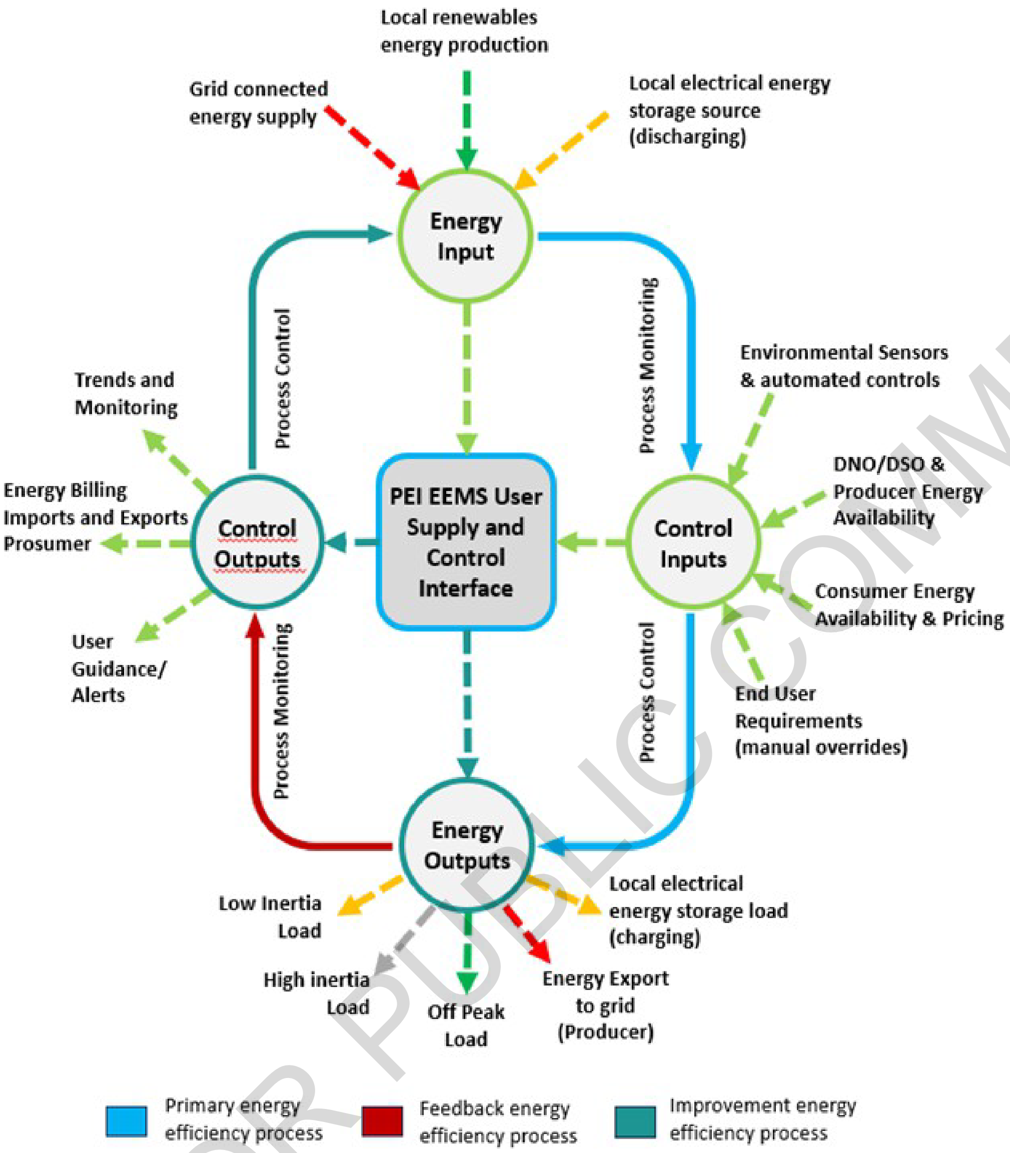

Figure 7.7 — Engineering design for energy efficiency (Adapted from original source: IET *Guide to Energy Management* Figure 2.1)

This model concept demonstrates energy and control processes that a PEI EEMS will need to drive and improve efficiency using active energy management and shows several aspects:

h) a continuous process loop around the outside;

i) a vertical energy path, top to bottom, from source to use; and

j) a horizontal control path, right to left, from inputs to outputs.

The process loop consists of three main components:

k) The primary energy efficiency process. This is a traditional linear process where use of energy flow is modified by user demands or simple controls like thermostats to provide energy at the point of use. Efficiency are simple and not always effective.

l) The feedback energy efficiency process. This part of the loop will provide insight into performance through monitoring outcomes, flagging up issues and highlight potential changes.

m) The improvement energy efficiency process. To complete the loop the process reverts to control mode to implement improvements, hence making better use of the energy sources available. The loop then repeats to ensure iterative changes, over time, provide better energy efficiency outcomes under a variety of scenarios, be that a PEI in direct feed, reverse feed or island mode.

The energy process from top to bottom shows:

n) various energy inputs with a direct feed from the grid with local support from on-site generation and energy storage; and

o) various energy outputs including various categories of on-site loads, energy export to the grid and energy charging to the on-site EESS.

Control input interfaces with the grid include:

p) real time information on tariffs and grid capacity;

q) a mechanism for the grid to initiate energy exports from energy storage;

r) automated environmental sensors for certain loads and services, for example electrified heat; and

s) facility for the end user to temporarily override automated timer controls, such as operating electrified heat on cold days.

Control outputs will include:

t) facilities to communicate energy consumption and production for billing and invoicing purposes;

u) connections to visual aids for ends users to inform them of energy usage; and

v) connections to monitoring devices and software tools to gain information on trends and patterns of energy use and generation.

IEC documents relating to electrical energy efficiency, such as BS HD 60364-8-1, describe the need to identify and manage low and high inertia loads. These are more commonly known in the UK as essential (low inertia) and non-essential loads (high inertia). Off-peak loads could be either high or low inertia in operation, but the key diffentiator is that they can be operated outside of peak periods when tariffs are typically cheaper.

An on-site electrical energy storage system (EESS) operates as both a source (when discharging) and as a load (when recharging).

7.4 Load shedding, load planning and load shifting

Maximum demand and diversity assessments ensure the overall capacity of the installation has been designed to the optimum level. These are typically informed estimates to ensure the installation is not overengineered and that appropriately rated protective devices and optimised cable infrastructure can be provided.

To ensure operational efficiency of the PEI throughout the day, it is important to understand and plan, where possible, what loads may be on and when. Depending on the complexity of the installation, this could mean an involved study of electrical load profiles for individual final circuits, their time of use and dynamic diversity, that creates a moving assessment of maximum demand throughout a 24-hour period.

Load shedding is defined in BS 7671 Part 2 Definitions as:

> *"Approach where the electrical loads are switched off for variable periods of time to optimize demand."*

A load shedding strategy is used during times of supply constraint. It is essentially a reactive approach and involves curtailed usage of some final circuits under certain operational conditions to avoid overloading of electrical installations.

This will be controlled and facilitated via the EEMS. BS 7671 Regulation C82.5 describes the activity as being initiated:

"In response to the public network needs through, for instance, communication facilities, the local PEI may shed some local loads."

The following sections, and Annex D in this guide, provide some guidance on how to assess an overall load for each final circuit, temper the findings with operational load diversity analysis and, from that, determine the likely maximum demand for the circuit. The figures are theoretical and are based on a fully electric installation including space heating and water heating.

Using a spreadsheet will allow cumulative loads to be assessed over a longer period and allow likely loads to be managed in a more predictable way.

7.4.1 Load planning and final circuit assessments

Load planning is an informed approach to anticipating which loads may run at a particular time and how long they may be in use for. It will not be possible to map all loads for a whole 24-hour cycle – many will be used spontaneously according to user needs – however, it should be feasible to analyse principal larger loads like electrical heat pumps for space heating and hot water, cooking appliances and use of final sockets.

Recharging EESS and EV loads may also be planned for specific limited periods. A proportion of other loads such as lighting and cooking may also be predictable up to a point.

Table 7.2 (cooker), Table 7.3 (heat pumps) and Table 7.4 (showers) show examples of final circuit analysis, where the initial load is noted and an informed assessment of likely operational demands set against the full circuit demand.

The circuit infrastructure should still be designed for the full load in accordance with BS 7671, but it is assumed that it will only operate with full demand on rare occasions. For cookers this may be when entertaining a number of visitors, for instance. Heat pumps will demand more power input in the winter months. Showers will be used only intermittently but at almost full demand.

The examples show a simplified one hour interval between load assessments that illustrates load utilisation throughout a 24 hour period. The actual intervals, and level of calculation detail, should be determined by the designer and could be set at half-hour intervals to match many contemporary metering technologies and tariffs.

For energy management purposes, especially on sites with constrained power supplies, the intervals could be reduced still further with energy management controls and interlocks implemented to prevent some loads operating at the same time. Using the same table allows energy consumption to be estimated too.

With all loads assessed it is possible to show the overall load for the site and use this information to inform the overall load efficiency and operational strategy. Refer to Section 7.4.2 and Annex D of this guide for further information.

