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Programme Area: Light Duty Vehicles

Project: Electricity Distribution and Intelligent Infrastructure

Title: Charging Network Requirements Report

Abstract:

This project was undertaken and delivered prior to 2012, the results of this project were correct at the time of publication and may contain, or be based on, information or assumptions which have subsequently changed. This report presents the results of an evaluation of the different ways in which Plug-in Electric Vehicle (PiEV) recharging infrastructure may be provided in the UK and their recommendations on the requirements for its deployment. PiEV recharging infrastructure requirements are presented for domestic, commercial and public applications. Power requirements, which are fundamental to determine PiEV connection capacities and ultimately system design solutions are determined for a range of recharging scenarios. Significant standards are discussed. A description of technology options is carried out for connectors, recharge points, DC recharging, inductive recharging and mitigation measures such as local load management and energy storage. The requirements capture, standards review and technology options are used to present system designs for a range of scenarios.

Context:

This project looked at the potential impact of electric vehicles on the UK electricity distribution grid.

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ETI PLUG-IN VEHICLES PROJECT, DELIVERABLE SP2/E.ON/04
CHARGING NETWORK REQUIREMENTS REPORT

prepared for
THE ENERGY TECHNOLOGIES INSTITUTE
by
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SUMMARY

The aim of this report is to present the results of E.ON's evaluation of the different ways in which Plug-in Electric Vehicle (PiEV) recharging infrastructure may be provided in the UK and to recommend the requirements for its deployment.

This report is part of the ETI Electrical Distribution and Intelligent Infrastructure Project and is a deliverable of Work Package 2.2, which covers the consumer side infrastructure from the connection to the distribution network to the point of connection to the PiEV. This analysis is priced in conjunction with costs and supply chain analysis report (SP2/E.ON/05).

PiEV recharging infrastructure requirements, constraints and solution options are presented for domestic, commercial and public applications. Significant standards are discussed, with particular focus on BS EN 61851 for PiEV conductive charging systems and the IEE wiring regulations (BS 7671). Appraisal of these standards focuses on how they may evolve and shape the development of PiEV technologies.

The use of a standard 13A, 3-pin plug for PiEV recharging is an enabling technology for early adoption of PiEVs. However, as technologies are emerging for Mode 3 recharging (i.e. control pilot functionality encompassing the infrastructure connection), it is recommended that all PiEV infrastructure system designs adopt Mode 3 recharging on safety grounds and to enable higher charge rates in the future.

It is recommended in domestic and small commercial locations, that PiEV installations are supplied from a separate feed from the consumer unit. It is recommend that where 16A single phase recharging is installed, that a cable sufficient for 32A recharging is installed, thereby catering for future upgrades at little expense.

It is recommended that an inductive recharge system be trialled to determine recharge efficiencies in comparison to conductive recharging. Inductive recharging offers a number of safety advantages, both electrically and practically, such as removal of cable trip hazards. Recharging takes place with reduced user intervention, minimising situations of "forgetting to connect". These benefits can be offset by the cost of such systems and reduced efficiency compared with conductive recharging. Such assessments should focus on the efficiency of

individual segments in the system and deduce how incorporating the inductive recharging within the PiEV converter improves overall recharging efficiency and cost saving.

It is recommended that a load management system, which monitors the local load and controls the PiEV recharging, be adopted to avoid situations where, as diversity of load within properties is reduced as a result of PiEV recharging, there is an increased risk of overloading and tripping of the main incoming circuit.

It is recommended that local load management systems are used for large car parks where expected PiEV connection durations are significantly longer than the recharge duration. In these cases the distribution network interface capacity may be significantly reduced which could result in a reduced infrastructure cost.

It is recommended that PiEV trials include equipment installed to determine the duty of recharge duration to connection duration as this is not currently known, and will vary from one location to another thereby informing the future developments of algorithms to adopt within the local load management system.

It is recommended that in all cases a local load management system must have a margin to allow for adverse cases, (for example large groups of employees leaving work early on Friday half day working, significantly reducing the recharge window).

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APPENDIX M: Public System Design Option 3

APPENDIX N: Public System Design Option 4

APPENDIX O: Public System Design Option 5

APPENDIX P: Low Voltage Network Overview

APPENDIX Q: Identification of Hazards, Risks and Likely Consequences

GLOSSARY

Term	Definition
AC	Alternating Current. Sinusoidal waveform as generated and transmitted on power system networks.
BMS	Battery Management System. Control system which monitors the condition of battery cells and controls the voltage and current levels. Resides on-board the vehicle.
Commercial	Mostly this will include commercial businesses, but it will also include some public service organisations, for example local authorities, employee car parks, etc. See Section 2.2 for more details.
DC	Direct Current. Non-sinusoidal waveform as used for battery storage.
DNO	Distribution Network Operator.
Domestic	Private residences. See Section 2.1 for further definitions.
HV	High Voltage. In the UK, high voltage is usually considered any voltage over 1 kV.
IP	Ingress Protection. Degree of protection offered by components to ingress of water and particles.
LV	Low Voltage. In the UK, low voltage is usually considered any voltage under 1 kV.
MCCB	Moulded Case Circuit Breakers. Similar to MCB but with higher rated overload capabilities.
MCB	Miniature Circuit Breaker. Device which monitors the live current and disconnects the circuit upon overload currents.
PiEV	Plug-in Electric Vehicle. Any vehicle capable of being powered wholly or partly by power from the electricity grid.
Public	Public recharging points are regarded as recharging locations which the public may use regardless of recharge point ownership. See Section 2.2 for more details.
PWM	Pulse Width Modulation. Sawtooth signal which is used to produce a pulsed signal whose width is controlled by a reference signal.
RCD	Residual Current Device. Device which monitors the current in the live and neutral current and opens when a difference is detected.

GLOSSARY (continued)

Term	**Definition**
Single Phase	Sinusoidal alternating current (AC) electrical supply fed from a single phase at 240 V.
SOC	State Of Charge. Expressed as the percentage charge remaining in a battery in comparison to its full charge capability.
SWA	Steel Wire Armoured. Armouring used in cables with protects the conductors from damage.
Three Phase	Sinusoidal alternating current (AC) electrical supply fed from three voltage phases each being displaced by 120 degrees (0, 120, 240). For the purpose of this report only voltage levels of 415 V (phase to phase) shall be considered.
TOU	Time Of Use.
V2G	Vehicle to Grid. Utilising “spare” energy in the PiEV battery to discharge to the power system (grid).
V2H / V2H	Vehicle to Home / Vehicle to Home. Utilising “spare” energy in the PiEV battery to discharge locally to the property load.

1 INTRODUCTION

This report presents the requirements, constraints and various solution options for the deployment of Plug-in Electric Vehicle (PiEV) recharging infrastructure in the UK. The requirements are presented taking into account the user, energy transfer, power capacity, location of recharge points, safety and business needs. Relevant standards and various technology options are presented and example systems are discussed.

This report covers the consumer side electrical infrastructure from the connection to the distribution network to the PiEV recharging point (Figure 1). The recharging infrastructure is broken down into three connected systems, namely the distribution network interface, recharge point and PiEV interface. This approach is applied to domestic, commercial and public locations.

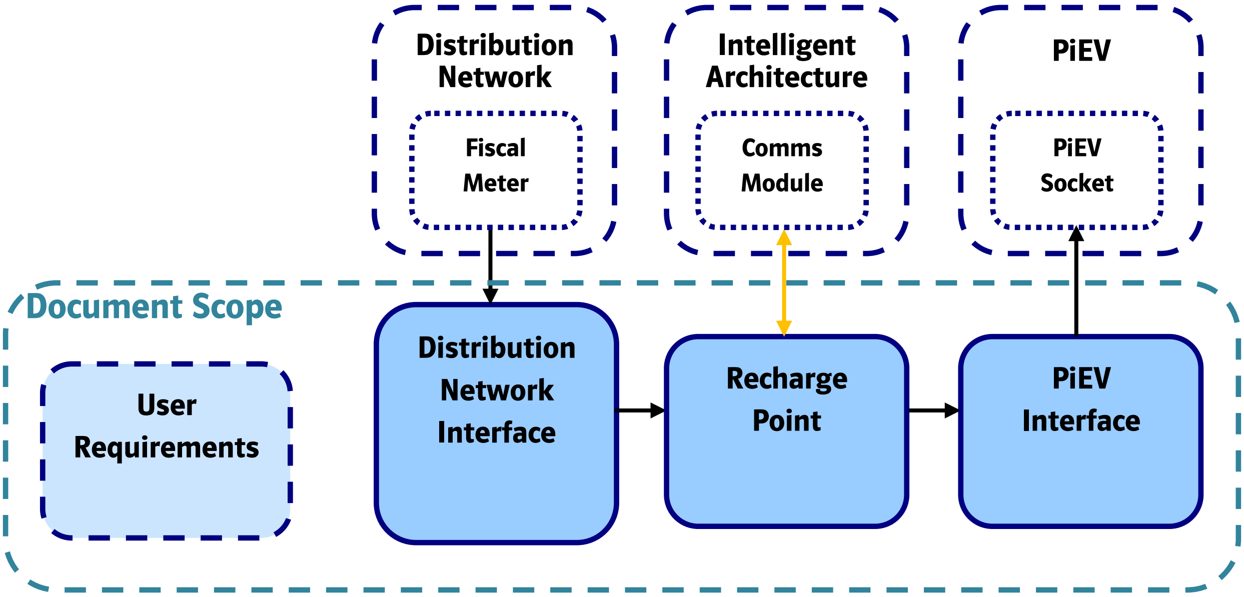


Figure 1: Scope of Report and Sub Categories

This report has been written such that the reader does not require detailed electrical knowledge; however it is assumed that the reader is familiar with basic electrical concepts and has a basic knowledge of plug-in vehicles.

1.1 Report Context in the wider ED&II Project

This report is part of the ETI Electrical Distribution and Intelligent Infrastructure (ED&II) project and is a deliverable of Work Package 2.2.

Table 1.1 shows the main deliverables from the ED&II project.

Table 1.1: Main Technical Deliverables from the ED&II Project (Note that a number of interim deliverables have been removed for clarity)

Work Package	Work Package Synopsis	Final Deliverable Reference	Final Deliverable Description	Interim Deliverable Reference	Interim Deliverable Description
2.1/2.3	To determine what barriers may exist within the UK electricity distribution system, develop potential mitigation strategies and create a macro-level model to enable city-level planning of charging infrastructure deployment. To evaluate the main cost drivers for plug-in vehicle recharging infrastructure, enabling a realistic forecast to be generated and the cost effectiveness of solutions in WP 2-1 to be evaluated.	SP2/EDF EN/04	Electricity Distribution Network Assessment and Analysis Final Report.	SP2/EDF EN/01	LV & HV Network constraints identification.
				WS2/EDF/04	Network implications of charging point infrastructure locations.
				SP2/EDF EN/02	Distribution network capacity and upgrade costs major factors identification.
				SP2/IMP/03	Final list of Generic Networks.
				SP2/IMP/09	Report on potential reinforcement / mitigation options.
				SP2/IMP/04	Report on mapping of available distribution networks data into the final generic networks.
				SP2/IMP/14	Report on mitigation strategy costs.
				SP2/IMP/15	Report on Demand Side Management evaluation.
				SP2/EDF/05	Intelligence upgrade cost report.
				SP2/EDF EN/03	Future changes to the UK electricity distribution network report.
				SP2/IMP/10	Potential benefit/impact of distributed energy.
				SP2/IMP/13	Final scenarios report.
				SP2/EDF/06	Vehicle-to-Grid (V2G) & Vehicle-to-Home (V2H) Evaluation.
				SP2/IMP/05	Model Development Summary Report - Electricity Distribution Network Models.
		SP2/IMP/07	Electricity Distribution Network Models - Final Version.		
2.2	To evaluate the different ways in which recharging infrastructure may be provided in the UK and recommend the requirements for the UK deployment. The scope of activities in this work package is limited to the consumer side of the connection to the distribution network up to the point of connection to the plug-in vehicle.	SP2/E.ON/04	Charging Network Requirements Report.	SP2/E.ON/05	Costs and Supply Chain Analysis Report.

Table 1.1 Continued

Work Package	Work Package Synopsis	Final Deliverable Reference	Final Deliverable Description	Interim Deliverable Reference	Interim Deliverable Description
2.4	To determine the complexity and scope of the intelligent architecture.	SP2/IBM/27	Completion Report - System Integration and Architecture Development.	SP2/E.ON/01	Intelligence Levels Workshop Report.
				SP2/IBM/14	Intelligent Architecture Requirement Report.
				SP2/IBM/15	Vehicle Design Standards Requirements Report.
				SP2/IBM/16	Conceptual Business Architecture.
				SP2/IBM/17	Conceptual Application Architecture.
				SP2/IBM/18	Conceptual Data Architecture.
				SP2/IBM/19	Conceptual Technical Architecture.
				SP2/IBM/20	Plan for Architecture Realisation.
				SP2/IBM/22	Back Office and Supporting Systems Cost Report.
				SP2/IBM/23	Systems Integration and Settlement Assessment Report.
				SP2/IBM/24	Emerging Technology Assessment Report.
				SP2/IBM/25	Vehicle Design Standards Gap Assessment Report.
				SP2/IBM/26	Risk Assessment Report.
2.5	To determine the regulatory, legislative and commercial issues associated with recharging infrastructure and recommend how they should evolve for the UK deployment..	SP2/E.ON/07	Recharging Infrastructure Implementation Recommendations Final report.		

1.2 Report Structure

Figure 1.2 details the layout of this report. Following the introduction, this report starts with the requirements, which pose the question “what does the recharging infrastructure need to provide?” It then goes on to look at constraints that impact on the requirements, then looks at various solution options to overcome the constraints. An evaluation of the solution options follows and some example system solutions are presented. Finally the conclusions and recommendations are presented.

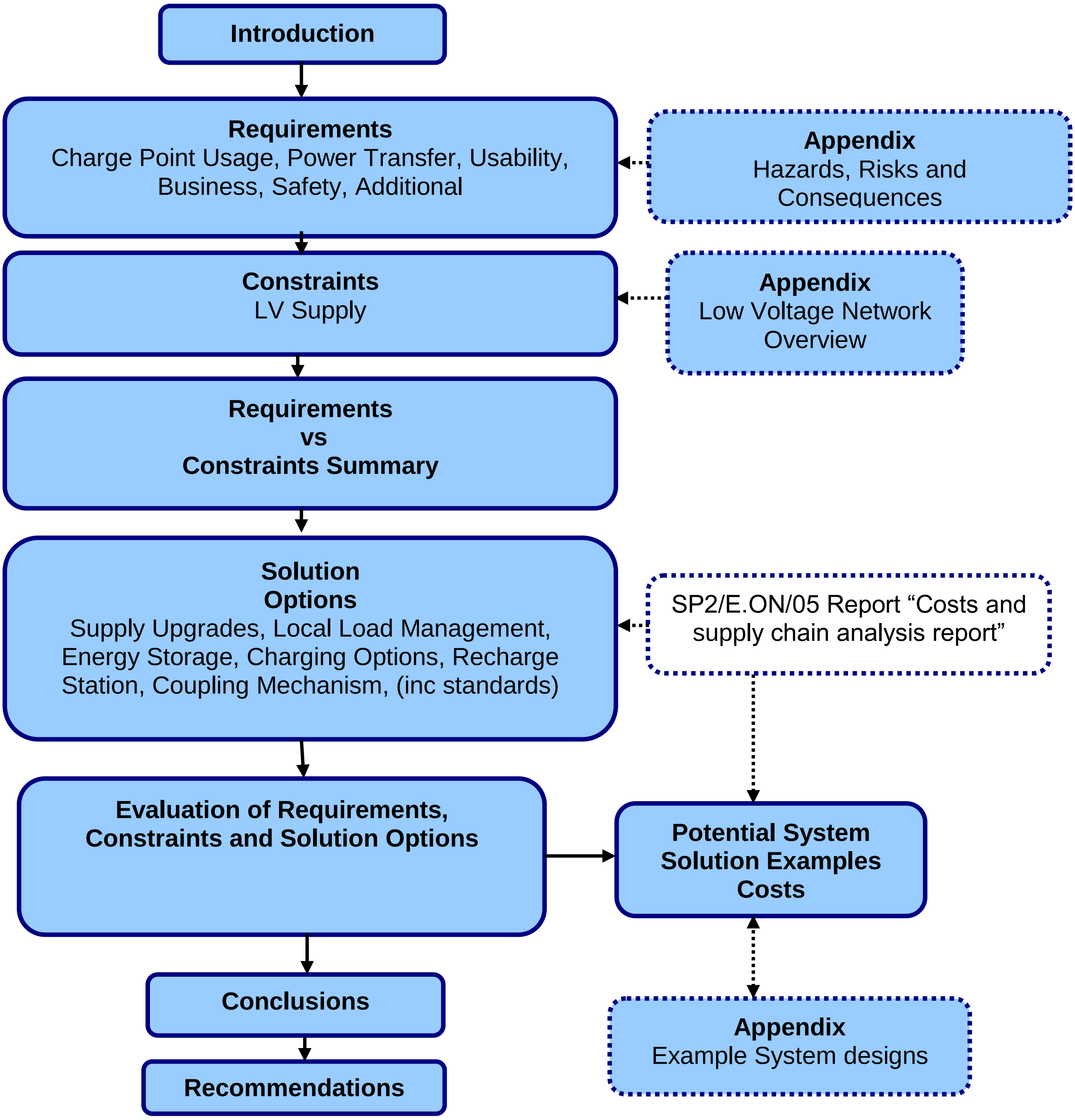


Figure 1.2: Report Structure

2 REQUIREMENTS

This section considers the high level requirements for PiEV recharging infrastructure, posing the question “what does the recharging infrastructure need to provide?”

Generic requirements for all recharge point locations are presented. The PiEV attributes and expected charge point usage behaviours are combined to give power transfer requirements. Usability and operational, business, safety and additional technical requirements complete the requirements presented.

The later sections of this report go on to explain the present electrical power landscape on which these requirements get overlaid, and looks at the options for meeting the requirements both now and with emerging technologies for domestic, commercial and public recharging.

The highest level requirement is that the PiEV will be able to safely and conveniently receive the energy necessary to fulfil the user’s immediate travel requirements, in a cost effective manner.

2.1 Context

This section reviews the locations where recharging may take place.

2.1.1 Domestic

Domestic premises considered in this report are those residential properties with private or dedicated parking for the user:

- On-drive recharging.
- In garage recharging.
- Private on street recharging.
- Block of flats, with private recharging.

2.1.2 Commercial

Commercial premises considered in this report are those that may have recharge points operated for the private needs of the organisation concerned. Mostly this will include commercial businesses, but due to similarities of requirements and installations, it will also include some public service organisations, for example local authorities.

Commercial recharging will be associated with a wide range of locations including: industrial warehouses, business compounds, employee car parks and university campuses. As a result, there is no one typical location.

2.1.3 Public

Public recharging points are regarded as recharging locations which the public may use regardless of recharge point ownership.

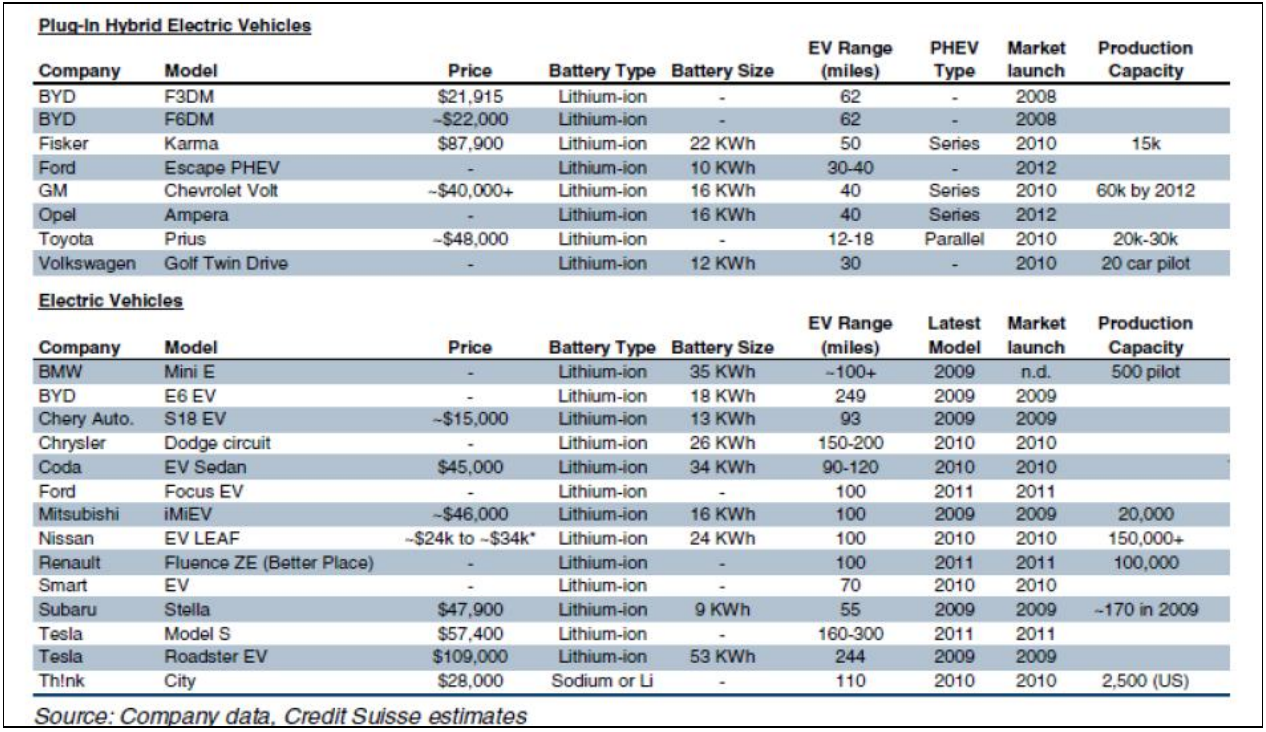
Public parking locations are generally associated with inner cities; however, there are numerous other possible locations which may yield a variety of requirements.

Presently the majority of public recharge locations comprise of typically 3 to 4 bays. Such bays are addressing the concerns of PiEV owners over range; however, they are seldom used with early adopters, preferring to recharge at home. On this basis the number of bays is not expected to significantly increase in the short term; however, the future is uncertain and mass PiEV uptake may see large demand for public recharging bays. Estimates from the *Economics and Carbon Benefits Project* indicate that there may be a ratio of approximately six PiEVs to one public charging point. Such large uptake may see significant demand for recharge bays, particularly in large car parks.

2.2 PiEV Attributes

2.2.1 Domestic

There are several PiEVs likely to be used for private use. Figure 2.2.1 provides a snapshot of those currently available and indicates the vehicle price, battery type and size and range for a selected range of PiEV manufacturers. Prices shown are in USD.



Plug-In Hybrid Electric Vehicles

Company	Model	Price	Battery Type	Battery Size	EV Range (miles)	PHEV Type	Market launch	Production Capacity
BYD	F3DM	$21,915	Lithium-ion	-	62	-	2008	
BYD	F6DM	~$22,000	Lithium-ion	-	62	-	2008	
Fisker	Karma	$87,900	Lithium-ion	22 KWh	50	Series	2010	15k
Ford	Escape PHEV	-	Lithium-ion	10 KWh	30-40	-	2012	
GM	Chevrolet Volt	~$40,000+	Lithium-ion	16 KWh	40	Series	2010	60k by 2012
Opel	Ampera	-	Lithium-ion	16 KWh	40	Series	2012	
Toyota	Prius	~$48,000	Lithium-ion	-	12-18	Parallel	2010	20k-30k
Volkswagen	Golf Twin Drive	-	Lithium-ion	12 KWh	30	-	2010	20 car pilot

Electric Vehicles

Company	Model	Price	Battery Type	Battery Size	EV Range (miles)	Latest Model	Market launch	Production Capacity
BMW	Mini E	-	Lithium-ion	35 KWh	~100+	2009	n.d.	500 pilot
BYD	E6 EV	-	Lithium-ion	18 KWh	249	2009	2009	
Chery Auto.	S18 EV	~$15,000	Lithium-ion	13 KWh	93	2009	2009	
Chrysler	Dodge circuit	-	Lithium-ion	26 KWh	150-200	2010	2010	
Coda	EV Sedan	$45,000	Lithium-ion	34 KWh	90-120	2010	2010	
Ford	Focus EV	-	Lithium-ion	-	100	2011	2011	
Mitsubishi	iMiEV	~$46,000	Lithium-ion	16 KWh	100	2009	2009	20,000
Nissan	EV LEAF	~$24k to ~$34k*	Lithium-ion	24 KWh	100	2010	2010	150,000+
Renault	Fluence ZE (Better Place)	-	Lithium-ion	-	100	2011	2011	100,000
Smart	EV	-	Lithium-ion	-	70	2010	2010	
Subaru	Stella	$47,900	Lithium-ion	9 KWh	55	2009	2009	~170 in 2009
Tesla	Model S	$57,400	Lithium-ion	-	160-300	2011	2011	
Tesla	Roadster EV	$109,000	Lithium-ion	53 KWh	244	2009	2009	
Th!nk	City	$28,000	Sodium or Li	-	110	2010	2010	2,500 (US)

Source: Company data, Credit Suisse estimates

Figure 2.2.1: PiEV Characteristics[1]

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[1] Credit Suisse "Electric Vehicles, " Equity Research, Energy Technology / Auto Parts & Equipment, October 1, 2009

2.2.2 Commercial

Typically, PiEVs will be owned or leased by the organisation and driven by the operatives of the organisation, or personally owned by employees. Following are some examples of PiEV types:

- Local delivery vans e.g. couriers, wholesale delivery and supermarket home shopping delivery vans.
- Medium size fleet vehicles e.g. tradesperson vans.
- Small fleet vehicles e.g. company cars.
- Campus vehicles which operate within a confined region.
- Employee vehicles - work place car parking provided by an employer.

It is expected that commercial local delivery PiEVs will make up a significant proportion of the initial uptake rates of PiEV, driven by businesses that have the financial capital to invest in such technologies, and having suitable urban drive cycles and high utilisation to reduce the payback period.

2.2.3 Public

The same PiEVs as identified for domestic recharging will use public recharging points.

2.3 Charge Point Usage

This section reviews the recharging patterns that may take place.

2.3.1 Domestic

Preliminary findings from the Coventry and Birmingham Low Emission Demonstration (CABLED) project[2] indicate that most PiEV users will choose to plug their PiEVs in when they return from work in the evening. The batteries will then be left to recharge overnight and the user expects the battery to be fully charged by the morning. Thus a domestic recharge period of approximately eight hours is envisaged, although for some users, shorter recharge periods of say 4 hours may be preferred.

The size of battery, trip distances and PiEV energy consumption rates will dictate how long and often the PiEV user is likely to recharge at home.

The overnight load will depend on the battery state of charge (SOC) when the PiEV is plugged in. The SOC in turn depends on the length and type of travel carried out between recharge instances and will also be impacted by environmental factors such as seasonal changes, ambient temperature, inclement weather etc.

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[2] CABLED Second Data Report, http://www.cabled.org.uk/press

2.3.2 Commercial

Table 2.3.2 shows the likely scenarios of commercial PiEV recharging identified and expected trip distances and durations of recharge.

For the purpose of analysis, trip distances are categorised as:

Low	< 10 miles.
Medium	≥ 10 miles, ≤ 30 miles.
High	> 30 miles, ≤100 miles.
High+	> 100 miles.

Table 2.3.2: Indication of Commercial Recharging Scenarios and Variation of Use

Recharging Scenario	Likely Recharge Duration	Recharging Location	Trip distance between Recharging
Employee vehicle - Workplace recharging	4 to 10 hours	Urban	L/M
Campus vehicles	< 1 hour to 12 hours	Urban	Medium (Multiple L)
Local delivery vehicles e.g. couriers, supermarket home shopping etc.	< 1 hour to 12 hours	Suburban	High (Multiple L/M)
Medium size fleet vehicles	< 1 hour	Suburban	L/M/H
Small size fleet vehicles	1 to 4 hours	Suburban	L/M/H

In addition to commercial vehicles, many workplaces also have staff and/or visitor parking. For workplace recharging, staff will generally arrive at very similar times of day and connect their PiEV to the recharge point.

2.3.3 Public

Table 2.3.3 identifies a spread of possible recharging scenarios, indicating connection durations, expected PiEV trip distance and generic public locations. PiEV ranges are categorised as detailed in Section 2.3.2.

Table 2.3.3: Indication of Public Recharging Scenarios and Variation of Use

Recharging Scenario	Likely Recharge Duration	User Trip Distance	Location
Kerbside (Inner city)	1 to 4 hrs	L	Urban
Kerbside (Residential)	8 hours	L/M/H	Rural
Public Car Park - Short Stay	30 mins to 4 hrs	L/M	Urban
Public Car Park - Long Stay	4 to 10 hrs	L/M	Urban
Park and Ride	4 to 8 hrs	L	Suburban
Railway Stations	6 to 10 hrs	L	Urban
Airport Car Parks - Short Stay	Up to 24 hrs	L/M	Rural
Airport Car Parks - Medium Stay	1 to 3 days	L/M	Rural
Airport Car Parks - Long Stay	3 to 21 days	M/H	Rural
Supermarkets	15 mins to 2 hrs	L	Suburban
Retail Outlets	1 hr to 6 hrs	L/M/H	Suburban
Leisure – Gym	1 to 2 hrs	L	Suburban
Leisure – Cinema	1½ to 3 hrs	L/M	Suburban
Leisure – Attractions, Theme parks/Zoos	4 to 8 hrs	L/M/H	Rural / Suburban
Service Stations (e.g. motorways)	10 to 60 mins	H+	Rural

2.3.4 Summary of Charge Point Usage Requirements

From the scenarios discussed in Sections 2.3.1 to 2.3.3, a variety of charging requirements can be envisaged. These have been collated into the charge point usage requirements presented in Table 2.3.4. The Req.ID column is the requirement identity reference and is used as a cross-reference or shorthand for that requirement later in this report.

Table 2.3.4: Summary of Charge Point Usage Requirements

Req. ID	Charge Point Usage Requirements
CP1.0	Energy supplied to the PiEV should be sufficient to meet the intended range of the PiEV user (or maximum capacity of the PiEV battery) and this must be transferred during recharging within an acceptable timescale.
CP1.1	Domestic recharging infrastructure must support the full re-charge of a PiEV passenger car within 8 hours.
CP1.2	Some domestic users will require faster charging times, typically around 4 hours for a full charge (e.g. to charge up visiting relatives' vehicles).
CP1.3	Some domestic users may require multiple vehicles to be charged simultaneously at home.
CP1.4	Commercial recharging infrastructure must support the full charging of light vehicles within 8 hours, to support employee commutes or the recharging of company vehicles overnight. Faster recharge times may be required in some cases.
CP1.5	Commercial recharging infrastructure may need to support the full charging of heavier vehicles within 8 hours (overnight recharge).
CP1.6	On street public charging will probably be used to partly recharge vehicles and therefore must be able to top up 50% of the battery of a typical passenger vehicle within a maximum of 4 hours
CP1.7	On street public charging will probably be used to partly recharge vehicles and therefore will *ideally* be able to top up 50% of the battery of a typical passenger vehicle within a maximum of 2 hours
CP1.8	Public rapid charging (e.g. at motorway service stations) will need to provide a passenger vehicle with a full charge in approximately 30 minutes, ideally less.

2.4 Power Transfer to PiEV

Recharging infrastructure requirements are primarily dictated by the energy requirements of the PiEV. There are numerous factors such as vehicle weight, battery capacity/efficiency, range, auxiliary loads, terrain, driving style, vehicle design and weather conditions, which ultimately determine the energy consumption for a given drive cycle. This energy must be replenished by the recharging infrastructure within a suitable connection period (as per the requirements identified in Section 2.3). It is these base variables which determine the required capacity of the recharging infrastructure.

Figure 2.4a shows the required recharge duration for a 24 kWh recharge energy requirement (as per the Nissan EV Leaf's battery size), as a function of recharge power. In this example, it can be seen that constant recharge currents based on present standard connector ratings of 63A, 32A and 13A, require recharge durations of 90, 186 and 456 minutes respectively (assuming a single phase 240V supply). Increasing the current, and hence the power, reduces the recharge duration, as shown. Whilst recharge rates are generally discussed in terms of current, energy transfer is also dependent on the voltage level and number of phases; therefore power requirements are discussed throughout this report.

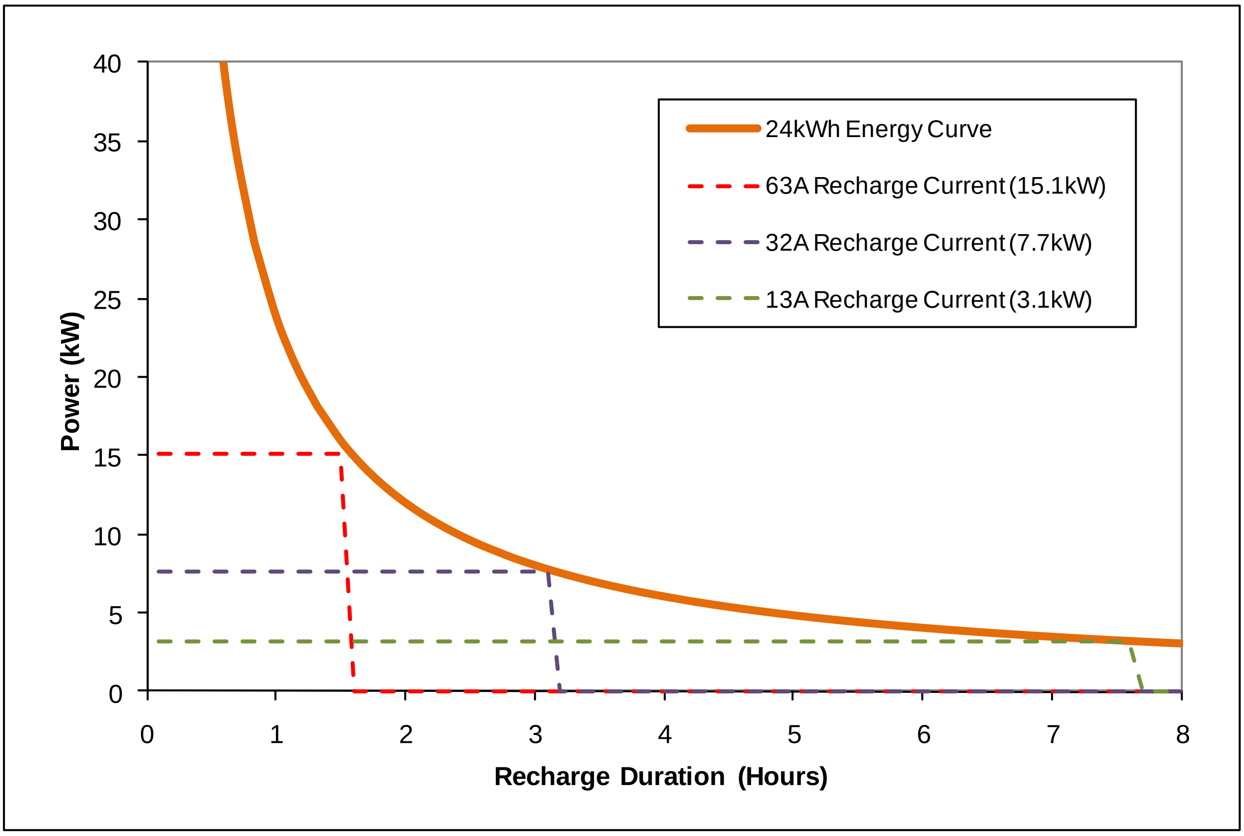

Figure 2.4a: Power Requirements for Varying Recharge Durations of 24 kWh Energy Transfer

Considering that there are a range of PiEVs with different battery capacities and recharge energy requirements which vary from one user to another, based on range between recharging and consumption. The level of energy transfer is a significant requirement. In addition to the recharge duration, the amount of energy transfer is a significant requirement. Figure 2.4b shows power and recharge duration requirements for 5 kWh increments in energy transfer up to 30 kWh. This equates to approximately 17 to 100 miles range for present small PiEV based on a practical consumption figure of 0.3 kWh/mile as determined during E.ON trialling a Mitsubishi iMiEV over a three week period.