Table 7.2 — Load planning example - cooker circuit

Ref	Description	Grid priority	Watts			
1	Cooker circuit	Medium	6,000			
Time	Load diversity	Load (W)	Maximum demand (kW)	Period (mins)	Energy (kWh)	Commentary
01:00	0.0	6,000	0.0	0	0.0	
02:00	0.0	6,000	0.0	0	0.0	
03:00	0.0	6,000	0.0	0	0.0	
04:00	0.0	6,000	0.0	0	0.0	
05:00	0.0	6,000	0.0	0	0.0	
06:00	0.0	6,000	0.0	0	0.0	
07:00	0.5	6,000	3.0	20	1.0	Breakfast - 2 x hob
08:00	0.0	6,000	0.0	0	0.0	
09:00	0.0	6,000	0.0	0	0.0	
10:00	0.0	6,000	0.0	0	0.0	
11:00	0.0	6,000	0.0	0	0.0	
13:00	0.3	6,000	1.8	25	0.8	Lunch - 1 x hob
14:00	0.0	6,000	0.0	0	0.0	
15:00	0.0	6,000	0.0	0	0.0	
16:00	0.0	6,000	0.0	0	0.0	
17:00	0.0	6,000	0.0	0	0.0	
18:00	0.0	6,000	0.0	0	0.0	
19:00	0.8	6,000	4.8	30	2.4	Dinner - oven and 2 x hob
20:00	0.5	6,000	3.0	20	1.0	Dinner - 2 x hob
21:00	0.0	6,000	0.0	0	0.0	
22:00	0.0	6,000	0.0	0	0.0	
23:00	0.0	6,000	0.0	0	0.0	
00:00	0.0	6,000	0.0	0	0.0	
Maximum demand (kWh)			4.8		5.2	Predicted energy (kWh)

The assumptions within Table 7.2 are that the cooker could be used for short periods with the actual load varying according to the type of meal being prepared.

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Table 7.3 — Load planning example - heat pump

Ref	Description	Grid priority	Watts			
1	Heat pump	Medium	5,000			
Time	Load diversity	Load (W)	Maximum demand (kW)	Period (mins)	Energy (kWh)	Commentary
01:00	0.0	5,000	0.0	0	0.0	
02:00	0.0	5,000	0.0	0	0.0	
03:00	0.0	5,000	0.0	0	0.0	
04:00	0.0	5,000	0.0	0	0.0	
05:00	0.0	5,000	0.0	0	0.0	
06:00	0.6	5,000	3.0	40	2.0	Space heating & water heating
07:00	0.6	5,000	3.0	40	2.0	Space heating & water heating
08:00	0.3	5,000	1.5	30	0.8	Space heating only
09:00	0.0	5,000	0.0	0	0.0	
10:00	0.0	5,000	0.0	0	0.0	
11:00	0.0	5,000	0.0	0	0.0	
13:00	0.0	5,000	0.0	25	0.8	
14:00	0.0	5,000	0.0	0	0.0	
15:00	0.0	5,000	0.0	0	0.0	
16:00	0.5	5,000	2.5	30	1.3	Space heating only
17:00	0.5	5,000	2.5	30	1.3	Space heating only
18:00	0.6	5,000	3	40	2.0	Space heating & water heating
19:00	0.6	5,000	3	40	2.0	Space heating & water heating
20:00	0.7	5,000	3.5	40	2.3	Space heating & water heating
21:00	0.7	5,000	3.5	40	2.3	Space heating & water heating
22:00	0.6	5,000	3	40	2.0	Space heating & water heating
23:00	0.5	5,000	2.5	30	1.3	Space heating only
00:00	0.0	5,000	0.0	0	0.0	

Table 7.3 — Load planning example - heat pump *(continued)*

Ref	Description	Grid priority	Watts			
Maximum demand (kWh)			3.5		19.2	Predicted energy (kWh)

The assumptions within Table 7.3 for heat pumps are simplified and could be more nuanced than illustrated here depending on the actual heat pump primary energy source.

The coefficient of performance (CoP) of heat pumps does vary depending on the temperature and weather conditions at the time. An air source heat pump (ASHP) will need greater power, and electrical energy consumption in the winter than the summer. That seasonal increased demand will also coincide with less energy harvesting from any on-site PV. A ground source heat pump may have a more consistent performance over time but there may be some variations.

Periodic seasonal reassessments and updates are recommended.

Table 7.4 — Load planning example - shower

Ref	Description	Grid priority	Watts			
7	Shower	Medium	6,000			
Time	Load diversity	Load (W)	Maximum demand (kW)	Period (mins)	Energy (kWh)	Commentary
01:00	0.0	6,000	0.0	0	0.0	
02:00	0.0	6,000	0.0	0	0.0	
03:00	0.0	6,000	0.0	0	0.0	
04:00	0.0	6,000	0.0	0	0.0	
05:00	0.0	6,000	0.0	0	0.0	
06:00	0.9	6,000	5.4	10	0.9	Morning shower for 10 minutes
07:00	0.6	6,000	0.0	0	0.0	
08:00	0.3	6,000	0.0	0	0.0	
09:00	0.0	6,000	0.0	0	0.0	
10:00	0.0	6,000	0.0	0	0.0	
11:00	0.0	6,000	0.0	0	0.0	
13:00	0.0	6,000	0.0	0	0.0	
14:00	0.0	6,000	0.0	0	0.0	
15:00	0.0	6,000	0.0	0	0.0	
16:00	0.5	6,000	0.0	0	0.0	
17:00	0.5	6,000	0.0	0	0.0	
18:00	0.6	6,000	0.0	0	0.0	
19:00	0.6	6,000	0.0	0	0.0	
20:00	0.7	6,000	0.0	0	0.0	
21:00	0.7	6,000	0.0	0	0.0	
22:00	0.6	6,000	0.0	0	0.0	
23:00	0.5	6,000	0.0	0	0.0	
00:00	0.0	6,000	0.0	0	0.0	

Maximum demand (kWh)	3.5		19.2	Predicted energy (kWh)

The assumptions on which Table 7.4 is based are fairly simple. The shower is assumed to run for a short period in the morning, but will represent a significant load. If a heat pump system with a satisfactory domestic hot water (DHW) heat store is installed then use of the shower may not be necessary at all.

7.4.2 Grid connected mode and load shifting

Load shifting is a proactive approach, as a response to load planning, to smooth out the peak demands of an installation and optimise costs. This strategy involves a load being set to a specific time to reduce peak loads and perhaps make use of cheaper tariffs.

An historical example of this is an installation with electrical storage heaters using a separate meter, separate electrical consumer unit and final circuits. Now, with dynamic energy monitoring through smart meters, and lower tariffs for off-peak use, load shifting is encouraged for normal grid connected installation supplies.

Developing the examples in Table 7.2, Table 7.3 and Table 7.4 across a complete PEI, a spreadsheet could be used to summate all potential loads at their respective time of use. With additional colour coding to highlight larger loads, it is possible to see where maximum demands could rise. In the example shown in Figure 7 8, taking action to shift the EVCP load to the early hours of the day will reduce the late evening load, and could be more cost effective by taking advantage of lower tariffs during that period.

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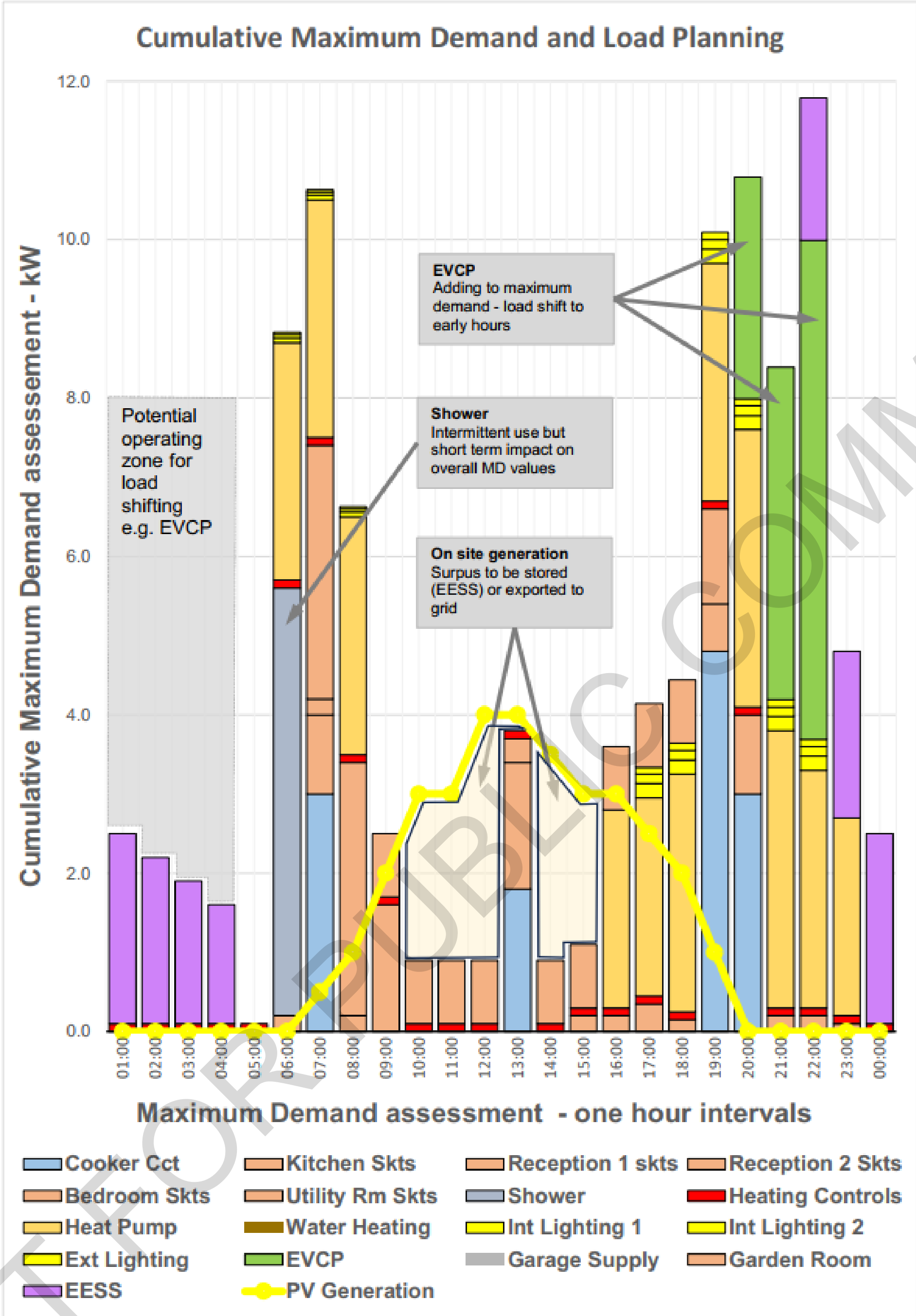

Figure 7.8 — Load planning and shifting in grid connected mode

This example focuses on all the loads and hence imports for a PEI as a cumulative bar chart. It includes the production of power from PV as an example of on-site generation that can be sent directly to the grid, using the EEMS configuration, or diverted to the local EESS for deferred use on the site during later periods.