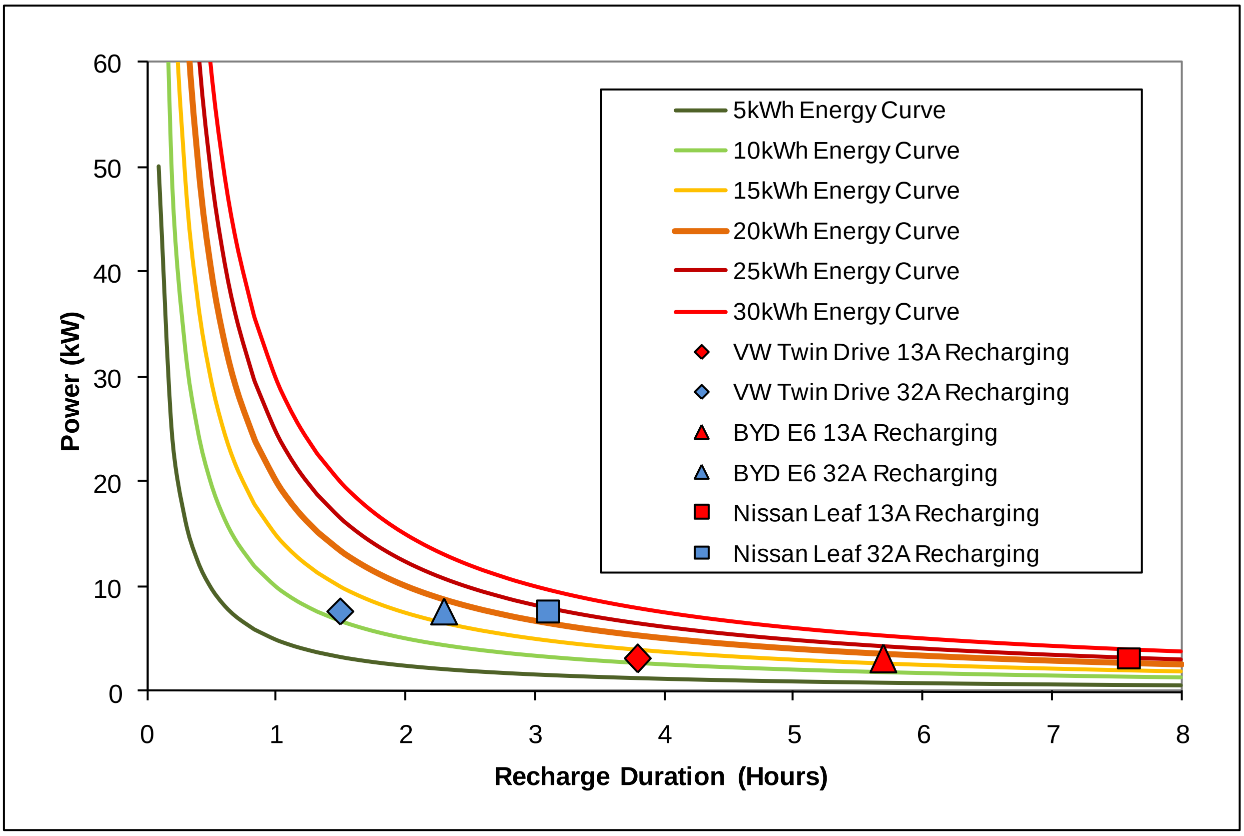

Figure 2.4b: Power Connection Requirements for a Range of Energies and Connection Durations

Figure 2.4b also shows power and recharge duration requirements for a full recharge at 13 and 32 A for three PiEVs selected from Figure 2.2.1. Whilst Figure 2.4b presents individual connections, it equally may be used for multiple vehicle connections to determine an infrastructure connection capacity.

With most lithium-ion batteries, the recharge profile is such that the battery draws peak current until it is >95% full. The amount of current it draws then tails off. The PiEV continues to draw a nominal current for the rest of the time that it is plugged in (even if the battery is full). The amount of energy consumed between the time when the battery is fully recharged and the PiEV is unplugged, depends on whether the PiEV has any auxiliary requirements such as battery heating etc. In general, the total energy consumed is almost negligible compared to a full battery recharge.

2.4.1 Domestic Power Requirements

Individual PiEV connection power requirements are sized against present, emerging and expected future ratings of PiEV connectors. These developments are based around standard BS EN 61851 as shown below.

- 3.8kW, 16A single phase AC recharging (Slow)
- 7.7kW, 32A single phase AC recharging (Fast)
- 11.5kW, 16A three phase AC recharging (Fast)
- 23kW, 32A three phase AC recharging (Rapid)
- 240kW, DC recharging (DC-Rapid)

Further details on connectors can be found in Section 5.

The majority of domestic PiEVs are expected to have a 13A charger which can utilise present domestic sockets. From Figure 2.4b it can be seen that for a full recharge at 13A the vehicle needs to be plugged in for 2 hours (6 kWh energy transfer) to 7.5 hours (22.5 kWh energy transfer). Similarly, with a 32A charger the vehicle should be plugged in for 0.75 to 3 hours.

In 2008, the average trip to work distance was 8.6 miles, with approximately 70% of journeys completed by car[3]. It can be expected that the work commute distance by car might be larger than this, but a typical distance of around 10 miles seems reasonable. Based on an electrical energy consumption of 0.3 kWh/mile, a typical commute will require 3 kWh of electricity to replenish which approximately equates to an hour of slow recharging (13A).

2.4.2 Commercial Power Requirements

A significant aspect of commercial recharging is the inclusion of medium sized vehicles (vans and minibuses). At present such PiEVs have higher capacity batteries, higher energy consumption and recharge typically via 3 phase supplies. This presents a greater capacity requirement for the recharge infrastructure.

A typical consumption of 0.3 kWh/mile is assumed for lightweight small vehicles, whereas medium sized PiEVs with typically a gross weight of 7500 kg or more will consume more. Data sourced from Smiths[4] who manufacture electric powered vans, indicate 150 miles range from a 130 kWh battery. This equates to a consumption 0.87 kWh/mile which when considering charging efficiency may be in the region of 0.9 kWh/mile.

This high energy requirement as a result of higher consumption may be counteracted by typically shorter trip distances. However, there may be many trips completed over the duration of a day between recharges, for example a delivery round.

Typical power requirements for commercial PiEV recharging are illustrated in Figure 2.4.2. The green squares represent the PiEV power requirements and corresponding recharge durations for a sample of scenarios presented previously in Table 2.3.2, taking into account vehicle type

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[3] Transport Trends 2009, DfT, http://www.dft.gov.uk/pgr/statistics/datatablespublications/trends/

[4] Smiths Electric Vehicles Technical Data, http://www.smithelectricvehicles.com/ourranges.asp/

and total trip distance between recharging. The recharging power requirements translate to the power requirements at the PiEV interface.

With the simplest recharging system of one charger unit with its own supply, the power required will scale linearly with the number of recharging points. For example, using a slow recharge of 3 kW, 10 PiEVs in a car park will require a combined peak power of 30 kW and 100 PiEVs will require a combined peak power of 300 kW. This peak will then quickly drop off with the posts not active for the majority of the connection period.

Note that Figure 2.4.2 shows the power requirement to provide the energy to cover the expected trip distance. This is not the total range of the PiEV and nor does it consider that a PiEV may be fully recharged overnight and steadily depleted in SOC during the course of the day, regardless of trips and recharge intervals.

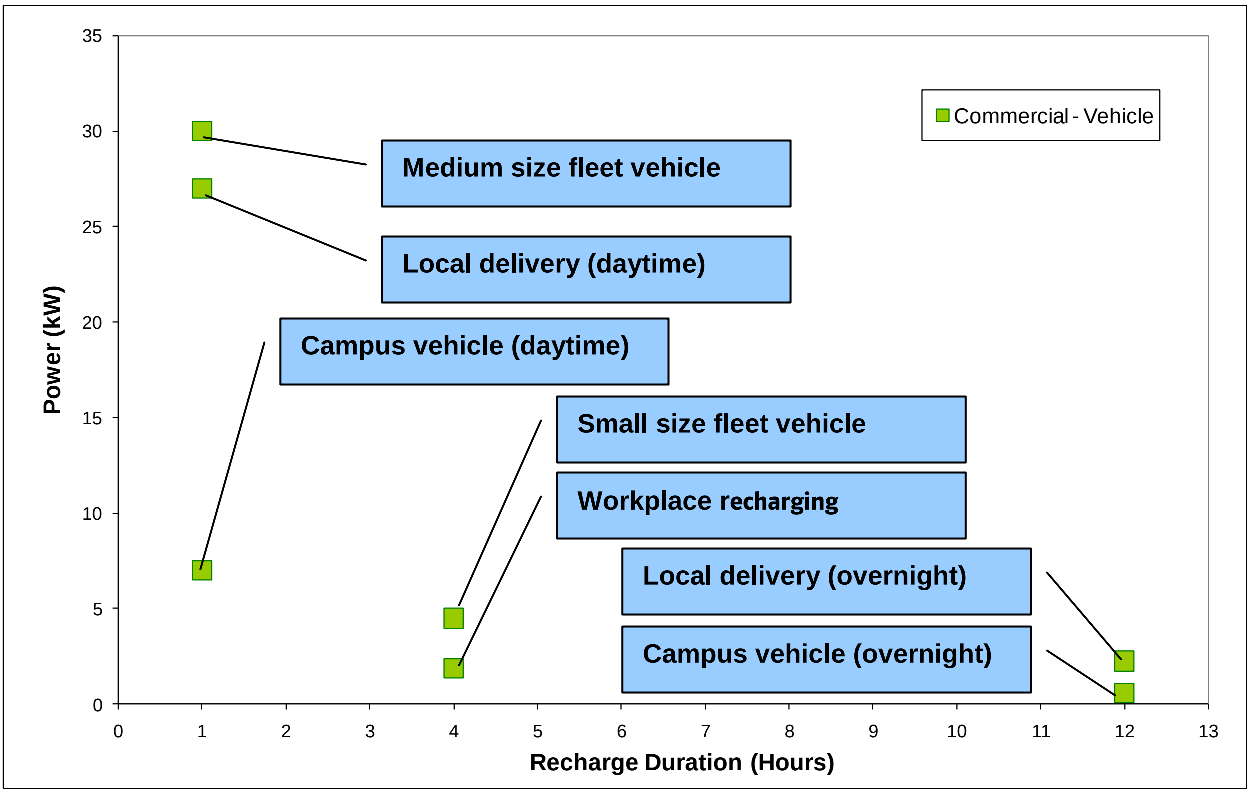

Figure 2.4.2: Spread of Commercial Recharge Requirements Based on Table 2.3.2

2.4.3 Public Power Requirements

Figure 2.4.3 shows the power and duration requirements for public recharging scenarios presented previously in Table 2.3.3. In all scenarios, small to medium sized vehicles are considered with a typical consumption of 0.3 kWh/mile.

The majority of the identified recharge scenarios for individual PiEVs require only a slow (13A) recharge capacity as seen in Figure 2.4.3. Not shown in Figure 2.4.3 is the airport parking scenarios which typically have long connection durations such that the power requirement is negligible.

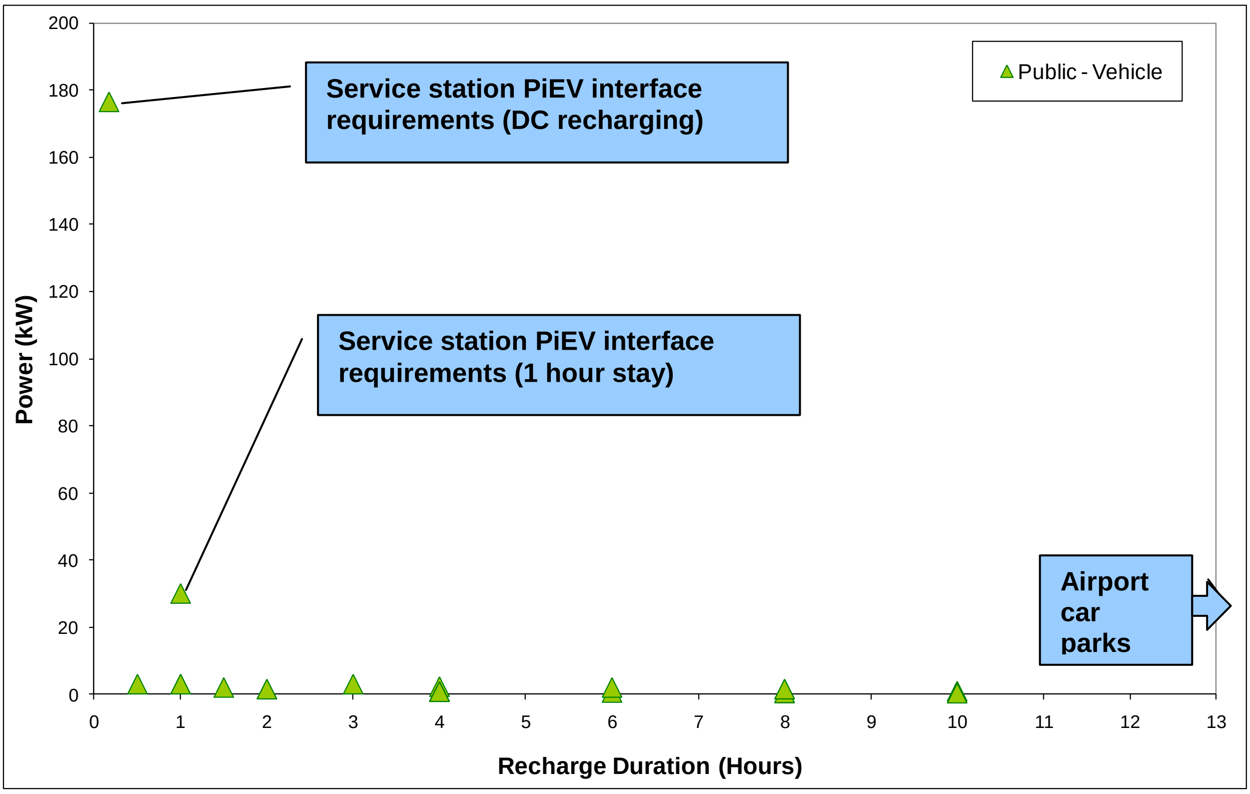

Figure 2.4.3: Spread of Public Recharge Requirements Based on Table 2.3.3 (Standard Supply)

Service stations present the greatest power requirements. The individual PiEV recharge levels are particularly high due to the large trip distances and short durations to recharge. A trip distance of 100 miles has been assumed for the service station scenario presented in Figure 2.4.3. This is the practical range of presently emerging PiEVs which could recharge half way on a 200 mile trip. Recharge durations of 10 minutes and 1 hour are considered which yield power ratings above the limits of a 3 phase PiEV connector (and therefore DC recharging is required).

2.5 Power and Charge Point Usage Requirements Summary

Table 2.5 shows the charge point usage requirements identified in Section 2.3 (Table 2.3.4) mapped against energy requirements.

Table 2.5: Charge Point Usage Mapped Against Power Requirements

Req. ID	Charge Point Usage Requirements	Req. ID	Power Requirements
CP1.0	Energy supplied to the PiEV should be sufficient to meet the intended range of the PiEV user (or maximum capacity of the PiEV battery) and this must be transferred during recharging within an acceptable timescale.	PR1.0	Energy supplied to the PiEV should be sufficient to meet the intended range of the PiEV user (or maximum capacity of the PiEV battery) and this must be transferred during charging within an acceptable timescale.
CP1.1	Domestic recharging infrastructure must support the full re-charge of a PiEV passenger car within 8 hours.	PR1.1	Domestic recharging infrastructure must support a minimum of 13A (3kWh) charging.
CP1.2	Some domestic users will require faster charging times, typically around 4 hours for a full charge (e.g. to charge up visiting relative's vehicles).	PR1.2	Some domestic users will require infrastructure to support 32A charging.
CP1.3	Some domestic users may require multiple vehicles to be charged simultaneously at home.	PR1.3	Some domestic users will require infrastructure to support 2 or more 13A or 32A recharging points.
CP1.4	Commercial recharging infrastructure must support the full charging of light vehicles within 8hours, to support employee commutes or the recharging of company vehicles overnight. Faster recharge times may be required in some cases.	PR1.4	Commercial recharging must support 13A recharging of a number of vehicles at the same time. Recharge rates of 32A are likely to be desirable.
CP1.5	Commercial recharging infrastructure may need to support the full charging of heavier vehicles within 8 hours (overnight recharge).	PR1.5	Commercial recharging may need to support charging at greater than 50A; higher rates are likely to be desirable.
CP16	On street public charging will probably be used to partly recharge vehicles and therefore must be able to top up 50% of the battery of a typical passenger vehicle within a maximum of 4 hours.	PR1.6	On street public recharging must support 13A recharging.
CP1.7	On street public charging will probably be used to partly recharge vehicles and therefore will *ideally* be able to top up 50% of the battery of a typical passenger vehicle within a maximum of 2 hours.	PR1.7	It is desirable for on street public recharging to support 32A or three phase recharging.
CP1.8	Public rapid charging (e.g. at motorway service stations) will need to provide a passenger vehicle with a full charge in approximately 30 minutes, ideally less.	PR1.8	Public fast chargers (e.g. at motorway service stations) will require a minimum of a three phase supply for DC charging.

2.6 Additional Usability and Operational Requirements

A high level requirement is that recharging should be convenient. Table 2.6 shows requirements that relate to the operational aspects of the recharge point.