7.4.3 Island mode and load shedding

For practical reasons, it is recommended that a parallel planning exercise is considered for PEIs operating in island mode. The planning for PEI should consider various scenarios, for instance:

a) whilst island mode is initiated, is the local generation still operating or not?

b) can the local generation directly support loads and/or recharge the EESS?

c) what likely capacity is the EESS at 25%, 50% 75%?

d) what essential or priority loads for island mode have been identified?

e) how long should these essential loads continue to operate for whilst still in island mode?

f) what load shedding should be implemented to maintain EESS supplies for as long as possible?

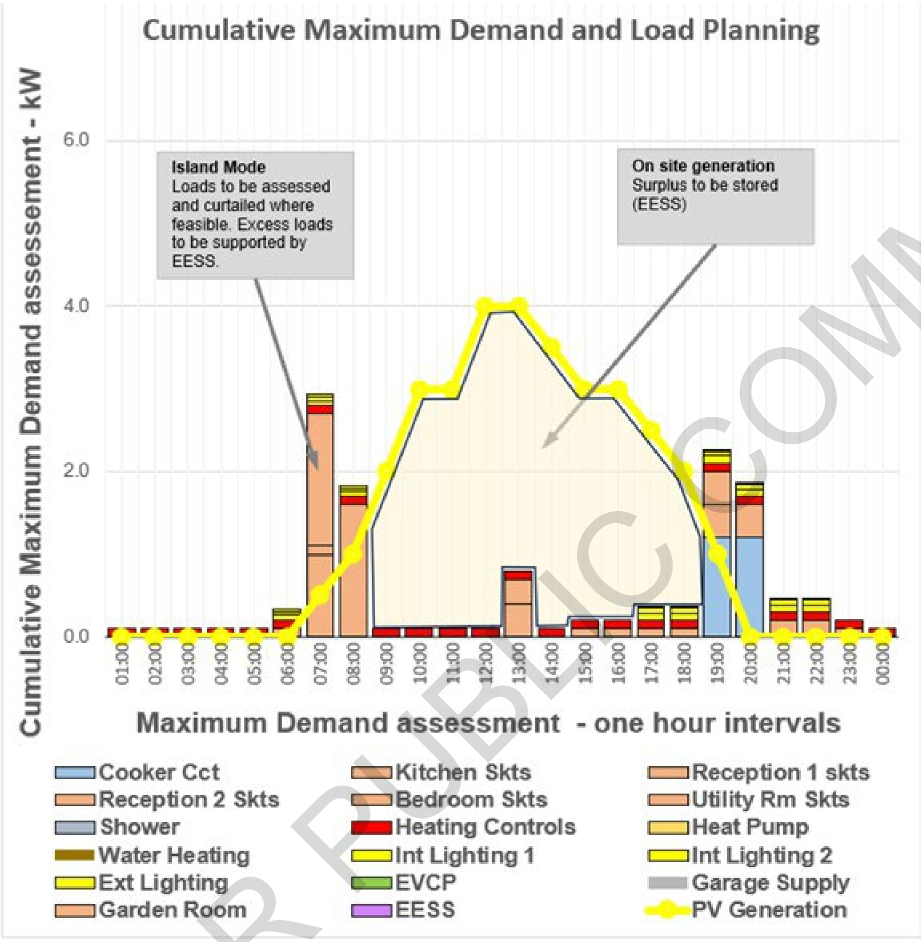

Figure 7.9 — Load planning and shedding in island mode

This example assumes that the installation is in island mode and drawing its electrical supply from the remaining capacity of the EESS and from the power output from local generation – PV in this case.

It is also assumed that the capacity of the EESS and PV does not match the grid connection. A load shedding exercise needs to be carried out to prevent an overload situation and ensure the EESS lasts for as long as possible.

Using the priorities already determined in Section 5.1.2 and Table 5.2 and Table 5.3, the load diversities can be reassessed and maximum demand in island mode recalculated. This is represented in the

cumulative bar chart, which also portrays the production of power from on-site generation (PV in this example). By optimising the load during the day, any surplus power can be diverted to the local EESS, for deferred use on the site during later periods

7.5 Micro-grid installations

Micro-grids are a collection of electrical supply points, electrical installations, electrical energy storage and on-site generation (both fossil fuel and low carbon alternatives). The types of PEI described in Section Clause 6 are all forms of micro-grid.

A more familiar micro-grid may be a larger installation with a number of buildings spread over a campus, for example a hospital. It may have an extensive electrical distribution system, on-site generation changeover panels and battery backup for critical areas. Such installations are designed and operated to consume power from the grid, sometimes with an HV point of connection. They are also capable of operating for extensive periods under their own power supporting a significant proportion of the load. Large data centres are another example.

In these examples the standby generation is often provided by diesel generators and any battery systems are designated uninterruptible power supplies (UPS) for emergency purposes. The principal strategy for these types of installations is based on risk mitigation and the need to continue operating for as long as possible without interruptions.

Control systems are a key part of any micro-grid and predetermined strategies should determine how distribution equipment operates and where loads are deriving their electrical power from. For hospitals, that means maintaining supplies to equipment which supports critically ill patients or allows medical staff to carry out critical procedures. In data centres, where downtime costs money, it is about maintaining business continuity.

As a micro-grid, a PEI will have a completely different controls strategy and load priorities. The emphasis is on decarbonisation, energy efficiency and reducing costs through cheaper tariffs.

Any on-site low carbon generation in a typical domestic dwelling or small business is unlikely to have sufficient capacity to support the whole installation. The intermittent nature of power production means it may not be available when needed.

A battery-based EESS in a PEI is not necessarily there for emergency purposes. It is there to harvest and store power produced by the on-site generation, or to store electricity from overnight grid based generation at a cheaper tariff.

A PEI has all the necessary hardware of a micro-grid but its operating strategy is very different.

8 Conformity and interaction with the grid

BS 7671 Annex C82, 'Interaction with the Public Network', outlines some informative considerations about PEIs with respect to connections to the grid.

The electrical grid has developed over many decades, but always with the design philosophy of electrical loads instantly consuming power through metered connections. Energy flow has been one way, towards to the installation from the generation source. PEIs change that paradigm and are a form of embedded generation. As well as being a potentially disruptive business model, which is outside the scope of this guide, there are technical considerations.

The Electricity Safety, Quality and Continuity Regulations 2002 and the Electricity Safety, Quality and Continuity Regulations (Northern Ireland) 2012 (collectively termed ESQCR) define parameters for voltage and frequency:

a) voltage is permitted to vary by not more than 10% above and 6% below; and

b) frequency is permitted to vary by ± 1%.

Regulations 21 and 22 of ESQCR 2002, and Regulations 22 and 23 of ESQCR(NI) contain particular provisions for consumers' electrical installations that have generators operating in parallel with the grid, or as a switched alternative.

When energy flow is in one direction this is easier to control. The advent of local generation and export from PEIs could provide risks to the grid without careful controls and management.

The connection of just one PEI to the grid amongst many more conventional electrical installations is unlikely to have a significant effect on the performance of the overall network. However, many such installations in relatively close proximity, all exporting to a common grid connection point, could cause stability issues. Examples may include:

c) multiple buildings on an urban industrial estate with roof PV and EESS and all with grid connections derived from a common transformer; and

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d) A new housing estate with dozens of dwellings each having an individual PEI operating independently from its neighbours.

A website reference for the Distribution Code of Licensed Distribution Network Operators of Great Britain (DCode), www.dcode.org.uk, is provided in Annex C of this guide. The information and documents on the website, which is is operated on behalf of the licensed distribution network operators, provide the background requirements to these topics and many other requirements for electrical distribution and installations.

DCode provides a series of Distribution and Connection Codes (DPCs) which set out design principles and standards. Of interest to the scope of this guide are:

e) DPC4.2, which covers the obligations of the DNOs in terms of supply characteristics, including security of supply, voltage and frequency limits, voltage disturbance and harmonic distortion;

f) DPC4.3, which covers the requirements of customers with electrical installations of up to 100 A. An installation that complies with BS 7671 will comply with DCode; and

g) DPC7, which outlines the information and data that embedded generation installations need to provide to DNOs to assess the impact of PEIs on the wider network.

Installations with embedded generation, for example PEIs, are also referenced in DCode and are designated as Distributed Generation (DG) or Customers with Own Generation (CWOG).

8.1 PEI connection and stability of the grid

BS 7671 Regulation 826.2 states that:

> *"The PEI shall comply with all the supply requirements (e.g. voltage, frequency)."*

BS 7671 Regulation 551.7.3 is more direct and requires that any form of generation, that is designed to run in parallel with the mains grid connection, should avoid adverse effects to the grid and to other installations. Parameters include power factor, voltage changes, harmonic distortion, unbalance, starting, synchronizing or voltage fluctuation effects.

Distribution Code DPC7 advocates detection of:

a) over voltage;

b) under voltage;

c) over frequency;

d) under frequency; and

e) loss of mains.

If a PEI is deemed to be a source of danger, or to compromise the safety or quality of supply to other consumers, ESQCR Regulation 26 allows the DNO to disconnect the PEI to prevent that danger.

8.1.1 ENA Engineering Recommendation (EREC) Documents

Reference should be made to ENA Engineering Recommendation (EREC) Documents G98, G99 and G100, which are useful publications providing more detail on different connections to installations with combined import and parallel export capabilities.

Depending on their respective export capacities or infrastructure configuration, grid connected PEIs should be compliant with the recommendations of either G98 or G99 and the installation will require a relevant and compliant application to the appropriate DNO/DSO.

The EREC documents are available on the Energy Networks Association website (www.energynetworks.org/publication) using the initial search term EREC then G98, G99 or G100 as appropriate. Forms are also available from the website that can be used to compile evidence demonstrating the compliance of a PEI.

The requirements for various different PEIs will depend on the scale of on-site generation and type of connection to the grid. These range from simple single phase, low voltage systems to larger scale systems connected directly to the high voltage network.

Many small scale individual PEIs will fall within the remit of G98 (micro-generators up to and including 16 A per phase), but it is important to review the capacity of any on-site generation as G99 requirements may often apply.

Any installations that are collective or shared PEIs would be deemed multiple installations and will fall within the scope of G99.

Where G99 applies, especially within the domestic housing market and small commercial enterprises, the Type A definition set out in G99 is for a generation capacity of greater than 0.8 kW but less than 1 MW.

The Type B, C and D definitions described in G99 are for significantly larger installations and are outside the remit of this guide. Figure 2.1 of G99 sets out which sections apply to Type A, including 1-10, 14-15 and Annex D generally, and 11, 16 and Annex A specifically.

It should be noted that Section 4.11 of G100 states that the principles and requirements of G100 "apply in full to domestic installations".

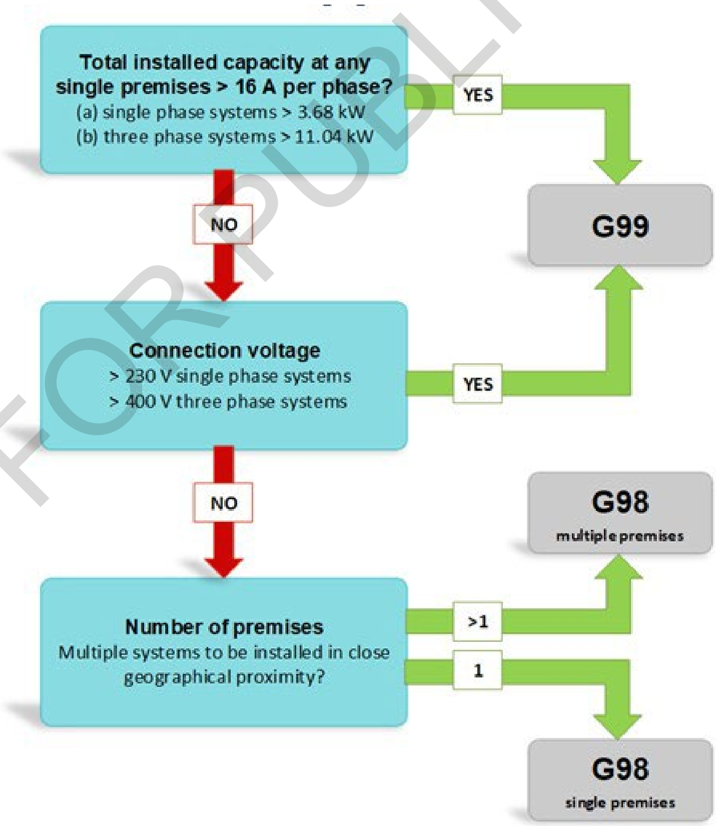

Figure 8.1 — G98, G99 Application pathways - ***Source EESS presentation at S&S NEC Oct 2024***

8.1.2 ENA EREC G100 and customer import and/or export limitations

ENA EREC G100 was issued in May 2023 and describes:

a) the requirements of Customer Limitation Schemes (CLSs); and

b) the operational performance and constraints of PEIs with regard to Maximum Import Limits (MILs) and Maximum Export Limits (MELs).

The purpose of a CLS is to ensure that an electrical installation, e.g. a PEI, does not impose import ot export current flows on the distribution network that exceed the agreed MEL or MIL. An installation should still be able to import and export with a degree of flexibility, but the connection agreement will provide parameters within which it must operate.

Figure 8.2 — Operational state concept from ENA G100

The components of a CLS are shown schematically in Figure 4.1 of G100. They are, in essence, the PEI EEMS as described in Section [Clause 7](#) of this guide.

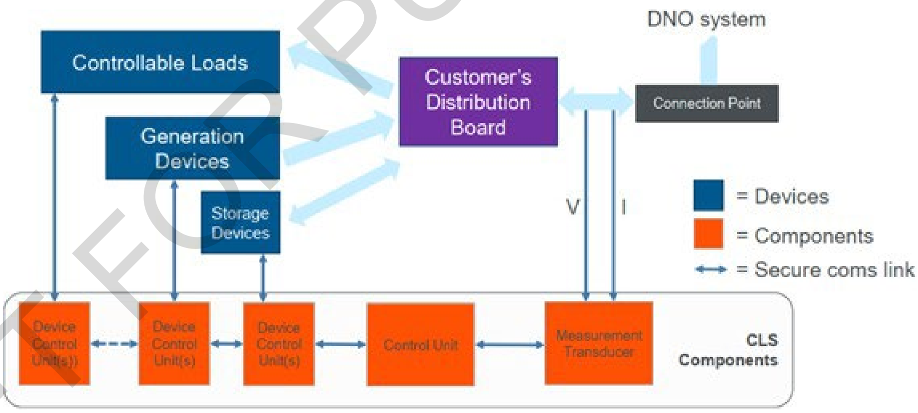

Figure 8.3 — CLS concept from ENA G100 ***Source G100 Figure 4.1***

Section 4.3 of G100 defines four principal operating CLS operating states, as described here in [Table 8.1](#).

Table 8.1 — Operating states of CLS from ENA Document G100

CLS State	CLS Title	CLS Purpose
1	Normal operation	The installation will be operating as designed and changing as necessary between export and import using the CLS to stay within the defined limits of the MEL and MIL. The voltage and frequency at the intake will remain within statutory limit. External communication systems, via the EEMS, may instigate operating patterns in response to market or other signals. CLS control always takes precedence to ensure the installation stays within limits.
2	Occasional excursion	The preferred steady operation of State 1 may be compromised for various reasons including a sudden change of installation load. Examples include the starting profile of large loads or the failure of other loads or on-site generation. External distribution networks may be able to tolerate short term changes, or excursions, as an intermittent or occasional, measure. These should not last more than 15 seconds nor be regular occurrences. Longer term impacts on the installation, although rare, are not considered as normal operation. The CLS must be able ensure that the installation is brought back within limits of the MEL or MIL in a proscribed time period.
3	Failed state	This state assumes that if the CLS fails the installation will not exceed the MEL or MIL, either by switching off some or all parts completely or by continuing to operate at a much lower level. Some automatic load shedding may be needed to facilitate this.

Table 8.1 — Operating states of CLS from ENA Document G100 *(continued)*

CLS State	CLS Title	CLS Purpose
		Under some scenarios, generation may also need to be curtailed. G100 sets out responses to scenarios such as excessive import and excessive export. It is a requirement that the installation shall respond to a failure of the CLS by switching designated parts of the installation to State 3 (Failed State) within 15 seconds.
4	Operation without CLS	State 4 considers scenarios where the CLS is not in service for considerable time, for maintenance purposes or other operational reasons, Like State 3, the installation will need to be assessed for high and low priority loads. An installation without a CLS may only continue to operate with prior agreement of the DNO. An understanding of how the installation will operate without a CLS will be required, especially with larger loads and their operating profile. Like State 3 lower limits will be necessary.

Section 4.5 of G100 describes the expectations of the CLS under failure conditions. It is important that a CLS, or EEMS of a PEI, fails to safety.

Section 4.5.3 of G100 states that the:

> *"design and settings of protection shall be agreed with the DNO and recorded in the Connection Agreement".*

8.2 Requirements of BS 7671 and Annex C82

BS 7671 Regulation 551.7.3 highlights a preference for automatic synchronizing systems that consider frequency, phase sequence and voltage for the export of electrical energy from the PEI to the grid.

Annex C82 states that:

> *"PEIs should be designed in such a way that their dynamical influence on the stability of public networks is reduced or, even better, that they improve the dynamic stability of these public networks."*

To reinforce this, Annex C82 addresses the compatibility of the PEI with the grid connection and the requirements to ensure its compliance with:

a) the monitoring and control of active and reactive power;

b) the regulation and control of voltage;

c) the monitoring and control of frequency; and

d) load shedding strategy.

8.2.1 Monitoring and control of active and reactive power

Electrical energy efficiency at the installation's connection point is a direct outcome of the ratio of the active power (P, kW) and reactive power (Q, kVAr). The monitoring and control of reactive power is an issue for the efficiency of all electrical installations. Power factor correction is a common feature in older large installations.

The use of inverters in a PEI for conversion of DC generation and storage to AC for export and consumption potentially raises more concerns. Annex C82.2 states that inverters might be used to:

> *"adjust the magnitude and the phase angle of the output voltage allowing the control of the active and reactive power consumed by or injected to the public network."*

Annex C82.2 of BS 7671 refers to the Distribution Code for further requirements on active and reactive power. EREC documents G98 and G99 provide additional content.

Sections 9.3 and 9.4 of G98 describe the requirements to modulate active power outputs when the grid frequency alters above or below 50.0 Hz. The document also describes strategies that may be used where installations incorporate EESS.

EREC G99 provides details on the requirements to control active and reactive power for various power generation module types. Section 11.1.6 of G99 describes the need for Type A installations to discuss operating parameters, control protocols and communication interfaces with the DNOs, and noting the agreed requirements in the connection agreement.

8.2.2 Regulation and control of voltage

Regulation and control of operating voltage within PEIs is fundamentally important. Within low voltage installations in the UK that will be based on single phase 230 V or three phase 400 V.