Table 2.6: Usability and Operational Requirements

Req. ID	Requirements
UR1	Clear user interface for recharging status, errors and payment information.
UR2	The recharge point must be easy to use and maintain
UR3	Kerbside parking spaces should be delimited, for example, with painted lines.
UR4	The recharging unit should clearly indicate which bay it belongs too, thus avoiding crossing of cables or possible redundancy of bays.
UR5	Recharging posts shall be located such that users have easy access.
UR6	The recharging bays shall have adequate signage (safety and street signage).
UR7	The recharge point shall clearly indicate the recharge status.
UR8	The recharge point shall clearly indicate its availability, which is visible on approach.
UR9	Interoperability (recharging capacity as well as connectors/hardware) is required to enable PiEVs to charge in multiple locations.

2.7 Business Requirements

A high level requirement is that the infrastructure should be cost effective and able to operate in a commercially viable manner. Table 2.7 expands on this high level requirement.

Payment for the recharge energy is a significant consideration of a public recharge point. Whilst billing systems are out of the scope of this document; public and some commercial recharge points shall have to take into account equipment for methods of payment.

Table 2.7: Business Requirements

Req. ID	Requirements
BR1	Recharge point installation costs shall be minimised to meet a user’s requirements.
BR1.1	The supply connection capacity should be minimised, thereby providing the most cost effective recharging solution.
BR2	Bi-directional power flow shall be accommodated to support V2G where required.
BR3	The energy consumed must be accurately metered and billed.
BR4	A method of payment/billing may be required for public and commercial locations.

Intelligent architecture covering communications and business models and supporting infrastructure are examined in detail under SP2/IBM/27[5]. The current regulatory environment is examined in detail in report SP2/E.ON/07[6]. V2G and V2H is examined in detail SP2/EDF/06[7].

2.8 Safety Requirements

As with any electrical system, there is an inherent danger or risk to personal safety. PiEV recharge points are no exception and due to the potentially large user base, this risk will only be amplified. Therefore, it is essential that every party involved in the PiEV recharge post supply chain ensures that every reasonable measure is taken to minimise the risks associated with PiEV recharging.

Any electrical work that is done in the home needs to comply with Building Regulations Part P (Electrical Safety)[8] which requires that installations meet the safety standards in British Standard BS 7671 Chapter 13[9].

For commercial recharge points, The Electricity at Work Regulations 1989[10] defines health and safety regulations that must be observed with regards to using electricity in work places.

For public recharge points (in additional to all other installations), the Electrical Safety, Quality and Continuity Regulations 2002[11] require the safety of equipment and work carried out, and quality of the power supply.

Appendix Q outlines foreseeable hazards, risks and likely consequences associated with PiEV recharge posts. Mitigation measures, including some statutory obligations, have been identified along with the parties who may be responsible for implementing them. The measures listed are not exhaustive and ensuring compliance with them does not necessarily guarantee that all legal duties have been satisfied. The hazards have been broadly categorised as follows:

- Design & Specification of Equipment.
- Environmental Hazards.
- Hazards associated with a fault scenario.
- Potential risks foreseeable from everyday use.
- Risks during Inspection, Test and Maintenance activities.

Table 2.8a summarises the safety requirements identified which aim at providing a safe means of recharging a PiEV, therefore avoiding the deterioration of system components, and mitigating the risk of electric shock.

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[5] SP2/IBM/27 Completion Report - System Integration and Architecture Development

[6] SP2/E.ON/07 Recharging Infrastructure Implementation Recommendations Final report

[7] SP2/EDF/06 Vehicle-to-Grid (V2G) & Vehicle-to-Home (V2H) Evaluation

[8] Building Regulations Part P (Electrical Safety)

[9] British Standard BS 7671 – Requirements for Electrical Installations; the IEE wiring regulations

[10] The Electricity at Work Regulations 1989

[11] Electricity Safety, Quality and Continuity Regulations 2002

Table 2.8a: Safety Requirements

Req. ID	Requirements
SR1	The installation must be fit for purpose, suitable for the load and designed to withstand fault current characteristics.
SR2	Shall provide protection against over-current and thermal constraints.
SR3	Hazardous live parts must not be accessible (even after removal of parts that can be removed without a tool).
SR4	Exposed conductive parts must not become live under normal operating conditions and single fault conditions.
SR5	Shall have suitable protection against low speed impact.
SR6	Shall have suitable protection against electric shock as a result of mechanical disconnection (high speed impact).
SR7	The PIEV recharging infrastructure shall be capable of supplying power to an electric PiEV such that equipment ratings are not exceeded.
SR8	The recharge point shall be easily accessible and within a reasonable distance of a PIEV recharge bay.
SR9	The recharge point shall have a means of electrical isolation.
SR10	Able to ensure safe connection of PiEV before energy is transferred.
SR11	A safety interlock shall prevent the cable connector from being removed from the recharge point socket whilst the system is energised.
SR12	Able to de-energise the system if unsafe operation is detected.
SR13	Current capacity limits of the charging infrastructure should be available to the charging control.
SR14	Must be designed to limit the introduction of harmonic, DC and non-sinusoidal currents that could impact the operation of protection devices and other equipment.
SR15	Shall minimise the injection of harmonic currents on to the power network.
SR16	The positioning of the recharging unit should consider the operation of the PiEV, e.g. reversing, and opening of PiEV doors.
SR17	The recharging unit will be subject to periodic inspections.
SR18	PiEV recharging unit must be earthed according to location and standards.
SR19	The recharging circuit should be protected by residual current protection with an operating current not exceeding 30mA – operation of this system should be tested quarterly.
SR20	An energy supply point must be within reach of the PiEV inlet socket, using conventional connection means (e.g. an accredited cable).
SR21	Must provide the means to verify that the PiEV is safely connected.
SR22	Must provide the means to verify that the earth conductor is continuous.
SR23	A safety interlock shall prevent the PiEV connecter from being disconnected from the PiEV inlet whilst the system is energised.
SR24	The recharging cable should have increased visibility, considering periods and areas of low light. In addition there should be sufficient contrast between the cable colour and that of the backdrop.

Req. ID	Requirements
SR25	Recharging cable should be flexible to minimise trip hazard.
SR26	Recharging cable must be able to withstand suitable impact and “drive-over” tests.
SR27	The PiEV cable length should be standardised.
SR28	Recharging cable design and installation should consider handling by a user.
SR29	The placement of a recharge point shall consider pedestrian access routes.
SR30	Shall adhere to traffic management orders for on-street sites.

All installations should be in compliance with the IEE wiring regulations and all components comply with their relevant standards. Some of the key electrical safety standards applicable to PiEV infrastructure design are listed in Table 2.8b

Table 2.8b: Electrical Safety Regulations

Req. ID	Requirements
ST1	Shall provide suitable protection against electric shock (IEC60364-4-41).
ST2	Protection against direct and indirect contact (IEC60364-4-41).
ST3	Stored energy after disconnection of the recharging equipment from the supply mains shall be below a required level (IEC61851).
ST4	Operating temperature of connectors must be according to regulations IEC 60309-1/2; IEC60884-1.
ST5	Connectors should be easy to connect and disconnect without excessive force IEC62196-1.
ST6	Installations must adhere to standards relevant to electrical installations in domestic, public or commercial environments. Any installation that is carried out must comply with BS7671:2008 Wiring Regulations. This defines the requirements for safe electrical installations. In many respects, a PiEV is like any other load in that the protective devices, circuitry and other components must be rated for the load under normal operating conditions as well as fault conditions. The wiring regulations do not explicitly refer to PiEV installations; however, additional protection against electric shock is required for external equipment. This is in the form of a residual current device (RCD). The recharge point must be suitably IP rated for the environment it will be installed in as described in the standard. A rating of at least IP54 should be used for external sockets. However, situations where it is envisaged that the installation may be subject to power water jets i.e. whilst cleaning then an IP56 rated should be considered.

2.9 Additional Technical Requirements

The distribution network interface includes all equipment required to safely connect between the recharge point installation and the distribution network.

The primary component in the distribution network interface is the consumer unit or distribution board depending on the location. This component may serve other loads within the property which must be considered in the design requirements of the distribution network interface.

The financial meter, including future smart metering, is outside the scope of this report; however, it is accepted that some control and billing functionalities of smart meters may interface with the PiEV recharge point.

Table 2.9 presents distribution network interface requirements. The primary focus of these is to minimise the impact of PiEV recharging on the electricity supply network and to meet Ofgem regulations (as described in SP2/E.ON/07).

Table 2.9: Distribution Network Interface Requirements

Req. ID	Requirements
AT1	PiEV recharging during system peak demand should be minimised to avoid infrastructure reinforcement.
AT2	The distribution network interface should ensure that the load on phases is balanced where appropriate.
AT3	The suitability of the incoming supply cable for the additional PiEV recharging infrastructure shall be assessed prior to installation.
AT4	PiEV loads must be considered in conjunction with other loads within the property.
AT5	Shall facilitate the control of reactive power (leading and lagging).
AT6	Installation of loads greater than 7 kW must be reported to the local Distribution Network Operator (DNO).
AT7	A fiscal meter should be installed at the point of connection to the distribution network.
AT8	The recharge point shall have a fiscal meter for each recharge point connection.

3 CONSTRAINTS

This section examines the key constraints, or barriers, that exist to achieving the requirements identified in Section 2.

3.1 Power Constraints

The constraints and impact of PiEVs on the distribution network is a major topic of this project and is the subject of work package 2.1 and 2.3. A full discussion of the LV network and the impact on it from PiEV uptake and the mitigation options available can be found in reports SP2/EDF EN/01[12] and SP2/IMP/09[13]. The meter (including SMART meters) is outside of the scope of this analysis and is covered in report SP2/EDF/05[14]. This section is concerned only with the constraints from a recharge point user or installer's perspective, not from those of the DNO managing the LV network.

One of the main constraints in meeting the power requirements identified is the limitation of the electricity supply currently available from the Low Voltage (LV) network at each location. For high level background information on LV networks see Appendix P.

Where PiEV recharging is incorporated into an existing supply, the additional load as a result of PiEV recharging should be considered in tandem with the existing load.

3.1.1 Domestic Loads

Most UK domestic dwellings have single-phase supplies. This acts as an upper limit on the amount of power that could feasibly be supplied to a domestic PiEV recharge point. Further limitations are set by the rating of commercially available components such as circuit breakers, connectors and cables. The component with the lowest rating in the system will dictate the level of current that the PiEV can safely draw.

The installation of the PiEV recharge point should also be considered within the context of the local domestic load requirements. Long recharging durations will increase the possibility of the PiEV load coinciding with other loads in the home on the same circuit (reduced diversity); this could result is operation of overload protection in the home.

Typical single dwelling domestic load profiles are shown in Figure 3.1.1[15]. (Half hour settlement periods, as shown in Figure 3.1.1, are routinely used by the electricity industry when describing load profiles as electricity is traded using these settlement periods. Settlement period 0 represents midnight and each subsequent period represents 30 minutes (e.g. settlement period 24 is noon to 12.30)).

The blue line, Profile Class 1, shows how an average unrestricted customer will consume energy over the course of a day. Peak consumption reflects the activities of the occupants of the house as they wake up in the morning or return from work in the evening.

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[12] SP2/EDF EN/01 "LV & HV Network Constraints Identification"

[13] SP2/IMP/09 Report on potential reinforcement / mitigation options

[14] SP2/EDF/05 Intelligence Upgrade Cost Report

[15] Profile Class 1 – unrestricted customers as defined by ELEXON

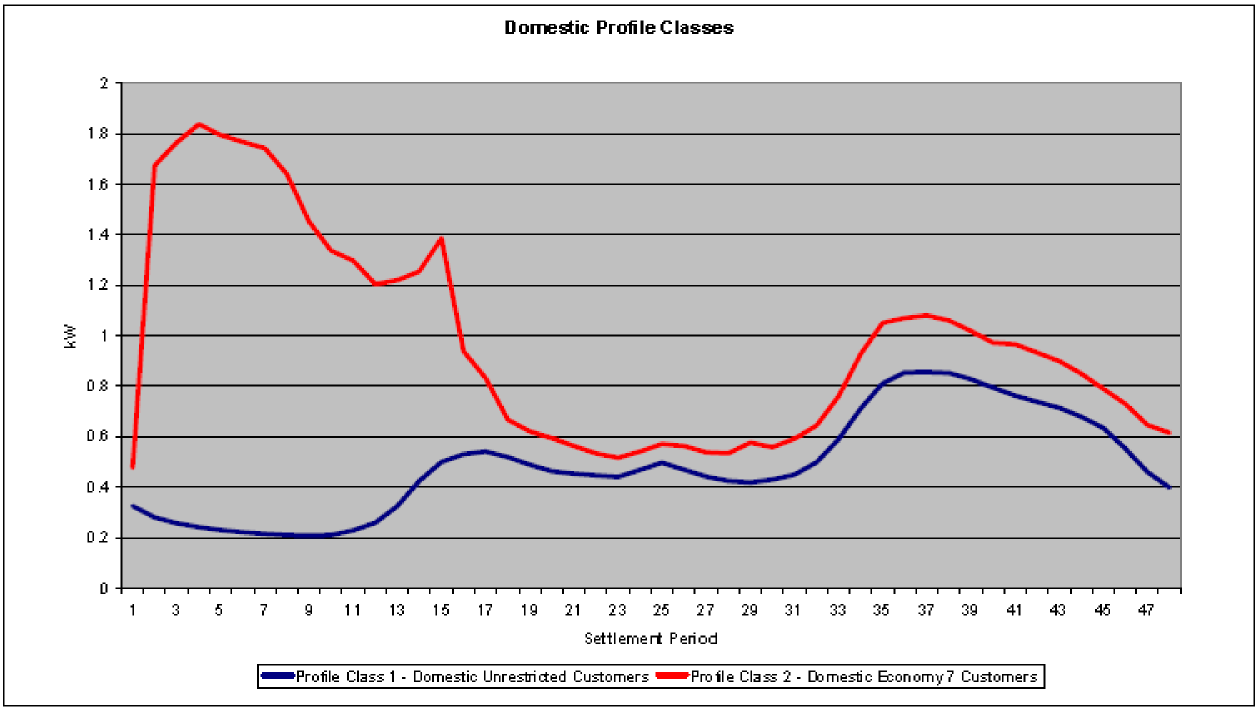

Figure 3.1.1: Typical Winter Weekday Domestic Load Profiles

The red line, profile class 2, illustrates a large peak that starts at around settlement period 0 occurring at midnight. This peak reflects the transition from day to night rates on an economy 7 tariffs and the power required by domestic latent heating systems which are automatically triggered to operate during the 7-hour period of cheaper night time rates. This results in a significant load being shifted from critical peak times to times when the electricity network is not as heavily loaded. The benefit of load shifting is that it can alleviate the need to invest in infrastructure in locations where the network is operating close to system capacity.

The most basic domestic recharging solution is a 13A charger (requirement PR1.1). This would mean that the PiEV battery could draw a maximum power of approximately 3 kW during its recharge cycle.

In the future, PiEV users may require higher levels of energy transfers in order to reduce the time required to recharge their PiEV. This could be achieved by installing a dedicated single phase circuit rated at 32A (requirement PR1.2). In this case the maximum power capacity would be much higher (up to 7.5 kW).

From Figure 3.1.1 it is evident that PiEV loads could require significantly more energy than that required by an average domestic load. Additionally, the duration of this load is likely to be several hours.

The instance of PiEV recharging will normally be significant and needs to avoid contributing to the domestic and distribution LV circuit peak loads.

The long duration of overnight recharge instances indicates that the domestic load profile is likely to change significantly, with a rise in energy demand overnight. Additionally, there are expected to be an additional contribution to the peak load if users choose to plug their vehicles in as soon as they get home, during evening peak loading times (see Figure 3.1.1, Settlement Periods ~33-43).

It should be remembered that the analysis presented in this work, considers general practices and using typical worst case scenarios. A more detailed case specific analysis is required to understand the potential effects of PiEV load on a particular network and consequent new build requirements.

3.1.1.1 Design Considerations

Residential properties are usually supplied via single phase services. These are distributed across the phases of the mains cable as evenly as possible to balance load. Electrically heated properties may have three phase services. Currently, less than 1% of domestic properties in the UK have three phase services[16].

A typical connection arrangement for a residential house is shown in Figure 3.1.1.2. The services are breech jointed directly onto the mains. Service cables do not have their own individual protective device; they are protected by the mains cable protective device. Each DNO uses a set of standard size mains and service cables. Typical sizes and ratings of standard mains and service cables are given in Table 3.1.1.2a and Table 3.1.1.2b, respectively[17].