A critical function of an EEMS should be to constantly monitor voltages, and Section 4.8 of EREC G100 suggests that customers should provide their own monitoring using a signal derived from the point of connection.

One purpose of this monitoring, and integration with the EEMS, would be to automatically assess the voltage value at the point of connection and provide corrective action to the operational performance of the PEI to reduce the risk of a State 3 (Fail Safe) condition arising. This proactive approach should be discussed with the DNO.

Another approach could be to ensure that the installation stays with the parameters of State 2 (Occasional Excursion) as outlined previously in this guide.

The performance of a PEI should not adversely affect neighbouring installation and the wider network. Likewise, it is the DNOs' responsibility to maintain the performance of the wider network so that it does not affect PEIs.

BS 7671 Annex C82.3, 'Voltage Control', adds to the simple requirements of Regulation 826.2 and states that:

> *"Correct voltage regulation avoids circulation of reactive current between power supplies.*
>
> *In some architectures, electrical power sources of several prosumers may not be far from each other. Line inductance between each source is not high enough to limit currents circulating between prosumers' sources."*

EREC G98 provides a definition of close geographic region where a micro-generator (as part of a PEI) is placed within 500 metres of another. An example of this might be in developments with adjacent terraced townhouses all with individual PEI connections.

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8.2.3 Monitoring and control of frequency

Like voltage, the regulation and control of frequency within PEIs is fundamentally important. Within low voltage installations in the UK that will be based on a nominal frequency of 50 Hz.

The principal electrical safety cases for frequency control are highlighted in BS 7671 Annex C82.4:

a) operating in island mode following loss of main power supply; and

b) when several local power supplies operate in parallel.

As outlined in Section 4.2.3 of this guide the transition from grid connection to island mode and back again should be set up as a 'break before make' sequence of operations. Frequency control is important to ensure that when the PEI operates in island mode it is at the nominal frequency of 50 Hz.

A PEI may have more than one form of generation. A simple arrangement will be PV and EESS, more complicated arrangements may include a wind turbine or a vehicle to grid connection. It is important that frequency control is applied to all outputs to ensure they are synchronised with each other and with the grid.

Increasingly, housing developments will provide dwellings with individual PEIs. The close proximity of these installations, all operating independently, creates various electrical risks. Frequency control will be one, and it is important that all PEIs work within the frequency range dictated by the Distribution Code.

Section 9 of EREC G98 discusses various technical requirements including frequency control. It states that whilst a micro-generator, or PEI, remains connected to the grid it should operate within a specified frequency range and for various time periods. This is dependent on the rate of change of frequency. Where this rate of change is exceeded the installation may need to disconnect.

Table 8.2, taken from G98, shows the minimum time periods for which a micro-generator, or PEI, should be able to continue operating without disconnecting from the grid.

Table 8.2 — Grid connected operating frequency range from G98

Lower Limit (Hz)	Upper Limit (Hz)	Permissible time period
47.0	47.5	20 seconds
47.5	48.5	90 minutes
48.5	49.0	90 minutes
49.0	51.0	Unlimited
51.0	51.5	90 minutes
51.5	52	15 minutes

Section 11.2 of EREC G99 also discusses the technical requirements of frequency control and lists identical requirements for continuing to operate under fluctuating grid frequency. It has the same time limits.

8.2.4 Load shedding strategy

Section 7.4 of this guide discusses some practicalities of load shedding. Within BS 7671.Annex C82.5, load shedding is highlighted as a:

"response to the public network needs ...".

Section 822.1 notes that one of the objectives of a PEI's interaction with the smart grid is the:

"consideration of the prosumer's needs, taking into account the constraint of the public network".

Section 822.1 also highlights the:

"design and configuration of the installation to allow load shedding (according to BS IEC 60364-8-1) ...".

The requirement for load shedding, under particular circumstances, will be agreed within the supply contract between the DSO and the prosumer.

BS 7671 Appendix 17.9 is an informative section on loads in energy efficient electrical installations. It recommends that loads:

"should be classed regarding their users acceptance of load shedding."

The actual signal to initiate load shedding activities will come from the DSO to the PEI via the communications hub and the EEMS. The communication signal may include requests for the PEI to:

a) shed loads – this may be automatic and comply with a previously defined priority list;

b) increase site generation and exports to the grid where this is feasible either through additional generating plant or by discharging energy storage facilities; or

c) switch to island mode, taking the whole installation off grid for a period of time – this may require some level of load shedding to prevent overload on site generation and energy storage.

Design strategies may include:

d) separate controls for individual loads and so called 'energy smart appliances', especially larger loads (refer to PAS 1878 BSI Standard for Energy Smart Appliances. System Functionality and Architecture, and PAS 1879 BSI Code of Practice for Energy Smart Appliances); and

e) split consumer units, or distribution boards, with low priority loads that can be load shed, all switching off at once. Higher priority loads remain energised.

8.2.5 Local and off-site monitoring

From an electrical installation energy efficiency perspective, BS 7671 Appendix 17.8 advises on the requirements of inputs from loads, sensors and forecasts:

"Provision must be made to allow the measurement and recording of energy consumption throughout the major parts of the installation, to provide for the management of that consumption."

In the UK Building Regulations, for new buildings, Section 5.17 of Approved Document Part L2 for non-domestic buildings calls for at least 90% of annual energy consumption to be assigned to an end-use such as heating, lighting and cooling. There are various strategies for doing that and guidance is available in CIBSE publication TM39: Building Energy Metering.

For commercial installations, distribution boards can be configured as split boards with independent sub-metering. This can then monitor general small power and lighting separately.

For domestic installations, there is no specific requirement for sub-metering within the equivalent Approved Document Part L1. It should be noted that for a PEI to operate at its optimum, sub-metering of some of the final circuits such as lighting, space heating and water heating is clearly advantageous. For energy storage and on-site generation it will be necessary to monitor energy exports to the grid.

Appendix 17.8 of this guide describes various scenarios for metering.

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Table 8.3 — Energy efficient metering strategy concepts

Item	Where	Purpose
	Origin of supply	This will be a fiscal meter and will require a high level of accuracy for billing and invoicing. The recorded values may also be used to monitor the performance and efficiency of the whole installation.
	At sub distribution board level	The use of the space should be assessed for billing and/or energy management requirements. For areas of the building that have separate tenancy, billing may also be required so metering will need to be rated to the EU Measuring Units Directive (MID) or similar. For energy management purposes the meter specification will need clarifying to ensure all necessary electrical characteristics are recorded.
	At final circuit level	Monitoring at final circuit level will provide a detailed level of information for energy management purposes. Some manufacturers provide add on components that attach to protective devices to facilitate energy monitoring at this level.

BS7671 Appendix 17.8 also advises that:

> *"Measurement is a key parameter to determine the efficiency of the installation giving the user an awareness of energy consumption. Consequently, device accuracy and measuring range must be adapted to the intended use, as close as possible to the loads."*

Using the data from from various levels of metering and sub-metering will allow end users to successfully monitor their own energy use and apply strategies to optimise their consumption.

By connecting the EEMS to appropriate hardware and app-based software various monitoring devices can be deployed, as illustrated in Figure 8 4. These local and remote user interfaces can include:

a) in-house displays (IHDs);

b) mobile phone apps; and

c) cloud based apps.

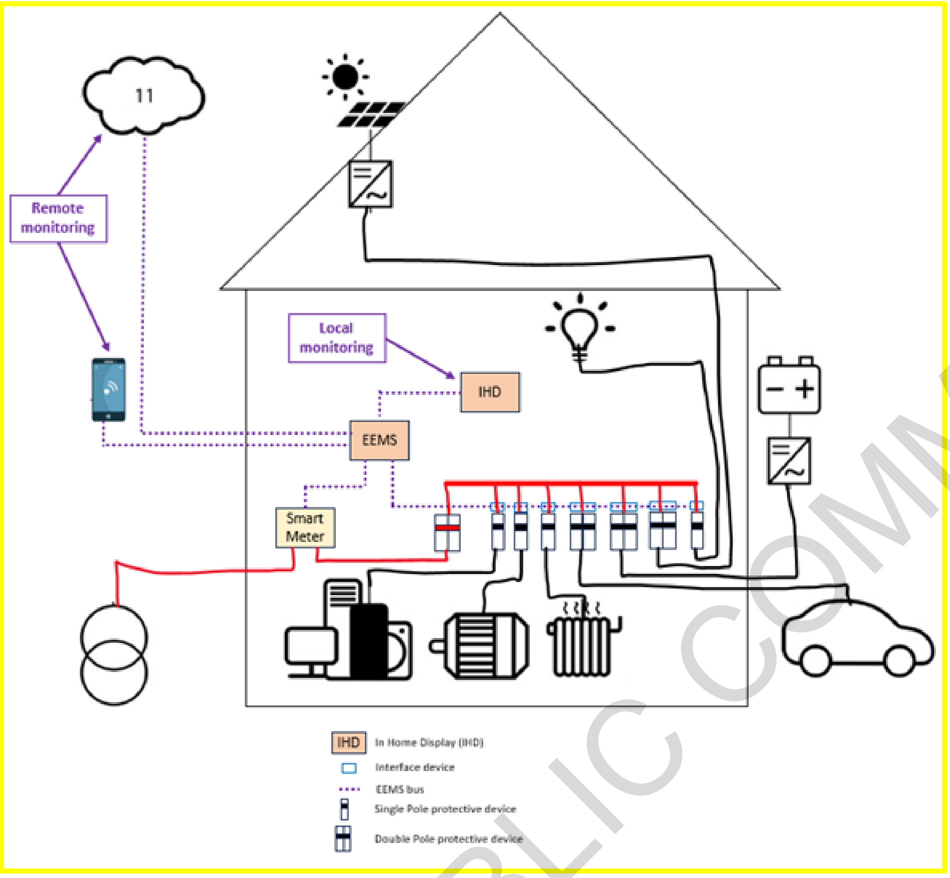

Figure 8.4 — Local and remote monitoring in domestic PEI *(Placeholder)*

8.3 Distribution network operators (DNOs)

On the subject of additions and alterations to an installation, BS 7671 Regulation 132.16 states that:

> *"No addition or alteration, temporary or permanent, shall be made to an existing installation, unless it has been ascertained that the rating and the condition of any existing equipment, including that of the distributor, will be adequate for the altered circumstances.*
>
> *Furthermore, the earthing and bonding arrangements, if necessary for the protective measure applied for the safety of the addition or alteration, shall be adequate."*

For both new and existing installations, a UK government webpage "How to register energy devices in homes or small businesses" provides some guidance to device owners and installation contractors on the correct procedures for connecting low carbon technology energy devices to electrical installations. The website states that notification to the relevant distribution network operator (DNO) is required if one of the following energy devices is connected:

a) solar photovoltaic (PV);

b) heat pump;

c) electric vehicle (EV) charge point; or

d) battery storage.