Table 3.1.1.2a: Typical Mains Cable Sizes and Ratings

LV Mains Cables - Residential Housing			
Size (mm^2)	**Application**	**Continuous Summer Rating in Ducts**	
		A	**kVA**
95	Branches, cul de sacs etc.	201	145
185	Main feeders and interconnectors.	292	210
300	Electric heating sites. Other sites where volt drop or loop impedance requirements can't be met by 185 mm^2.	382	275

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[16] From Meetings with Central Networks design engineers, October 2010

[17] Central Networks Design Manual

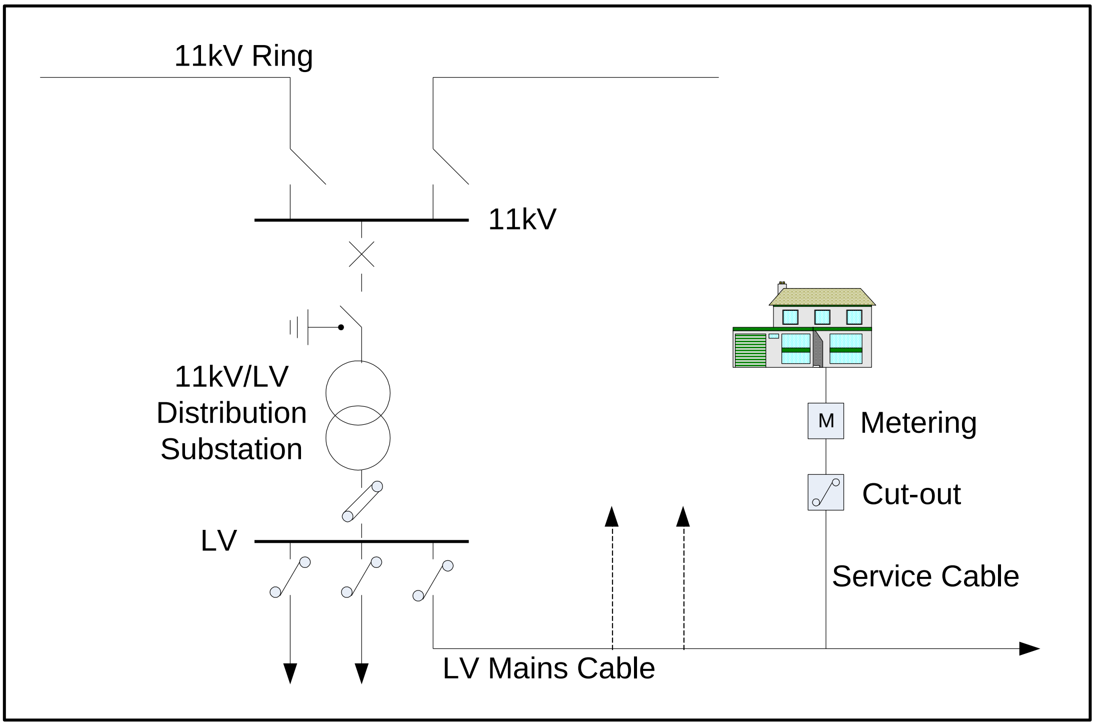

Figure 3.1.1.2: Typical Electrical Connection Arrangement to a Domestic Property

Table 3.1.1.2b: Typical Service Cables and Cut-outs used by DNOs

Service Cables and Cut-outs			
Service Size (mm^2)	**Application**	**Cable Cont. Rating in Ducts**	**Cut-out Rating in Meter Box**
35 hybrid	1-ph **80 A Cut-out fuse** Non-electric heating	115A 24 kW	80A=16 kW
35 hybrid looped service	1-ph **80 A Cut-out fuse** Non-electric heating	115A 24 kW	80A=16 kW (90A=18 kW main and loop)
35 hybrid	1-ph **100 A Cut-out fuse** Direct Acting Electric heating	115A 24 kW	90A=18 kW
35 hybrid	1-ph **100 A Cut-out fuse** Electric storage /mixed heating	115A 24 kW	90A=18 kW
35 hybrid Wavecon	3-ph **100 A Cut-out fuse** Electric storage /mixed heating	100A 62 kW	90A=54 kW

In general, all new domestic properties will have an outdoor meter box unless prohibited by local planning regulations. Where the use of internal services is unavoidable they are terminated in a cut-out immediately inside the building.

Similar to mains and service cables, each DNO has a standard set of service cut-outs. Typical cut-out (fuse) ratings associated with domestic properties are also listed in Table 3.1.1.2b. The existing non-electrically heated properties usually have a lower rating cut-out (typically 80A); whereas the properties with electric heating will have a higher rating cut-out (typically 100A). However, regardless of type of the heating new build properties are usually equipped with a 100A cut-out.

Mains cables supplying non-electrically heated residential properties are normally equipped with a 315A fuse, although a 630A fuse may be used in extreme circumstances. Similarly, mains cables supplying electrically heated properties are normally equipped with a 400A fuse though a 630A fuse may be used under some cases.

3.1.1.2 Service Cable Loading (per Individual House)

The loading on a service cable supplying an individual domestic property, depends on the property's peak load characteristics. This is mainly influenced by the type of heating (electric or non-electric) associated to that property. Most DNOs use a standard service cable (such as a 35 mm^2 hybrid cable as given in Table 3.1.1.2b) irrespective of the loading.

Depending on the type of heating, number of PiEVs per property and their connection type; the following eight scenarios are analysed for domestic properties:

Case A: Non-electric heating.

Case B: Direct electric heating.

Case C: Electric storage *plus* direct heating.

Case D: Electric storage heating only.

Case E: Electric storage heating *plus* one 1-ph 13A recharging point.

Case F: Electric storage heating *plus* two 1-ph 13A recharging points.

Case G: Electric storage heating *plus* one 1-ph 32A recharging point.

Case H: Electric storage heating *plus* two 1-ph 32A recharging points.

The first four scenarios (Cases A to D) represent domestic properties under different types of heating but without PiEVs (base cases). The second four scenarios (Cases E to H) represent the properties with storage heating *plus* one or two PiEV recharging points per property. The number of bedrooms in a property is not considered as part of the service cable loading design; however, they are considered in determining the ADMD for mains cable design (see Section 3.1.1.4).

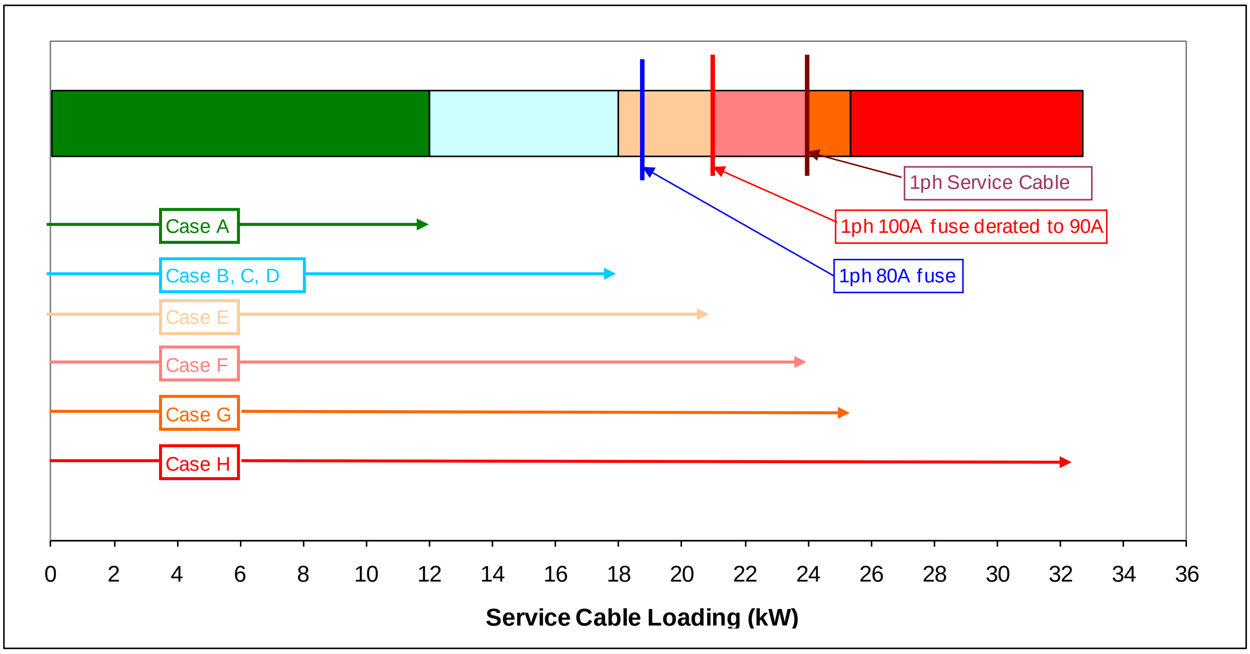

Figure 3.1.1.3: Domestic House Service Cable Loading

Figure 3.1.1.3 shows service cable loading under the scenarios listed previously. It can be seen that PiEV loads can have a significant effect on cut-out and service cable loading. For properties without electric heating the effect of PiEV loading is less pounced. The electrically heated houses may not have any margin left (with the standard 100A cut-out) to connect more than a single 13A charger.

However, the load diversity within an individual house also needs to be taken into consideration. A service cable is not frequently expected to be subjected to its ‘calculated’ maximum demand. Also, a service cable can carry up to double its rated current for a few hours. Similarly, a cut-out fuse can also carry up to 1.5 times its rated current for a short time. A general DNO view is that it is possible to manage one 32A recharging point, on top of storage heating load, without any significant adverse effect on the standard cut-out or service cable[18]. Currently the DNO must be notified of instantaneous shower unit loads exceeding 7.2 kW so they can assess the suitability of the local LV network with regards to flicker[19]. It is expected that the same requirement will be introduced for 32A PiEV recharging.

DNOs have a cut-off figure for cut-out/service cable loading, above which a three phase supply will be recommended. This is mainly due to the fact that the imbalance introduced by the single phase service loads can increase beyond acceptable limits (as stipulated in Engineering Recommendation P29[20]).

3.1.1.3 Mains Cable Loading (Feeding Multiple Houses)

Mains cables for residential loads are selected based on the arithmetic sum of the after diversity maximum demand (ADMD) of each individual connected property. Each DNO has its own way of calculating ADMD; however, the philosophy is similar.

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[18] Meetings with Central Networks design engineers, October 2010

[19] Engineering Recommendation P28 - Addendum 3

[20] Ofgem, Standard Licence Conditions http://epr.ofgem.gov.uk/index.php?pk=folder100992

Figure 3.1.1.4a shows typical ADMD values of domestic properties under the scenarios listed in Section 3.2.1. The case of two recharging points is applied only to the properties with more than two bedrooms. The ADMD values for Cases E to H were calculated by adding the respective PiEV load to the corresponding ADMD value under Case D (storage heating load). This means 'zero diversity' is assumed for the PiEV load. This is because, as described in Section 3.1.3, the recharging window (or time taken to fully recharge the battery) of PiEVs is comparatively higher than any other large electric load (such as washing machine, electric cooker or even electric heaters) within a domestic property. Also, the initiation of the recharging window is more likely to occur during the peak load.

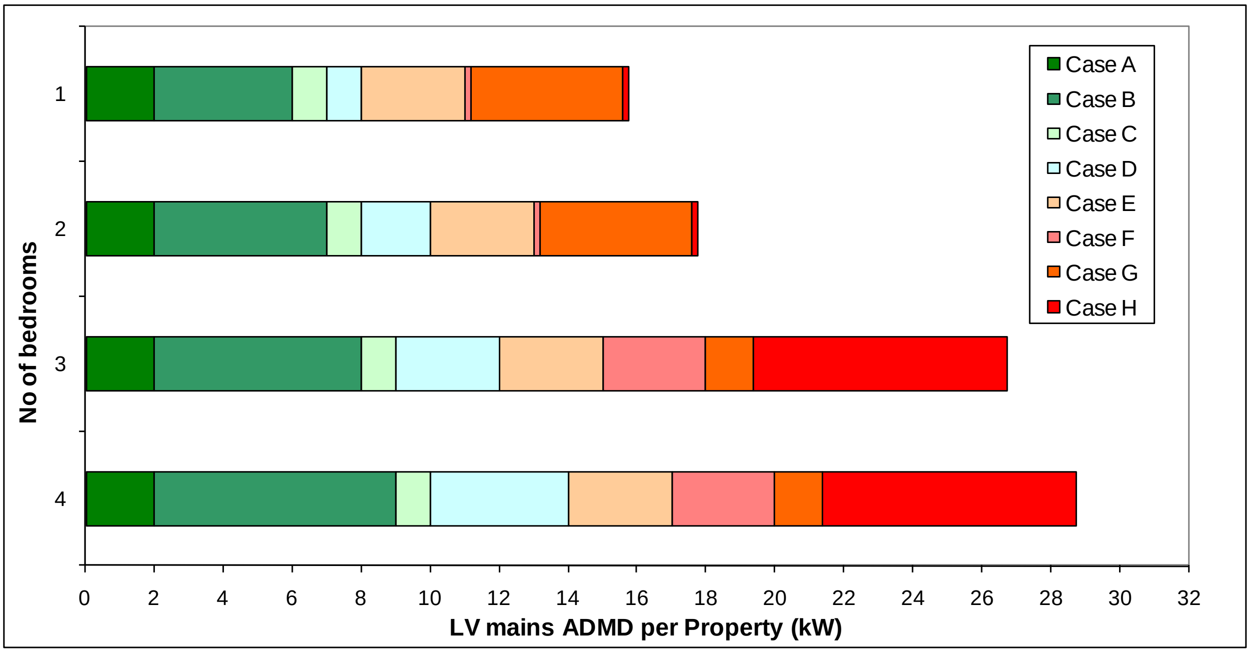

Figure 3.1.1.4a: After Diversity Maximum Demand of Domestic Properties

As mentioned previously, the number of bedrooms in a property has an influence on its ADMD. From Figure 3.1.1.4a it can be seen that the ADMD of electrically heated properties is much higher than non-electrically heated properties, and it is highest for properties that have electric storage heating.

Mains cable loading is the arithmetic sum of ADMDs of properties connected to that cable. As shown in Figure 3.1.1.4a, addition of PiEV load increases ADMD of individual properties substantially. This can have a significant effect on the mains cable loading under high penetration of PiEVs, as illustrated in Figure 3.1.1.4b. In this example a 100% penetration of PiEVs (i.e., 1 PiEV per property is assumed and therefore Cases F and H are omitted).

As an example, a 300 mm^2 mains cable (275 kVA rated) can supply approximately 28 (=275/10) [Rating/ADMD from Figure 3.1.1.4a] two bedroom houses with storage heating (Case D). If each of these houses had one PiEV each recharging at 13A (Case E), it can only supply 21 (=275/13) houses.

Things get worse for 32A recharging. If each of the properties in the above situation had one PiEV recharging at 32A, then the mains cable can only supply 16 (=275/17.4) two bedroom houses. It can be argued that a 100% penetration of PiEVs is an exaggeration of the situation, but this example explains the potential impact of PiEV load.

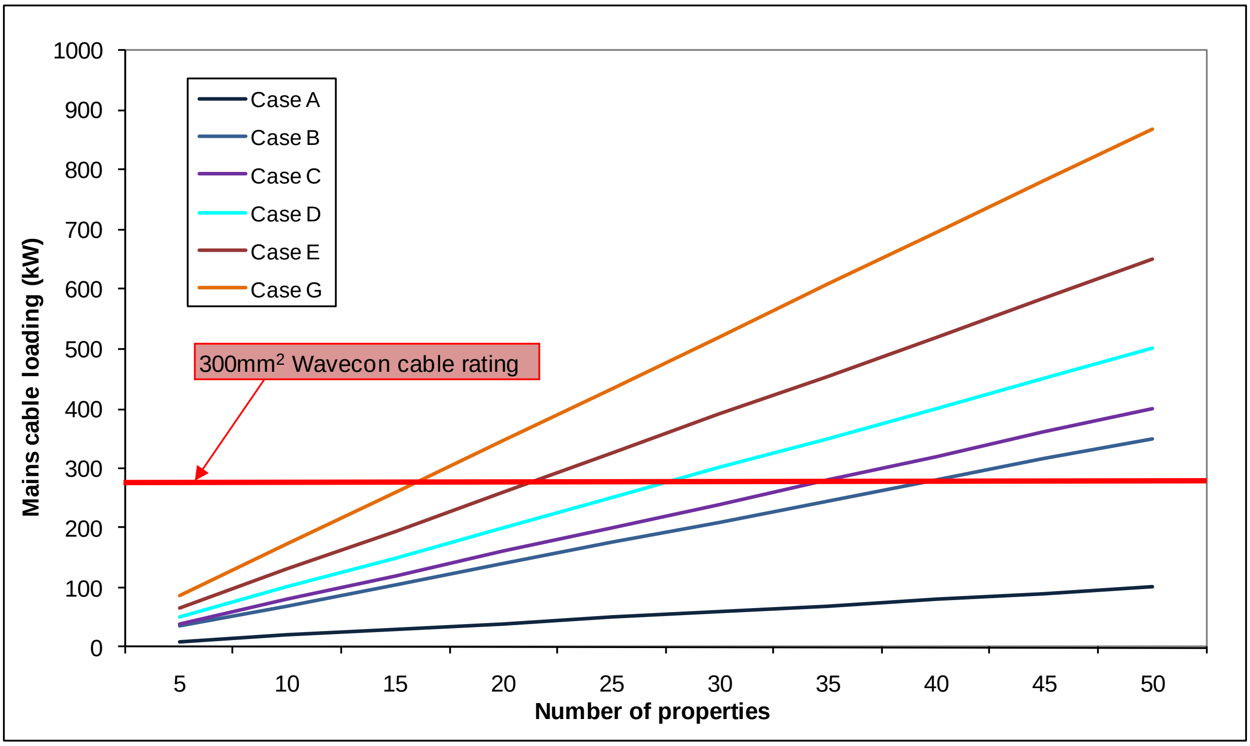

Figure 3.1.1.4b: After Diversity Maximum Demand of a Mains Cable Supplying Multiple Domestic Properties without and with PiEVs

The above analysis shows that high PiEV penetration levels can significantly impact the mains cable selection for new build properties. A high penetration can eventually lead to multi paralleled cable connections or the use of a new set of higher rating mains cables (greater than 300 mm^2).

3.1.1.3.1 Voltage Drop

Voltage drop along the mains and service cables increases as loads increase. As explained in the previous sections, the addition of PiEV recharging points increases loading of service and mains cables, which increases the voltage drop along them. Voltage drop along the mains cables can be an issue under higher PiEV penetration scenarios.

Voltage drop can get even worse if the PiEV recharging is done at lower power factors. DNOs assume a unity power factor for domestic properties. This is because domestic loading is mainly lighting and heating. However, this scenario may change with PiEV recharging as PiEV chargers can operate as lagging or leading reactive loads. In a worst case scenario, recharging can lead to the violation of statutory voltage limits (explained in Section 3.1.2). This can limit the length of the mains from the distribution transformer, which in turn may limit the number of customers allowed to connect to that mains.

The power factor performance of PiEV chargers will be an important factor in mains cable selection. Although currently there is not any power factor related requirement for domestic properties, in future DNOs may bring in strict power factor requirements for domestic properties with PiEV chargers. A power factor close to unity is always better from the DNOs point of view as losses are minimised and control of voltage is simplified.

It is important to remember that a case specific analysis, involving power flow studies, is necessary to understand the full extent of the PiEV effect on voltage drop at a particular location.

3.1.1.4 Blocks of Flats

It is a normal practice that blocks of flats will have a three phase supply installed at a central service (metering position) and lateral connections to flats are provided and owned by the flat owners. The service cables are selected based on the number of flats and type of heating. Depending on the service cable size a cut-out fuse as high as 400A may be used. If the number of flats is higher than a certain value as determine by in DNO design procedures (typically 30), multiple service cables and cut-outs will be used.

Figure 3.1.1.6 shows service cable loading for blocks of flats under the scenarios listed in Section 3.1.1.2 for simplicity, all flats are assumed to be two bedroom flats. Cases F and H are omitted for clarity because it is unlikely that flats will have two PiEVs. Depending on the number of flats a variable penetration level is assumed for PiEVs. As the number of flats increases it is more likely that the PiEV penetration level decreases as there will be fewer parking spaces per flat and it will be impractical to provide EV charging on the same supply as flats at higher levels.

From Figure 3.1.1.6 it can be seen that connecting PiEV loads to the same service cable that supplies flats can have a significant effect on service cable loading. For example, a 300 mm^2 service cable can accommodate 27 two bedroom flats that use electric storage heating (Case D). However, if each of these flats has one single phase 13A PiEV recharging point, supplied from the same circuit, the service can only supply 24 flats (Case E). Similarly, if each of these flats has one single phase 32A PiEV recharging point, supplied from the same service, it can only supply 19 flats (Case G).

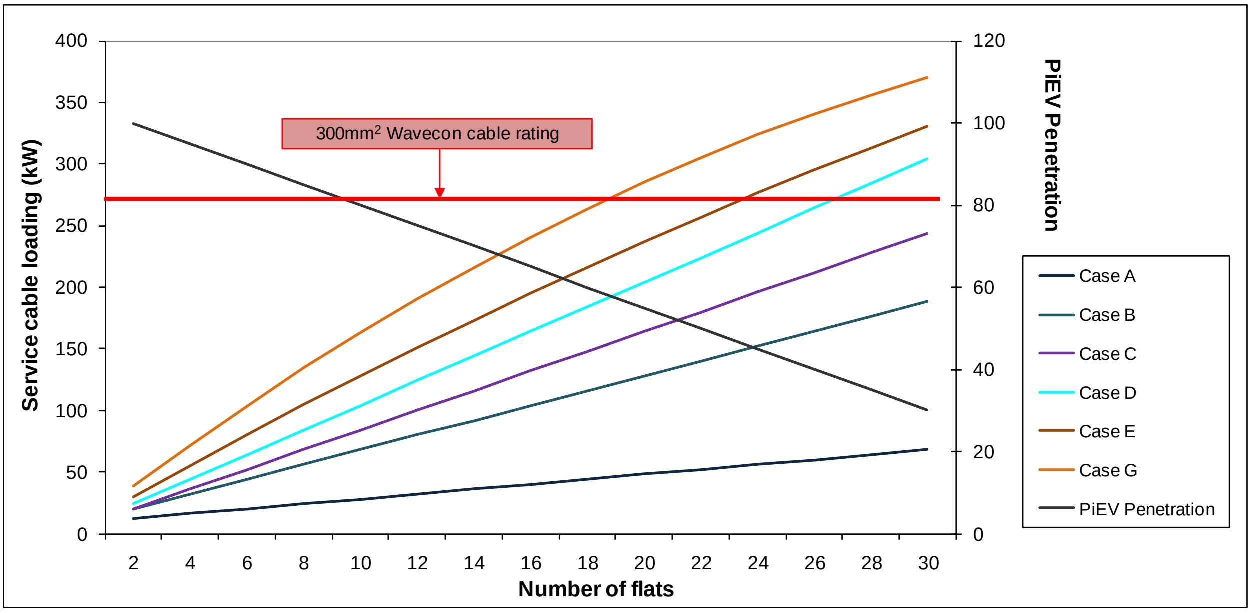

Figure 3.1.1.6: Loading on a Service Cable Supplying a Block of Flats

3.1.2 Commercial Loads

Commercial loads can vary from small shops with relatively small loads to large properties with specialist electrical equipment with high demand. Table 3.1.2a shows typical LV connected commercial applications and corresponding electrical load requirements. Large commercial loads (typically above 1000kVA) are usually HV supplied.

For small properties the equipment load requirements are identical to domestic properties; however they may exhibit a different daily load profile. Larger properties, greater then 20 MW are normally supplied via three phase services.

Table 3.1.2a: Typical Commercial Applications and their Load Requirements

	Commercial Type	Load (kW)
Case A	Small shop, salon etc.	10
Case B	Restaurant, pub, small hotel, small business etc.	20
Case C	Workshop, garage etc.	30
Case D	Church, milking parlour etc.	50

There are different types of connection arrangements to an LV supplied commercial location, including a connection from an existing/modified LV network, and one/two dedicated services direct from the distribution transformer. Total site load and local quality of supply requirements (such as voltage drop) dictate the required type of connection arrangement.

Table 3.1.2a shows typical cable sizes and their ratings used for commercial loads. Total site load and local quality of supply requirements dictate the required service cable to supply that particular site.

Table 3.1.2b: Typical Service Cables and Cut-outs used to Supply Commercial Loads

Typical Service cables used to supply small commercial loads			
Size (mm^2)	Current (A)	Power (kVA)	Cut-out fuse (A)
35	100	70	100/90
95	201	140	200
185	292	210	315
300	382	275	400

Figure 3.1.2a shows the effect of PiEVs on service cable loading. All recharging points are assumed to be 3 phase 32A, which is a typical requirement for commercial applications.

For example, consider a warehouse with a normal electrical load of 30kW (Case C). Such a warehouse will be typically supplied from a 35 mm^2 service cable. The warehouse may have a large fleet of vehicles out of which a few may be PiEVs. As shown in Figure 3.1.2a if the number of recharging points increases above 2, the total site load increases above the 35 mm^2 service cable rating. Hence, a 95 mm^2 service cable will be needed to supply that site.

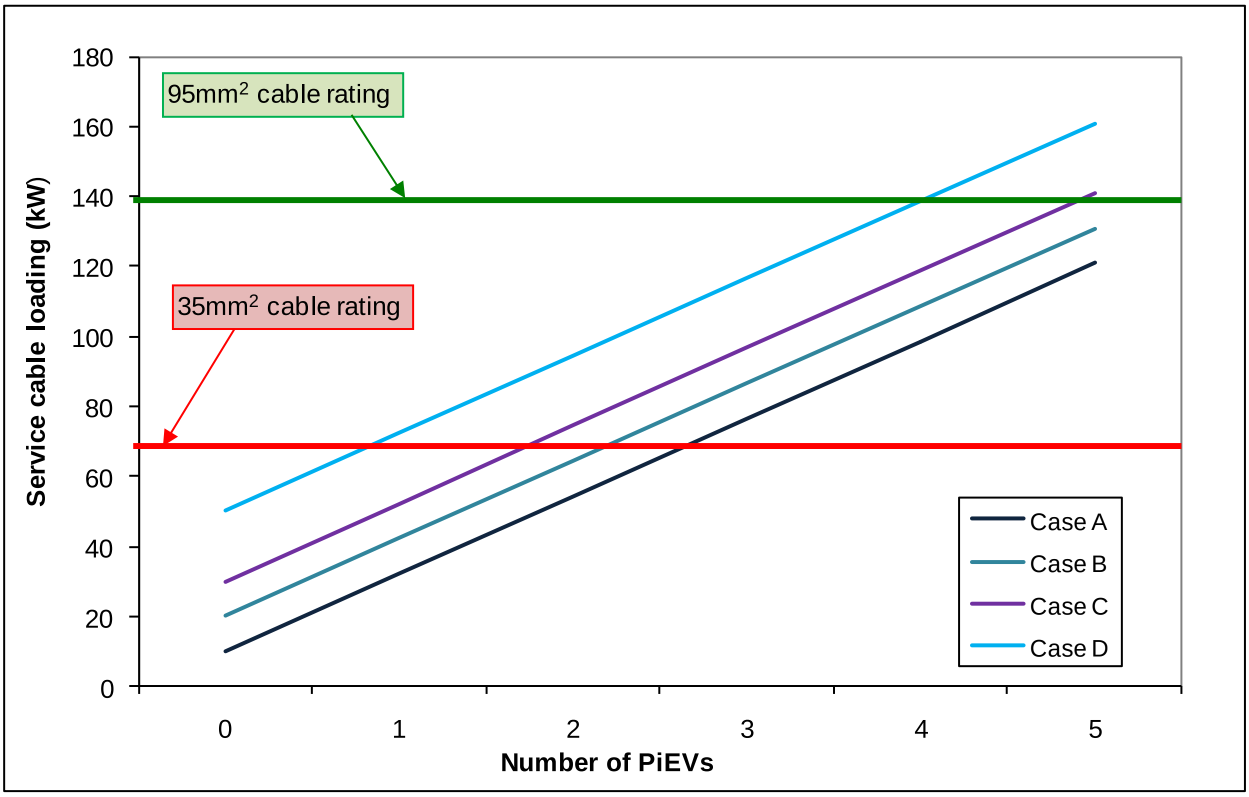

Figure 3.1.2a: Loading on a Service Cable Supplying a Commercial Load

Figure 3.1.2b shows the loading on a mains cable supplying multiple Case C (30 kW load) commercial properties. It can be seen that a 300 mm^2 cable can supply approximately 10 such properties with no recharging points. However, the same cable can only supply 4 such properties each with two 32A three phase recharging points. If the number of PiEVs per commercial location goes above 5 it will result in a need for a dedicated direct connection from the substation for each location. This shows that in extreme cases PiEV loads can result in a change of connection type required to supply some commercial locations.

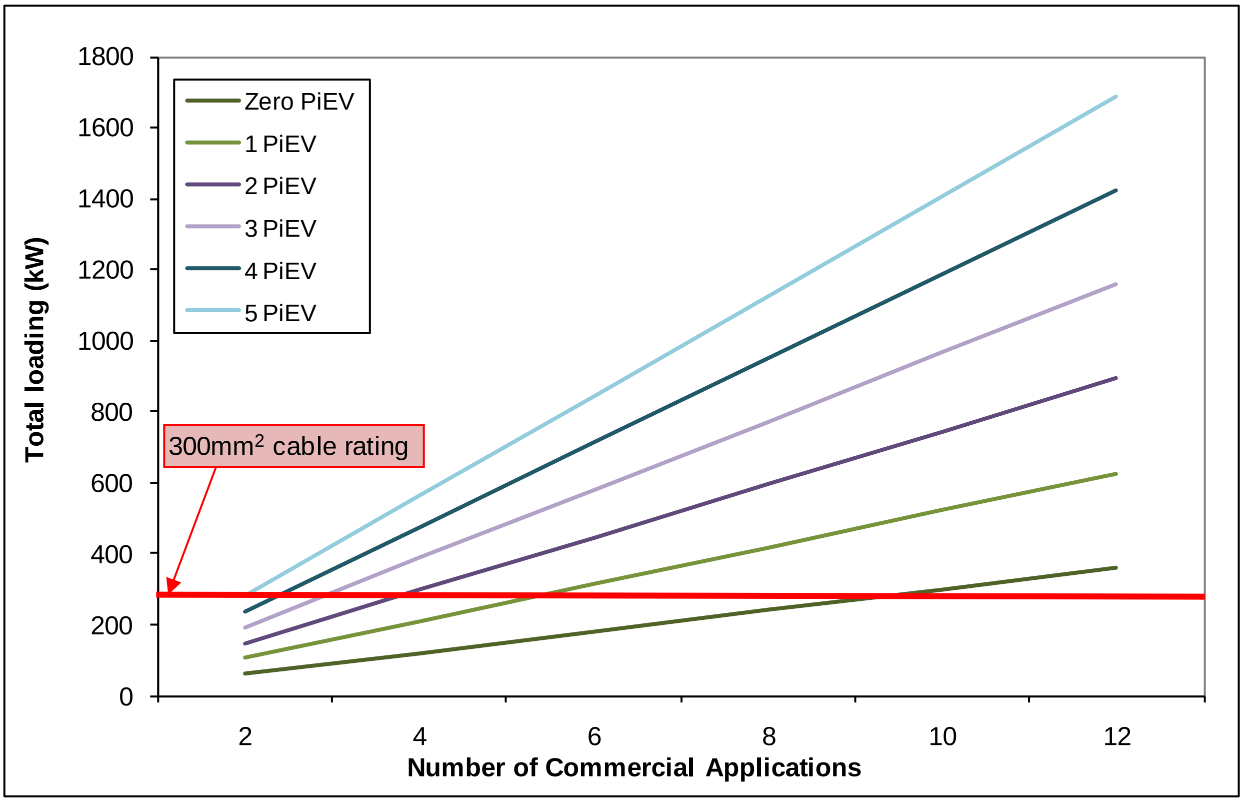

Figure 3.1.2b: Mains Cable Loading of Commercial Applications with PiEVs

Another important aspect that will have an effect on commercial applications is the load power factor. Commercial customers will be penalised for poor power factor load. Hence, power factor performance of PiEV chargers will be an important factor for commercial customers. A power factor close to unity is always better from a DNOs point of view.

Similarly to Figure 3.1.1 were domestic load profile classes were presented, there are two profile classes which refer to commercial properties as shown in Figure 3.1.2c. Profile class 3 shown in blue represents unrestricted customers, and profile class 4 shown in red shows economy 7 customers which accounts for a peak seen following midnight.

Both profile classes show peak load during the day time. For commercial PiEV recharging, the instance of recharge is expected to coincide with the baseload and therefore impact on power network. This is particularly true of workplace recharging which if uncontrolled would lead to a significant peak load at typically between the hours of 8am and midday.

Local load management systems for PiEV recharging as discussed in Section 5.2 should also consider the baseload of a location such as that typically shown in Figure 3.1.2c.

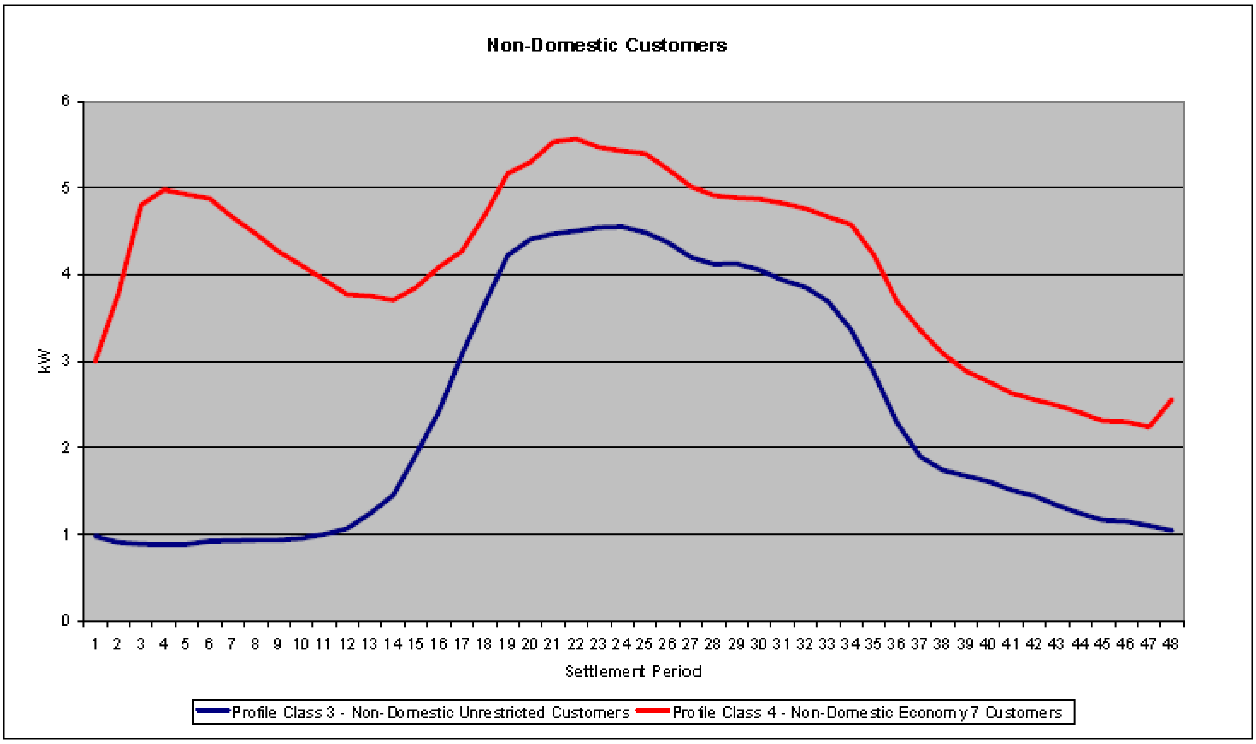

Figure 3.1.2c: Typical Winter Weekday Commercial Load Profiles

3.1.3 Public Loads

There are many possible types of public parking locations including dedicated parking locations (paid parking in multi storied buildings) and parking spaces near large supermarkets and other large retail shops etc (see Table 2.3.3 for more examples).

Regarding LV supplies, public recharging may be considered as stand alone or integrated in a commercial property.

Standalone public recharging applies to locations dedicated to parking with no or minimal other load; examples include kerbside parking, and public car parks. In such cases there will be no existing infrastructure and a supply can be sized accordingly as part of a new connection. Any constraints will therefore be found on the distribution network.

In cases were public parking is provided as part of other commercial premises, for example supermarkets. The PiEV load will be provided via the commercial supply. In such cases the appraisal provided in Section 3.1.2 applies.

3.1.4 Power Constraints Summary

This section summarises the power constraints research. Section 4 provides a summary of the Constraints against the related requirements.

The above analysis indicates that in general PiEVs contribute to increased loading of service and mains cables. High PiEV penetration scenarios may influence the design requirements for new builds.