The process highlights that:

e) the installer should be appropriately registered to undertake such installations. This may mean registration with industry bodies and could also mean accreditation with specific manufacturers for warranty purposes;

f) it is necessary to determine whether to notify the DNO before or after installation;

g) when installing the energy device it is advisable to check whether any relevant energy efficiency schemes requires application beforehand;

h) the requirement to ensure the installation is notified with the appropriate bodies;

i) the installer should provide the Customer the relevant documentation; and

j) complete any application to the relevant energy efficiency schemes.

Distribution Code DPC 5.2.1 states that:

> *"Users, shall contact the DNO in advance if it is proposed to make any significant change to the connection, electric lines or electrical Equipment, install or operate any generating equipment or do anything else that could affect the DNO's Distribution System or require alterations to the connection."*

8.3.1 DNO/IDNO identities

It is possible to identify which DNO to engage with by examining the Meter Point Administration Number (MPAN) of the installation.

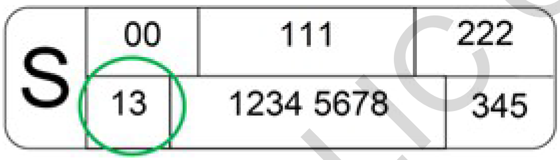

Figure 8.5 — MPAN illustration

The digits highlighted in Figure 8 5 refer to Table 8.4 and Table 8.5 for geographic DNOs and non-geographic independent distribution network operators (IDNOs).

Table 8.4 — Geographic DNO reference numbers

Area ID	Service Area	Distribution Business
10	Eastern England	UK Power Networks (UKPN) Eastern England (EPN)
11	East Midlands	Western Power Distribution (WPD) East Midlands
12	London	UK Power Networks (UKPN) London Power Networks (LPN)
13	Cheshire, Merseyside and North Wales	SP Energy Networks Cheshire, Merseyside and North Wales
14	West Midlands	Western Power Distribution (WPD) West Midlands
15	North Eastern England	Northern Powergrid (NPG)
16	North Western England	Electricity North West (ENW)
17	Northern Scotland	SSE Power Distribution Scottish Hydro Electric Power Distribution
18	Southern Scotland	SP Energy Networks
19	South Eastern England	UK Power Networks (UKPN) South Eastern Power Networks (SPN)
20	Southern England	SSE Power Distribution Southern Electric Power Distribution
21	Southern Wales	Western Power Distribution (WPD) South Wales
22	South Western England	Western Power Distribution (WPD) South West
23	Yorkshire	Northern Powergrid (NPG)

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Table 8.5 — Non-geographic IDNO reference numbers

IDNO ID	Service Area	Distribution Business
24	No area—IDNO	GTC (Independent Power Networks)
25	No area—IDNO	ESP Electricity Limited
26	No area—IDNO	Last Mile Electricity Limited
27	No area—IDNO	GTC (The Electricity Network Company)
29	No area—IDNO	Harlaxton Energy Networks Limited
30	No area—IDNO	Leep Electricity Network Limited
31	No area—IDNO	UK Power Distribution Limited
32	No area—IDNO	Energy Assets Networks Limited
33	No area—IDNO	Eclipse Power Limited
34	No area—IDNO	Murphy Power Distribution Limited
35	No area—IDNO	Fulcrum Electricity Assets Limited
36	No area—IDNO	Vattenfall Network Limited
17/20	No area—IDNO	Forbury Assets Limited
Tbc.	No area—IDNO	Utility Assets Limited

8.3.2 Load type application summary

Any application for metered electrical grid connections to PEI should include a summary of the types of loads and generators that are connected to the installation. The information is required for the DNO in relation to its Distribution Licence, the Distribution Code and to comply with the ESQCR.

As a minimum the installation details that are required by the DNO include:

a) maximum power requirements (kVA or kW);

b) type and electrical loading of the proposed equipment; and

c) connection date.

The guidance in the relevant G98 and G99 forms should be followed. It is advisable to have an understanding of the number and size of all likely disruptive loads including motors, cookers, showers, and space and water electrical heating arrangements.

For PEIs, which have appropriate control arrangements, the details of equipment that might be switched (load shed) by the electricity supplier should be provided.

Within the electricity supply application forms there is typically a section for detailing any low carbon technologies

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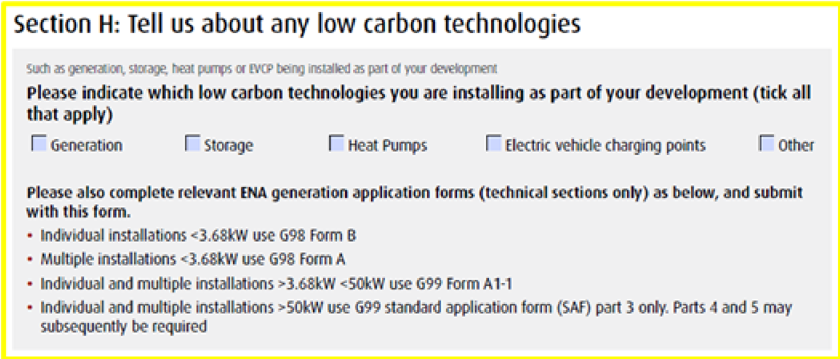
Section H: Tell us about any low carbon technologies

Such as generation, storage, heat pumps or EVCP being installed as part of your development

Please indicate which low carbon technologies you are installing as part of your development (tick all that apply)

☐ Generation ☐ Storage ☐ Heat Pumps ☐ Electric vehicle charging points ☐ Other

Please also complete relevant ENA generation application forms (technical sections only) as below, and submit with this form.

- Individual installations <3.68kW use G98 Form B
- Multiple installations <3.68kW use G98 Form A
- Individual and multiple installations >3.68kW <50kW use G99 Form A1-1
- Individual and multiple installations >50kW use G99 standard application form (SAF) part 3 only. Parts 4 and 5 may subsequently be required

Figure 8.6 — Low carbon technology notification *(Placeholder)*

8.3.3 ENA Connect Direct

A new initiative for electrical connections called ENA Connect Direct was launched in 2024. It aims to digitise the application process and reduce the timeline necessary for new connections of on-site generation (such as PV and wind turbines) and of low carbon technology (LCT) loads such as electric vehicles and heat pumps.

The process will notify DNOs, via registered installers, of the connection to the grid of LCT loads. The process will hold a central database of pre-approved ranges of equipment and the LCT models available to the UK market. This allows the automation of connection applications by digitalising the existing paper-based process. Whilst the aim is to automate the LCT connection process, the existing G98, G99 and G100 application procedures will still be accepted.

The initiative will involve all seven UK (including Northern Ireland) DNOs, with IDNOs expected to be involved on full product launch.

8.4 Tariffs and energy suppliers

B7671S HD 60364-8-1 provides informative guidance on energy efficient electrical installations. On the topic of energy tariffs, the doument states that the designer should take into account, the tariff structure offered by the supplier of electrical energy.

Section 8.4, under the title 'Inputs from the supplies: energy availability and pricing, smart metering', states that:

> *"The user should consider information concerning the energy availability and pricing which may vary with time."*

A correctly managed energy efficient electrical installation will have identified particular loads that can be operated at off-peak periods. Such an approach helps to reduce energy demands at peak periods and to benefit the customer by taking advantage of cheaper off-peak tariffs.

National Grid, working with other energy suppliers, rolled out a scheme in recent winter periods for UK customers with smart meters called the Demand Flexibility Service (DFS). It encourages load shifting. Participants receive indication of a DFS event, typically during peak winter periods from 4.00pm to 7.00pm, and are encouraged to switch out unnecessary loads so they operate at other times.

PEIs, with EEMS and control over individual loads, are designed to take advantage of this approach to energy use. PEIs will require a smart meter and consistent communications with the relevant energy supplier's controls system.

The energy market is evolving to provide new and innovative tariffs to the domestic market that include varying prices at half-hourly intervals for the import of energy to the installation.

Comparing like with like is always a challenge when it comes to energy tariffs and some energy suppliers may not be available in certain geographic areas. However, operators of PEIs should carefully examine all potential offerings and should consider:

a) compatibility of the software and hardware to control the installation and communicate with the cloud based platform;

b) what import tariffs are available and whether they vary through a 24 hour period;

c) what export tariffs are offered and whether this varies at peak times; and

d) what penalties are imposed if load demands in peak periods and how load shifting can assist.

Energy contracts are often set up for limited periods, and import and export rates can vary, so a regular review is recommended. Changing suppliers might be a consideration from time to time to optimise the investment in PEI.

8.5 Local authorities and building control

The location of PEI components such as PV, wind turbines and EESS may be subject to local planning controls. It is recommended that potential planning risks and constraints are fully investigated by the property owner and the installation contractor.

The UK government website, www.gov.uk, has guidance on renewable and low carbon energy. The UK planning website, www.planningportal.co.uk, has information on sustainability and planning; there is also further information on home energy production.