Following are considerations for individual residential properties:

- Loading on domestic property service cables will increase significantly with the addition of PiEV load, and this can have adverse affects, especially for electrically heated domestic properties.
- Addition of PiEV load can increase the after diversity maximum demand of individual properties substantially. Under high PiEV penetration scenarios, this can lead to a substantial increase in mains loading.
- A high PiEV penetration can result in either a reduced number of domestic properties that can be supplied from a given mains or a requirement to use non-standard cable sizes (higher than existing standard rating cables).
- Voltage drop can be an issue under high PiEV penetration scenarios. A more detailed case specific analysis, involving power flow studies, is required to estimate the extent of the potential effect on network voltage drop due to PiEV load.
- A low power factor of PiEV charger can lead to adverse effect on voltage drop. A power factor close to unity is recommended.
- Alternatively, higher capacity conductors may be used to minimise the effect on voltage drop, a solution which can have significant cost implications.

Following are considerations specifically for blocks of flats:

- High PiEV penetration levels can lead to a substantial increase in service cable loading, resulting in a reduced number of flats that can be supplied by a given service cable.
- A separate service to parking areas is recommended under high PiEV penetration scenarios or where it is impractical to join a recharge bay directly to the domestic supply.

Following are considerations for commercial and public parking locations:

- Again, for small commercial locations high PiEV penetration levels can lead to a substantial increase in service cable loading, which may require the use of higher rated cables.
- High PiEV penetration scenarios may require the use of higher rated mains cables and in extreme cases may affect the required type of connection arrangements to individual commercial locations.
- Applications such as supermarkets will have large electrical load and hence these are mostly HV supplied. The addition of PiEV load is not expected to change the overall load significantly as the non PiEV load is already very high.

3.2 Physical Constraints

The most obvious physical constraint is the lack of a dedicated parking location with a suitable power supply available. These constraints are likely to deter certain users from purchasing a PiEV or they would need to rely on a different recharging regime (workplace, public recharging).

4 REQUIREMENTS AND CONSTRAINTS SUMMARY

This section summarises the requirements identified and the constraints on those requirements being achieved.

Table 4: Power Requirements and their LV Constraints

Req. ID	Power Requirements	Con ID	LV Network Constraint
PR1.1	Domestic recharging infrastructure must support a minimum of 13A (3kWh) charging.	NC1.1	For electrically heated properties, standard design procedure indicates that no more than a single 13A charger may be facilitated with the existing standard service cables and cut-out fuses. However, practical experience considering thermal cycles, indicates that a single 32A charger can be facilitated. Most domestic premises (those with a 100A supply) are able to meet this requirement without upgrading their supply. Those with an 80A fuse and electric heating will not be able to support EV charging.
PR1.2	Some domestic users will require infrastructure to support 32A charging.	NC1.2	Those properties with at least a 100A supply and without electrical heating are currently able to meet this requirement. (However the DNO must be notified of loads >7 kW so they must be informed of a 32A charger). Those properties with electric heating or an 80A fuse will not be able to support fast (32A) charging.
PR1.3	Some domestic users will require infrastructure to support 2 or more 13A or 32A recharging points.	NC1.3	Most domestic premises (those with a 100A supply) and no electric heating can currently support either two 13A charge points or one 32A charge point. Other types of properties or those with more vehicles cannot currently be supported.
PR1.4	Commercial recharging must support 13A recharging of a number of vehicles at the same time. Recharge rates of 32A are likely to be desirable.	NC1.4	Commercial premises with a low baseload and therefore supply (100A, single phase) will be constrained by the number of PiEV recharging bays (similar to domestic). Larger premises with higher capacity supplies will be able to accommodate multi-PiEV recharging; however, baseload must be considered.
PR1.5	Commercial recharging may need to support charging at greater than 50A; higher rates are likely to be desirable.	NC1.5	A three phase supply is required for this level of recharge. PiEV recharging must consider the baseload.
PR1.6	On street public recharging must support 13A recharging.	NC1.6	LV supplies are common in streets. Capacity may only be restricted by the distribution infrastructure.

Req. ID	Power Requirements	Con ID	LV Network Constraint
PR1.7	It is desirable for on street public recharging to support 32A or three phase recharging	NC1.7	LV supplies are common in streets. Capacity may only be restricted by the distribution infrastructure.
PR1.8	Public fast chargers (e.g. at motorway service stations) will require a minimum of a three phase supply for DC charging.	NC1.8	A significant number of public fast chargers at motorway services it likely to increase the load beyond that available. Availability of a high capacity connection may be costly due service station remoteness.

5 TECHNOLOGY OPTIONS

This section presents measures that may be adopted to mitigate increasing PiEV loads and technologies to address the requirements of PiEV users. Figure 5 shows a range of emerging technologies and where they may fit into the recharging infrastructure highlighted previously in Figure 1.

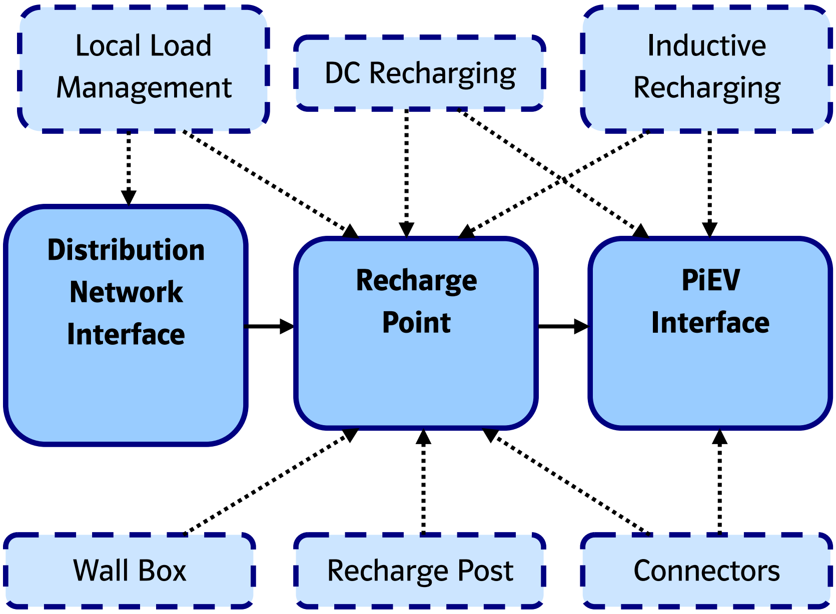

Figure 5: Technology Options and their Positioning in the Recharge Infrastructure

5.1 Power System Mitigation Measures

5.1.1 Network Design Solutions

This section presents some solutions to the power constraints identifies in Section 3.1

5.1.1.1 Domestic Loads

To avoid nuisance tripping of the overload protection in homes due to peak in domestic demand (as outlined in Section 3.1.1), a PiEV recharging circuit should have a dedicated feed from the consumer unit. In addition, to prevent nuisance tripping of the main circuit breaker, a device may be installed to monitor and manage the load of other circuits with high consumption (oven, showers, heating systems etc).

5.1.1.2 Service Cable Loading

A potential solution to the service cable loading problem is to recommend, where appropriate, a three phase supply to domestic properties with electric storage heating and PiEV loads.

An alternative solution is to install a load management scheme such that the cumulative loading does not exceed the cut-out/service cable rating at any given time.

5.1.1.3 Mains Cable Loading

It is possible to implement a load management system on individual PiEV chargers such that the mains cable is not over loaded. Due to the number of PiEV loads on mains cables a suitable communication infrastructure is required.

5.1.1.4 Blocks of Flats

A solution for the constraints identified in Section 3.1.1.4 for increased penetration of PiEV load in blocks of flats is to provide a separate supply cable to the communal parking. This is demonstrated in Figure 5.1.1.4 using the following two new scenarios:

Case I: Separate service to car park: one 1-phase 13A recharging point per flat.

Case J: Separate service to car park: one 1-phase 32A recharging point per flat.

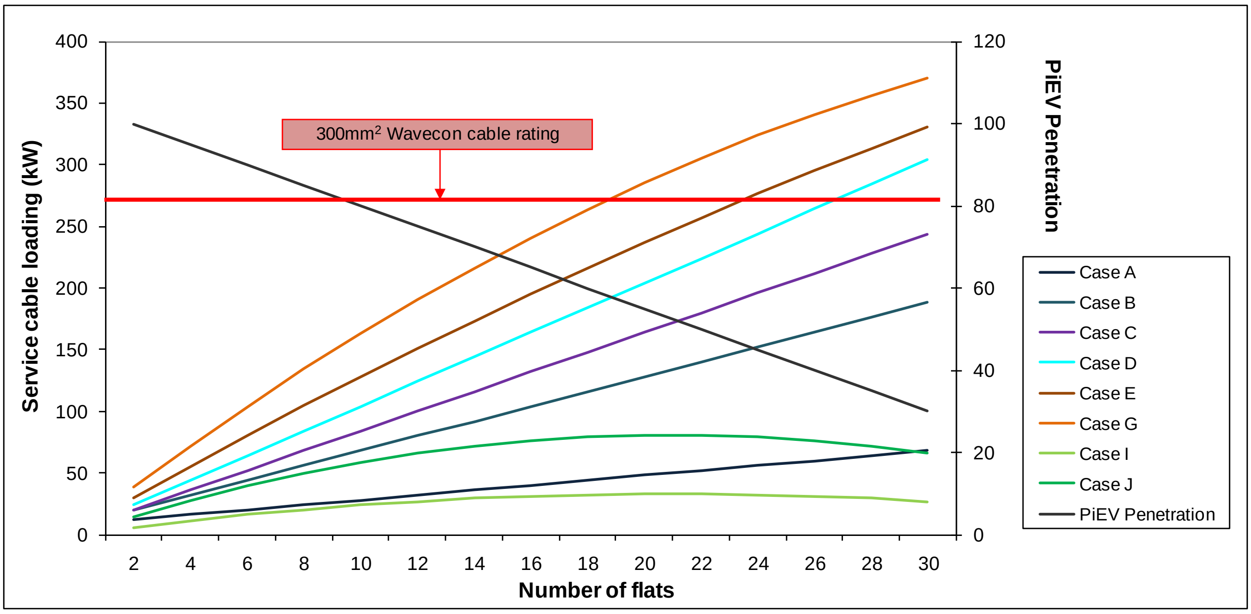

Figure 5.1.1.4: Loading on a Service Cable Supplying a Block of Flats

From Figure 5.1.1.4 it can be seen that the loading on the service cables can be effectively managed if it is a separate service to PiEV chargers. A separate service cable to recharging points, which will be located in the parking area, is also more acceptable from a practical point of view.

A future alternative approach could be to use a load management system to actively share the available supply power between all recharging units during the course of the working day; this technology is further discussed in Section 5.2.

Whilst a load management system has been discussed for an employee owned workplace recharging scenario, there may be benefits of such a system in other commercial situations. One example is to give fleet PiEVs priority recharging on the premise that they will have shorter connection durations and a defined route to meet the needs of the business. On the whole there are a wide range of commercial variations and a load management system would have to be designed for each condition in its own right.

Load management or even the basic design of a recharge installation should consider other loads on the same supply. Figure 3.1.2c shows a typical non-domestic load profile for locations with and without economy 7 tariffs. Unfortunately, though not unexpectedly, the base load occurs during the same hours an expected PiEV recharge would occur. With this consideration, overnight recharge of commercial based PiEVs would be preferential so long as the PiEV has sufficient battery capacity to cover the trips during the day. Alternatively a stationary storage scheme could be adopted that recharges during the night and can be used as the recharging supply during the day. This technology is further discussed in Section 5.2.

The majority of public recharging durations are relatively short, particularly in urban locations. A PiEV user’s decision to use such recharge points will be driven by the need to recharge in order to get to their next destination or to take an opportunity to recharge. In both cases there is a need to recharge without interruption in a short duration and therefore there is little merit in adopting a load management system.

5.1.2 Supply Upgrades

The simplest solution to a supply constraint is to get a new or upgraded supply to the property or charge point. Network reinforcement and related mitigation strategies are covered in report SP2/IMP/14 and SP2/EDF EN/01. Meter, (including SMART meter) costs can be found in SP2/EDF/05.

Table 5.1.2a and Table 5.1.2b show average new connection costs. New or upgraded distribution network connection costs largely depend on the distance to the nearest supply (the length of the cable run and the terrain it must cross (e.g. footpaths, roads, other utilities, local ground conditions)), available network capacity and any resulting distribution network reinforcement works. These factors lead to a huge range of new connection costs varying from zero to tens of thousands of pounds. Quotes for particular installations should be obtained from the local DNO, in some instances, it is very likely that high network costs will prohibitive and prevent a charge point being installed in a desired location, or the location will be moved to achieve a lower cost. For example, it will probably be significantly cheaper for rural property with a long driveway to install a new connection at the street end of the driveway, where the vehicle could be charged, compared to running the new supply the full length of the drive to charge the vehicle outside the house itself.

The DNO is responsible for managing the LV Network but reinforcement costs may be passed on to the user who requires the upgraded supply. A passive solution to the voltage drop problem is to use higher capacity conductors, a solution which DNOs may not like because of higher cost implications. Alternatively, smart systems could be implemented to control the PiEV charger power factor to minimise the impact on the mains cable. The commercial options for investment in the network are discussed in SP2/E.ON/07.

Such costs are therefore very location specific; however, transgressing the power thresholds (e.g. from single phase to three phase) are likely to result in significant extra connection costs.

Table 5.1.2a: New Single Phase Connection Prices

Service	Description	Average 2010 Price
Single Phase Domestic Connection	Includes excavation and laying a new service cable, and jointing to the existing network.	£1100[21]
Single Phase Public Charge post connection	Includes excavation and laying a new service cable, and jointing to the existing network.	£800[22]

Public street side posts are generally cheaper as they require shorter service cable runs than domestic premises. Table 5.1.2b shows the average of the median prices for the work for each DNO. It therefore represents the averages industry price but not the real actual cost of any particular DNO[23].

Table 5.1.2b: New Three Phase Connection Prices

Service	Details	Average of Median DNO Prices, 2010 Figure
Three phase service up to 200A per phase [120 kVA (de-rated)]	A single three phase service, from a passing main, including service cable, mains service joint, and termination. Service cable length up to 5 metres per service. Duct installation, excavation and backfill joint hole undertaken by third party.	£2047
Three phase service up to 300A per phase [180 kVA (de-rated)]	A single three phase service, from a passing main, including service cable, mains service joint, and termination. Service cable length up to 5 metres per service. Duct installation, excavation and backfill joint hole undertaken by third party.	£2168
Three phase service up to 400A per phase [240 kVA (de-rated)]	A single three phase service, from a passing main, including service cable, mains service joint, and termination. Service cable length up to 5 metres per service. Duct installation, excavation and backfill joint hole undertaken by third party.	£2890

Further details on the rules and regulations regarding connection works can be found in report SP2/E.ON/07.

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[21] Source: DNO Connection Charges Methodology documents

[22] Source: UK Power Networks, Average DNO cost of installing 600 public charge posts in 2010

[23] Source: Central Networks, January 2011

5.2 Local Load Management

This section describes a load management system dedicated to a PiEV recharging installation. It therefore does not cover the wider scope of demand side management which entails grid interfacing and tariff signals. Such measures are addressed in work package 2.4.

A local load management system should be considered as discussed in Section 4; this is prevalent to domestic properties with latent heating systems where the PiEV load must be managed around such demands.

Most generic loads are of short duration and there is little chance that all loads occur at the same time. The resultant diversity of these loads reduces the required network capacity. Conversely, PiEV loads have significantly longer demand durations, as identified in Section 2, and therefore the network interface capacity must account for reduced diversity. This results in significant costs to provide additional capacity, particularly when multiple PiEV recharge points are installed.

One solution to reduce the network capacity requirement is to implement a load management system. This system works on the principle of time shifting flexible load to a time when other loads are inactive. PiEV loads are generally the most flexible of loads due to their inherent storage which separates the demand of the user (for traction) with the demand on the network. Additionally the expected durations that PiEVs are stationary and therefore available for connection to the network, are greater than the trip durations.

Two possible load management functions are presented in this section. The first is a system which co-ordinates PiEV recharging in harmony with other loads and is ideally suited to domestic recharging. The second is a standalone system which only considers multiple PiEV recharging and is suited to large car parks. Both systems require some knowledge of expected duration of connection and subsequent trip distance; a user interface is therefore required. There is also the possibility to interface these systems to a wider smart grid or intelligent infrastructure linked into generation patterns, electricity prices or emission levels.

A domestic PiEV load management system will be suited to properties which have electric heating, cookers, showers, a second PiEV recharge point or PiEV fast charge capability. The primary role of the load management system will be to avoid the tripping of the main incoming circuit breaker. To implement this, the load of all power circuits must be monitored, and upon reaching a predetermined load threshold, recharging will be postponed or the recharging load will be reduced.

In a multiple recharge point car park situation, perhaps best suited to workplace charging where typical connection duration is 7 to 8 hours. Charging of vehicles could be staged throughout the day. Figure 5.2 illustrates how two possible systems could half the distribution network interface capacity required for the recharging of four PiEVs, each with a 12kWh recharge requirement. The first load management system starts recharging the first two PiEVs at the start of the recharge window; following the end of their recharge requirement the second two PiEVs start their recharge cycle. This system just requires a simple on/off control. The second load management system, however, has a more sophisticated current level control, whereby all four PiEVs start recharging together at half their rated current. The benefit of this system is that in the event that a user needs their PiEV midway through the day for a short run (e.g. lunch break), then there will still be a usable level of charge.