It is recommended that UK Building Regulations are also referred to. The approved documents provide a number of areas to consider, including:

a) Approved Document A for roof loadings (addition of PV etc.);

b) Approved Document B for fire;

c) Approved Document P for domestic electrical installations; and

d) Approved Document S for electric vehicles.

A complete set of the UK Building Regulations is available as The Merged Approved Document from the UK government website.

The addition of EESS and on-site generation such as PV will require additional circuits and connections. As such this is notifiable work under Approved Document P and must be subject to the published approval process with the local Building Control Officer within 28 days.

With care and good engineering design practice, PEIs can also be used as a retro-fit solution to improve the current housing stock.

In the UK, the Future Homes Standard is aimed at low carbon heating and will inevitably involve the electrification of space heating and hot water amongst other measures. PEIs, through on-site electrical energy generation and energy storage, will play a fundamental part in the decarbonisation of the domestic new housing market.

Annex A
(informative)

Glossary

Annex B
(informative)

Regulations, standards and guidance

Table B.1 — Further reading – British Standards Institution

Document	Specific content	Commentary
BS7671:2018 (Amd 2 2022)	Chapter 82 Prosumers Low Voltage Electrical Installations	Main normative text, originally derived from IEC documents, on the safe integration of grid connections, on site generation, energy storage and energy management systems all configured together as a PEI
BS7671:2018 (Amd 2 2022)	Section 712 Solar Photovoltaic (PV) power supply systems	Main normative text, on PV as a special location and the requirements for electrical safety
BS7671:2018 (Amd 2 2022)	Section 722 Electric Vehicle charging installations	Main normative text, on EVCP as a special location and the requirements for electrical safety
BS7671:2018 (Amd 2 2022)	Appendix 17 Energy Efficiency	Informative text, originally derived from IEC documents, on energy efficiency inn electrical installations as a PEI
BS EN 62446-1	Photovoltaic (PV) systems. Requirements for testing, documentation and maintenance - Grid connected systems.	Documentation, commissioning tests and inspection
PAS 1878	Energy smart appliances	System functionality and architecture – Specification
PAS 1879	Energy smart appliances	Demand side response operation – Code of practice
PAS 63100	EESS Specification for Fire Safety	Protection against fire of battery energy storage systems for use in dwellings

Table B.2 — Further reading - IET Guidance Notes

BS 7671 Guidance Note 2: Isolation & Switching 9th Edition	Chapter 10 Prosumers Low Voltage Electrical Installations	Summary of the requirements of Chapter 82 on aspects of PEI related to isolation and switching
BS 7671 Guidance Note 3: Inspection & Testing 9th Edition	Section 2.6.24 Prosumers Electrical Installations	Summary of the requirements of Chapter 82 on aspects of PEI related to inspection and testing
BS 7671 Guidance Note 6: Protection against overcurrent 9th Edition	Section 8 Introduction to Prosumers Electrical Installations	Summary of the requirements of Chapter 82 on aspects of PEI related to protection against overcurrent
BS 7671 Guidance Note 7: Special Locations 9th Edition	Section 10 Solar Photovoltaic (PV) power supply systems	Summary of the specific requirements of PV installations as a special location
BS 7671 Guidance Note 7: Special Locations 9th Edition	Section 15 Small scale embedded generators (SSEG)	Summary of the specific requirements of SSEG installations as a special location
BS 7671 Guidance Note 7: Special Locations 9th Edition	Section 20 Electric Vehicle charging installations	Summary of the specific requirements of EVCP installations as a special location
BS 7671 Guidance Note 8: Earthing & Bonding 5th Edition	Section 10.4 Small scale embedded generators (SSEG)	Summary of the specific earthing and bonding requirements of SSEG installations
BS 7671 Guidance Note 8: Earthing & Bonding 5th Edition	Section 10.13 Electric Vehicle charging installations	Summary of the specific earthing and bonding requirements of EVCP installations

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Table B.3 — Further reading - other IET publications

Document	Specific content	Commentary
Electrical Installation Design Guide: Calculations for Electricians and Designers 5th Edition	Section 14 Prosumers Electrical Installations (PEIs)	Summary of the calculation requirements of PEI, including supply characteristics and parallel supply points, overcurrent protection and connection modes
Code of Practice for Grid-Connected Solar Photovoltaic Systems 2nd Edition	Section 8.10.5 Prosumer's electrical installations	Brief summary of PEI
	Section 9	Information on the integration of PV connections to the grid including flow charts and descriptions on G98 and G99 requirements
Code of Practice for Electrical Energy Storage Systems 3rd Edition	3.5.2 Grid-connected system with other local generation	
Code of Practice for Electric Vehicle Charging Equipment Installation 5th Edition		

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Table B.4 — Further reading - Energy Networks Association (ENA)

Document	Specific content	Commentary
Engineering Recommendation G98 Issue 1 Amendment 7	Requirements for the connection of Fully Type Tested Micro-generators	(up to and including 16 A per phase) in parallel with public Low Voltage Distribution Networks on or after 27 April 2019
Engineering Recommendation G99 Issue 1 Amendment 9	Requirements for the connection of generation equipment	in parallel with public distribution networks on or after 27 April 2019
Engineering Recommendation G100 Issue 2 2022 Amendment 2	Technical Requirements for Customers' Export and Import Limitation Schemes	

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Table B.5 — Chapter 82 content tracker

PROSUMER'S LOW VOLTAGE ELECTRICAL INSTALLATIONS CONTENTS			
BS7671 ref	**Description**	**Location in Guide to PEI**	**Commentary**
821	Scope	Section 1.2	provides context and background
822	Interaction of smart grid and PEI	Section 2	
822.1	Main objectives	Section 1.2	provides context and background
822.2	Safety	Section 2.2.1 Section 4.0	Full coverage in 4.0 Electrical Safety
822.3	Proper functioning	Section 2.2.2 Section 5.0	Full coverage in 5.0 Functional Requirements
822.4	Implementation of PEI	Section 2.2.3	
823	PEI Concept	Section 2.1	
824	Types of PEI	Section 6	
824.1	General	Section 6	Full coverage in 6.0 Operational types and modes of PEI
824.2	Operating modes	Section 6	
824.3	Individual PEI	Section 6	
824.4	Collective PEI	Section 6	
824.5	Shared PEI	Section 6	
825	Electrical Energy Management System (EEMS)	Section 7.0	Full coverage in 7.0 Energy Storage and Energy Management
825.1	General	Section 5.3 Section 7.2	
825.2	Architecture of EEMS	Section 7.2 Section 7.3	
826	Technical Issues	Section 4.0	Full coverage in 4.0 Electrical Safety
826.1	Safety issues	Section 4.0	Full coverage in 4.0 Electrical Safety
826.2	Interaction with the public network	Section 4.3.4 Section 8.0	Full coverage in 8.0 Compliance and interaction with the grid
826.3	Energy storage	Section 7.1	
826.4	Design for flexibility of load and generators (demand/response)	Sections 7.2, 7.3 and 7.4	— Electrical Energy Management System — Active Energy Management

Table B.5 — Chapter 82 content tracker *(continued)*

PROSUMER'S LOW VOLTAGE ELECTRICAL INSTALLATIONS CONTENTS			
			— Load Shedding, Load Planning, Load Shifting
826.5	Electric vehicle charging	Section 4.4 Table 5.5	Cross reference to BS7671 sections 722.4, 722.826.3.201 and 825.1
826.6	Selectivity between protective devices	Section 4.1.4 Section 4.4	Plus calculation examples in Annex D
826.7	Testing and verification	Section 5.5 Table 5.7	Cross references BS7671 regulation 643 & sub-clauses
Annex A82	(Informative) Objectives and Concept of PEI	Section 2.1 Section 2.1.4 Section 7.3	
Annex B82	(Informative) Operating Modes	Section 4.3 Section 6.0	Full coverage in Section 6.0 Operational types and modes of PEI
Annex C82	(Informative) Interaction with the public network	Section 4.3.4 Section 8.0 Section 8.1 Section 8.2	Full coverage in Section 8.0 Compliance and interaction with the grid
Annex D82	(Informative) Architecture of PEI	Section 7.3	Active Energy Management

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Annex C
(informative)

System labels and signs

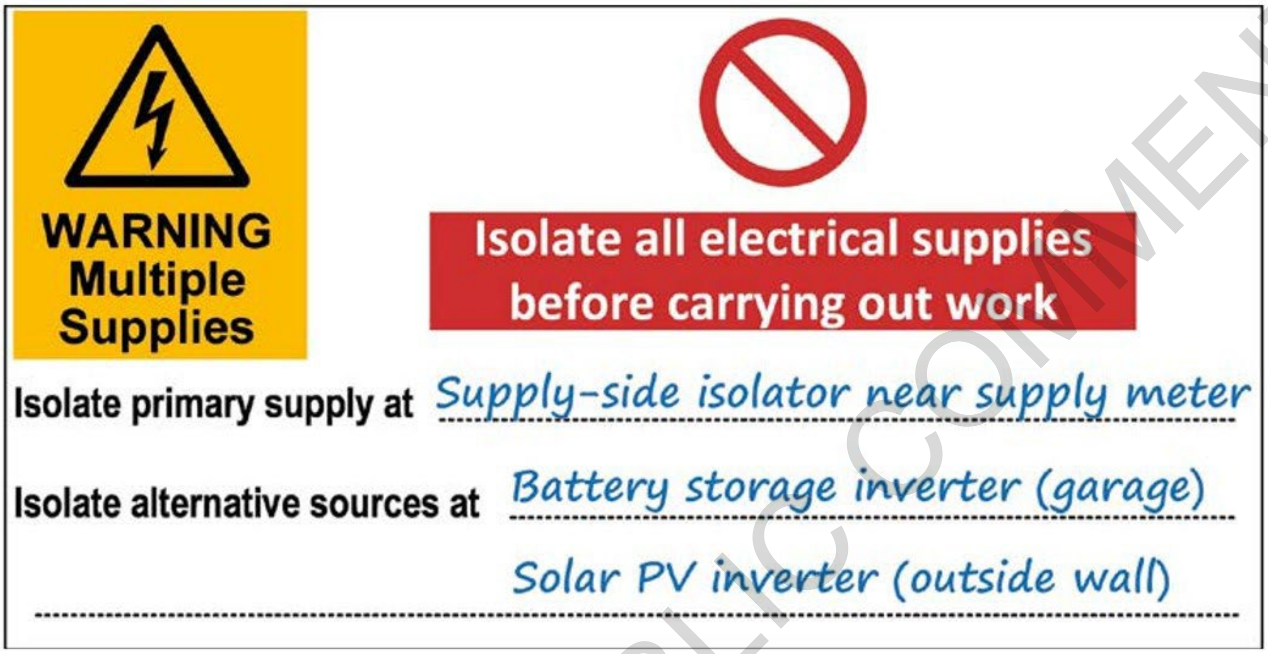

Figure C.1 — Warning notice for multiple supplies (BS 7671 Regulation 514.15.1)

Annex D
(informative)

Calculation examples

D.1 Maximum Demand and Load Diversity Calculations

Refer to Section 5.1.2

Refer to Section 7.4 (including 7.4.1, 7.4.2 & 7.4.3)

Provide illustrative example calculations

Ref	Description	Grid priority	Watts
G1	PV	NA	4000

time	load diversity	load (W)	maximum production (kWp)	period (mins)	energy (kWh)	commentary
01:00	0.0	4000	0.0	0	0.0	
02:00	0.0	4000	0.0	0	0.0	
03:00	0.0	4000	0.0	0	0.0	
04:00	0.0	4000	0.0	0	0.0	
05:00	0.0	4000	0.0	0	0.0	
06:00	0.0	4000	0.0	0	0.0	
07:00	0.13	4000	0.5	60	0.5	assumes no shadowing
08:00	0.25	4000	1.0	60	1.0	assumes no shadowing
09:00	0.50	4000	2.0	60	2.0	assumes no shadowing
10:00	0.75	4000	3.0	60	3.0	assumes no shadowing
11:00	0.75	4000	3.0	60	3.0	assumes no shadowing
12:00	1.00	4000	4.0	60	4.0	assumes no shadowing
13:00	1.00	4000	4.0	60	4.0	assumes no shadowing
14:00	0.88	4000	3.5	60	3.5	assumes no shadowing
15:00	0.75	4000	3	60	3.0	assumes no shadowing
16:00	0.75	4000	3	60	3.0	assumes no shadowing
17:00	0.63	4000	2.5	60	2.5	assumes no shadowing
18:00	0.50	4000	2	60	2.0	assumes no shadowing
19:00	0.25	4000	1	60	1.0	assumes no shadowing
20:00	0.0	4000	0	0	0.0	
21:00	0.0	4000	0	0	0.0	
22:00	0.0	4000	0	0	0.0	
23:00	0.0	4000	0	0	0.0	
00:00	0.0	4000	0	0	0.0	

maximum demand (kW)	4		32.5	predicted energy (kWh)

Figure D.1 — Maximum demand and load diversity calculations A

Description	Cooker Circuit	Kitchen sockets	Reception sockets 1	Reception sockets 2	Bedroom sockets	Utility Room sockets	Showers	Heating Controls	Heat Pump	Back up water heating	Internal Lighting 1	Internal Lighting 2	External Lighting	EVCP	Garage supply	Garden room supply	EESS
Grid priority	Medium	High	Medium	Medium	Low	Medium	Medium	High	Medium	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Watts	6000	2000	1000	500	250	4000	6000	100	5000	3000	300	200	150	7000	2000	1000	3000
01:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
02:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
03:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
04:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
05:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
06:00	0.0	0.0	0.2	0.0	0.0	0.0	0.9	1.0	0.6	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0
07:00	0.5	0.5	0.2	0.0	0.0	0.8	0.0	1.0	0.6	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0
08:00	0.0	0.0	0.2	0.0	0.0	0.8	0.0	1.0	0.6	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0
09:00	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
10:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
11:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
12:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
13:00	0.3	0.8	0.3	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
15:00	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
16:00	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
17:00	0.0	0.0	0.0	0.7	0.0	0.0	0.0	1.0	0.5	0.0	0.6	0.6	0.6	0.0	0.0	0.8	0.0
18:00	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.0	0.6	0.0	0.6	0.6	0.6	0.0	0.0	0.8	0.0
19:00	0.8	0.3	0.0	0.0	0.0	0.3	0.0	1.0	0.6	0.0	0.6	0.6	0.6	0.0	0.0	0.0	0.0
20:00	0.5	0.5	0.0	0.0	0.0	0.0	0.0	1.0	0.7	0.0	0.6	0.6	0.6	0.4	0.0	0.0	0.0
21:00	0.0	0.0	0.0	0.0	0.8	0.0	0.0	1.0	0.7	0.0	0.6	0.6	0.6	0.6	0.0	0.0	0.0
22:00	0.0	0.0	0.0	0.0	0.8	0.0	0.0	1.0	0.6	0.0	0.6	0.6	0.6	0.9	0.0	0.0	0.6
23:00	0.0	0.0	0.0	0.0	0.4	0.0	0.0	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
00:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8

Figure D.2 — Maximum demand and load diversity calculations B

Description	Cooker Circuit	Kitchen sockets	Reception sockets 1	Reception sockets 2	Bedroom sockets	Utility Room sockets	Showers	Heating Controls	Heat Pump	Back up water heating	Internal Lighting 1	Internal Lighting 2	External Lighting	EVCP	Garage supply	Garden room supply	EESS	Whole Installation	PV Installation	Whole Installation	Whole Installation
Grid priority	Medium	High	Medium	Medium	Low	Medium	Medium	High	Medium	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Maximum Demand	Maximum Output	Net Demand	Net Effect
Watts	6000	2000	1000	500	250	4000	6000	100	5000	3000	300	200	150	7000	2000	1000	3000	kW	kWp	kW	
01:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	2.5		2.5	Import
02:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.2		2.2	Import
03:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.9		1.9	Import
04:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.6		1.6	Import
05:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1		0.1	Import
06:00	0.0	0.0	0.2	0.0	0.0	0.0	5.4	0.1	3.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.8		8.8	Import
07:00	3.0	1.0	0.2	0.0	0.0	3.2	0.0	0.1	3.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	10.6	0.5	10.1	Import
08:00	0.0	0.0	0.2	0.0	0.0	3.2	0.0	0.1	3.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.6	1	5.6	Import
09:00	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	2.5	2	0.5	Import
10:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.9	3	-2.1	Export
11:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.9	3	-2.1	Export
12:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.9	4	-3.1	Export
13:00	1.8	1.6	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	4	-0.2	Export
14:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.9	3.5	-2.6	Export
15:00	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	1.1	3	-1.9	Export
16:00	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	3.6	3	0.6	Import
17:00	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.1	2.5	0.0	0.2	0.1	0.1	0.0	0.0	0.8	0.0	4.1	2.5	1.6	Import
18:00	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	3.0	0.0	0.2	0.1	0.1	0.0	0.0	0.8	0.0	4.4	2	2.4	Import
19:00	4.8	0.6	0.0	0.0	0.0	1.2	0.0	0.1	3.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0	10.1	1	9.1	Import
20:00	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.1	3.5	0.0	0.2	0.1	0.1	2.8	0.0	0.0	0.0	10.8		10.8	Import
21:00	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	3.5	0.0	0.2	0.1	0.1	4.2	0.0	0.0	0.0	8.4		8.4	Import
22:00	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	3.0	0.0	0.2	0.1	0.1	6.3	0.0	0.0	1.8	11.8		11.8	Import
23:00	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	4.8		4.8	Import
00:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	2.5		2.5	Import

Figure D.3 — Maximum demand and load diversity calculations C

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Description	Cooker Circuit	Kitchen sockets	Reception sockets 1	Reception sockets 2	Bedroom sockets	Utility Room sockets	Showers	Heating Controls	Heat Pump	Back up water heating	Internal Lighting 1	Internal Lighting 2	External Lighting	EVCP	Garage supply	Garden room supply	EESS	Whole Installation	PV Installation	Whole Installation	Whole Installation
Island priority	Medium	High	Medium	Medium	Low	Medium	Medium	High	Medium	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Maximum Demand	Maximum Output	Net Demand	Net Effect
Watts	6000	2000	1000	500	250	4000	6000	100	5000	3000	300	200	150	7000	2000	1000	3000	kW	kWp	kW	
01:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1		0.1	Import
02:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1		0.1	Import
03:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1		0.1	Import
04:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1		0.1	Import
05:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1		0.1	Import
06:00	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3		0.3	Import
07:00	0.0	1.0	0.1	0.0	0.0	1.6	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.5	2.4	Import
08:00	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1	0.8	Import
09:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2	-1.9	Export
10:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3	-2.9	Export
11:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3	-2.9	Export
12:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	4	-3.9	Export
13:00	0.0	0.4	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	4	-3.2	Export
14:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.5	-3.4	Export
15:00	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3	-2.8	Export
16:00	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	3	-0.7	Export
17:00	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	2.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	2.5	2.5	0.0	Export
18:00	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.4	2	-1.6	Export
19:00	1.2	0.4	0.0	0.0	0.0	0.4	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	2.3	1	1.3	Import
20:00	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.8	0.1	0.1	0.0	0.0	0.0	0.0	0.0	3.7		3.7	Import
21:00	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	1.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.8		1.8	Import
22:00	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3		0.3	Import
23:00	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2		0.2	Import
00:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1		0.1	Import

Figure D.4 — Maximum demand and load diversity calculations D

Annex D.3
(informative)

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Annex E

(informative)

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