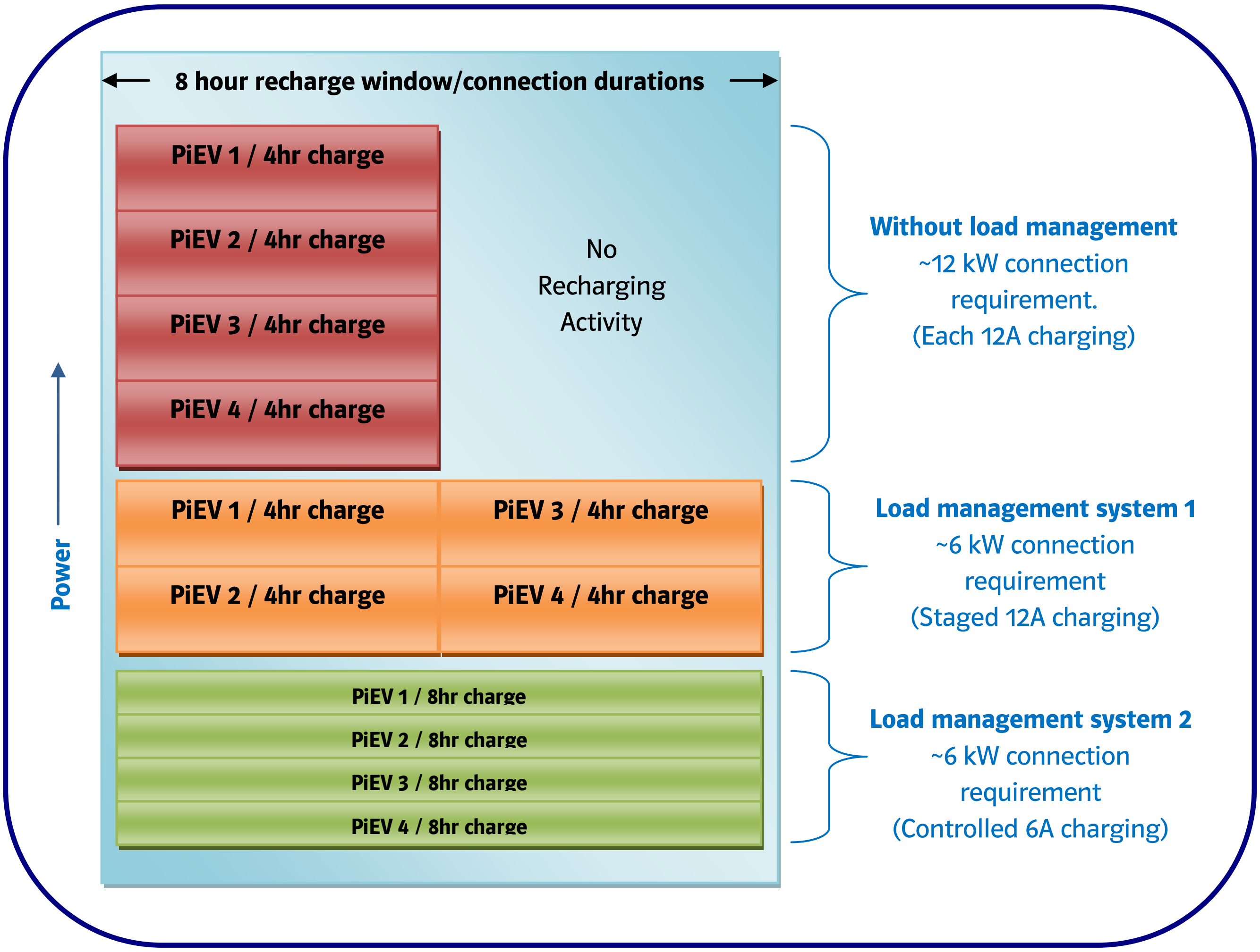

Figure 5.2: Illustration of Reduced Distribution Network Interface Capacity by Utilising Load Management

Figure 5.2 demonstrates the methods of “time shift” and “current level control” for a particular case. In reality there are many combinations of connection durations, number of recharge bays and energy requirements. However, in general the greater the number of recharge bays the greater the diversity and benefits that may be seen for local load management. Such benefits may include the difference in a single and three phase connection requirement as is presented in the example following:

Number of bays: 10

Maximum charge rate of each PiEV: 12A

Without local load management:

Load requirement = 10 x 12 = 120A:= 27.6 kW

Minimum connection requirement: Three phase supply, 40/50A per phase.

With local load management:

Diversity factor = 0.5

Load requirement = 10 x 12 x 0.5 = 60A: = 13.8 kW

Minimum connection requirement: Single phase supply, 63A per phase.

There are a number of control algorithms that may be adopted to suit a particular location; below are a list of possible strategies that may be adopted.

- Equal share available to each vehicle.
- First come first served until capacity reached.
- Prioritise to least charged first (smallest kWh available in battery).
- Prioritise to least charged by SOC percentage first.
- Prioritise to most charged first (smallest kWh until completion).
- Prioritise to most recharged by SOC percentage first.
- Prioritise based on deemed relative importance of connected vehicles, e.g. recharge company own fleet vehicles before employee vehicles.
- Prioritise based on price/unit of delivered energy user is prepared to pay.
- Prioritise based on predicted miles of energy required, i.e. a heuristic type analysis.
- Dynamic balancing providing greater recharging rate to the least charged vehicles, but progressively reducing recharging rate as the vehicle’s SOC approaches 100%.
- Charging slots giving a certain time at full rate charging, before moving on to the next vehicle, e.g. 30 minute slots.

5.3 Energy Storage

The inherent storage of a PiEV in combination with a load management system may not be viable if user connection profiles align with the infrastructure peak loading. Another option that may be adopted is to utilise off board energy storage. Network energy storage solutions are not covered in this report as the benefits of such systems are primarily for the power system network (voltage/frequency stabilisation, generation/load matching). This report focuses on the merits of local energy storage for PiEV recharging or recharging infrastructure.

An advantage of off board (stationary) energy storage is that there is not the same demanding battery requirement as there is for PiEV batteries, with respect to energy and power density. As a result more established battery technologies may be used which are significantly cheaper and generally have an increased number of charge cycles capability.

The principle of stationary energy storage for PiEV charging is that the stationary battery charges at times when the domestic (or commercial) load is low, a PiEV may then recharge from the stationary battery at peak times giving the PiEV user the greatest convenience of connection. An additional benefit is that greater PiEV recharge rates may be realised without impacting the power system or local charging infrastructure as would be seen if the PiEV was directly coupled.

The decoupling (or buffering) of the power source and PiEV recharging may be used in conjunction with the load management system described in the previous subsection. In such systems greater flexibility of recharging can be offered with a reduced network connection capacity.

A drawback of stationary energy storage is that an additional DC to DC conversion stage is introduced between the stationary battery and the PiEV battery. This stage is introduced to control the flow of energy between batteries, implemented by the switching of power electronic devices which introduces additional losses. The losses are dependent on the operational point of the converter but typically will be of the order of 2%.

Vehicle to grid (V2G) and vehicle to home (V2H) systems utilise spare energy stored in the PiEV batteries to deliver back to the power system and home respectively. The benefit of these concepts is primarily for the power system. In the case of V2H the benefits are based on financial models of discharging at high electricity prices. With respect to the recharging infrastructure the same power components will be used as the power rating is the same but in the opposite direction. The primary concern of such systems is the possibility of energisation of an islanded system from the PiEV battery when considered isolated during maintenance or upgrade. This is a wider topic for embedded generation in general and a standardised solution is yet to be realised. V2G and V2H are covered in detail in report SP2/EDF/06[24].

5.4 Charging Options

Requirements identified in previous sections have shown the need for charge rates which exceed those presently available, and therefore bring about the need for new technologies to facilitate safe, convenient, interoperable charging, suitable for the installed infrastructure.

Previously, Figures 2.4.2 and 2.4.3 showed that the majority of recharge scenarios are within a 32A three phase supply limit, which is the present limit of a PiEV AC connector interface. Those which exceed this limit would require DC recharging, unless three phase connectors develop for 63A. As discussed in Section 5.6.2 following, these connectors may have drawbacks, although niche applications in the commercial sector may facilitate the development of these connectors.

Table 5.4 summarises a range of power connections for individual PiEV recharging instances identified in previous sections. The table suggests a recharge mode, station and coupling mechanism, which are further detailed in subsequent sections, and which can be incorporated into system designs as outlined in Section 5.

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[24] SP2/EDF/06 Vehicle to Grid (V2G) & Vehicle to Home (V2H) Evaluation

Table 5.4: Charging Options and Technologies

Recharge Rate (kW)	Location	Mode	Recharge Station	Coupling Mechanism
Slow				
3.1 kW (Slow)	Domestic (Present)	1	Single Phase Supply BS 1363 socket	BS 1363 (3 pin plug)
3.1 kW (Slow)	Public (Present)	1	Single Phase Supply BS 1363 Recharge post	BS 1363 (3 pin plug)
3.8 kW (Slow)	Commercial (Present)	1	Single Phase Supply IEC 60309 socket	IEC 60309
3.8 kW (Slow)	Domestic (Emerging)	3	Dedicated single phase supply with wall box connection	IEC 62196
Fast				
7 kW (Fast)	Domestic (Future)	3	Dedicated single phase supply with wall box connection	IEC 62196
7 kW (Fast)	Commercial (Future)	3	Dedicated single phase supply with wall box connection	IEC 62196
7 kW (Fast)	Public (Future)	3	Dedicated single phase supply with charge post connection	IEC 62196
11.5kW (Fast)	Commercial (Future)	3	Dedicated three phase supply with wall box connection	IEC 62196
11.5kW (Fast)	Public (Future)	3	Dedicated three phase supply with charge post connection	IEC 62196
Rapid				
23 kW (Rapid)	Commercial (Future)	3	Dedicated three phase supply with wall box connection	IEC 62196
23 kW (Rapid)	Public (Future)	3	Dedicated three phase supply with charge post connection	IEC 62196
DC-Rapid				
30-240 kW (DC-Rapid)	Commercial (Future)	4	Off-board AC to DC converter	DC connector
30-240 kW (DC-Rapid)	Public (Future)	4	Off-board AC to DC converter	DC connector

5.5 Wall Boxes and Charge Posts

The charge point is the interface point to the infrastructure; presented in this sub section are technology options which provide solutions in the domestic and commercial/public environments.

The requirements that have an impact on charge points and their locations, as identified in Section 2, are summarised in Table 5.5. Note that coupling and decoupling with the vehicle (connectors) is covered in Section 5.6.

Table 5.5: Charge Point Design and Installation Requirements

Req. ID	Requirements
SR1	The installation must be fit for purpose, suitable for the load and designed to withstand fault current characteristics.
SR2	Shall provide protection against over-current and thermal constraints.
SR3	Hazardous live parts must not be accessible (even after removal of parts that can be removed without a tool).
SR4	Exposed conductive parts must not become live under normal operating conditions and single fault conditions.
SR5	Shall have suitable protection against low speed impact.
SR6	Shall have suitable protection against electric shock as a result of mechanical disconnection (high speed impact).
SR7	The PIEV recharging infrastructure shall be capable of supplying power to an electric PiEV such that equipment ratings are not exceeded.
SR8	The recharge point shall be easily accessible and within a reasonable distance of a PIEV recharge bay.
SR9	The recharge point shall have a means of electrical isolation.
SR12	Able to de-energise the system if unsafe operation is detected.
SR13	Current capacity limits of the charging infrastructure should be available to the charging control.
SR14	Must be designed to limit the introduction of harmonic, DC and non-sinusoidal currents that could impact the operation of protection devices and other equipment.
SR15	Shall minimise the injection of harmonic currents on to the power network.
SR16	The positioning of the recharging unit should consider the operation of the PiEV, e.g. reversing, and opening of PiEV doors.
SR17	The recharging unit will be subject to periodic inspections.
SR18	PiEV recharging unit must be earthed according to location and standards.
SR19	The recharging circuit should be protected by residual current protection with an operating current not exceeding 30mA – operation of this system should be tested quarterly.
SR20	An energy supply point must be within reach of the PiEV inlet socket, using conventional connection means (e.g. an accredited cable).
SR24	The recharging cable should have increased visibility, considering periods and areas of low light. In addition there should be sufficient contrast between the cable colour and that of the backdrop.
SR25	Recharging cable should be flexible to minimise trip hazard.
SR26	Recharging cable must be able to withstand suitable impact and “drive-over” tests.

Req. ID	Requirements
SR27	The PiEV cable length should be standardised.
SR28	Recharging cable design and installation should consider handling by a user.
SR29	The placement of a recharge point shall consider pedestrian access routes.
SR30	Shall adhere to traffic management orders for on-street sites.
BR1	Recharge point installation costs shall be minimised to meet a user’s requirements.
BR1.1	The supply connection capacity should be minimised, thereby providing the most cost effective recharging solution.
BR2	Bi-directional power flow shall be accommodated to support V2G where required.
BR3	The energy consumed must be accurately metered and billed.
BR4	A method of payment/billing may be required for public and commercial locations
UR1	Clear user interface for recharging status, errors and payment information.
UR2	The recharge point must be easy to use and maintain.
UR3	Kerbside parking spaces should be delimited, for example, with painted lines.
UR4	The recharging unit should clearly indicate which bay it belongs too, thus avoiding crossing of cables or possible redundancy of bays.
UR5	Recharging posts shall be located such that users have easy access.
UR6	The recharging bays shall have adequate signage (safety and street signage).
UR7	The recharge point shall clearly indicate the recharge status.
UR8	The recharge point shall clearly indicate its availability, which is visible on approach.
UR9	Interoperability (recharging capacity as well as connectors/hardware) is required to enable PiEVs to recharge in multiple locations.
AT1	PiEV recharging during system peak demand should be minimised to avoid infrastructure reinforcement.
AT2	The distribution network interface should ensure that the load on phases is balanced where appropriate.
AT3	The suitability of the incoming supply cable for the additional PiEV recharging infrastructure shall be assessed prior to installation.

As recharge methods progress from Mode 1 and 2 charging to Mode 3, a dedicated charge point will be required in premises as standard socket outlets become redundant.

The primary feature of the charge point is the control pilot functionality as detailed in Section 5.6.4. Initial implementations utilise a Pulse Width Modulated (PWM) signal generated within the charge point. This signal is sent down the control pilot wire and returns via the earth wire hence checking the continuity of each. The PWM signal may be modified at the PiEV to indicate to the charge point the capacity of the PiEV.

The possibility of PiEVs adopting Mode 3 recharging, designed primarily for safety reasons, could also pave the way for segregating PiEV loads from general loads, and therefore the possibility of charging different rates for each. This may be desirable for work place charging when the recharge could be considered as a taxable benefit or for the introduction of specific taxation for PiEV recharging. Whilst these aspects are beyond the scope of this report, the need for the resulting dedicated PiEV energy meter may see charge points with metering capability. In addition the charge point may become the focus of all communications with the vehicle. This may range from local load management as further detailed in Section 5.2 to high intelligence functions beyond the scope of this document.

There are two main conductive charge point options, namely wall boxes and free standing charge posts. Both options may incorporate additional basic functions, such as RCD and MCB protection and timer operation.

Wall boxes vary in prices, the typical cost for a wall box (excluding installation) is £891. Note that some products adopt case C recharging, whereby the cable is permanently fixed to the power supply. Wall boxes could be purchased to supply 13A and/or 32A charging. Figure 5.5a shows two wall box products by manufacturers Pod and AeroVironment (AV).

Figure 5.5a: Home Charge Solutions (Wall Box)

Free standing charge posts are more robust as they are at greater risk of high speed vehicle impacts and vandalism as they are more exposed than wall boxes. Charge posts can be purchased to supply 13A and/or 32A charging. Most 13A posts are designed to allow easy upgrading from a 13A to a 32A supply and the upgrade can cost in the order of few hundred pounds. They can are also available with multiple sockets so they can supply multiple vehicles/ bays. Charge posts vary a lot in prices depending on manufacturer and features (e.g. RFID tag readers, integrated fiscal meter), the typical cost for a charge post (excluding installation) is £2,827. Figure 5.5b shows two charge post designs.

Figure 5.5b: Public Recharge Posts

5.5.1 Installation and Maintenance

The wall box needs to be securely mounted on a wall in close proximity to the vehicles' parking space (or in the user's garage). The location needs to be carefully chosen to minimise the cable run from the wall box to the PiEV when recharging and also to minimise the tripping hazard. Wall box installation requires a qualified electrician to connect the box to the consumer unit as per, or a NICEIC[25] wiring inspection report if the user wires the wall box into the mains themselves.

The typical life expectancy of a wall box is 15–20 years. It is recommended that they should be inspected annually; however, it is recognised that many domestic users may choose not to pay for their wall boxes annual inspection and instead call out an electrician if the wall box fails. As failure can cause the user significant inconvenience, wall boxes lend themselves to businesses offering users service and maintenance contracts (in a similar way to boiler or central heating care).

Charge posts need to be securely anchored to the ground, this is likely to require the excavation of foundations and the costs and consent required for this work (planning consent issues are covered in SP2/E.ON/07). The electricity supply to the charge post will also arrive from underground cables and enter inside the post at the base. Depending on the particular installation location and ownership, a fiscal (DNO approved) meter may be supplied within the post or in a separate feeder pillar which supplies multiple posts.

The typical life expectancy of a charge post is 10–15 years. Some manufacturers recommend quarterly inspections, all should be inspected annually as a minimum.

5.6 Coupling Mechanism

There are two categorises of coupling: inductive and conductive recharging. This section presents the advantages and disadvantages of inductive recharging and the numerous conductive recharging options and technologies that may emerge.

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[25] NICEIC, National Inspection Council for Electrical Installation Contracting, as per BS7671

5.6.1 Inductive Recharging

Inductive recharging does not have any mechanical coupling between the PiEV and recharging infrastructure. Energy is transferred by forming a magnetic flux path in a similar way to which power system transformers operate. The distinct feature of inductive recharging is that the PiEV and infrastructure are electrically isolated from each other which give the following advantages:

- Significantly reduced risk of electric shock.
- No need for conductive connectors and the resulting issues of interoperability, degradation, misuse by users and arcing during disconnection.
- No need for a cable and the resulting issues such as trip hazards, reduced access and cable length voltage drop.
- Recharging equipment can be integrated into the parking bay, thereby reducing the amount of street furniture.
- Strategically placed inductive recharging points can facilitate recharge “on the go”; such as being integrated in the road at traffic lights, bus stops, drive-throughs, or even areas of high congestion.

These advantages improve the general user operation and acceptance of recharge systems; however, from a technical point of view the magnetic losses created in the inductive recharge system are significant, and concerns over stray magnetic circuits interfering with pacemakers have led to inductive charging being previously rejected in America. Inductive charging technologies have significantly improved, reducing losses and tackling some of the electromagnetic compatibility (EMC) issues. This new systems is developed in New Zealand by Auckland Uniservices and brought to the UK by the development company HaloIPT. One of the innovative aspects of the HaloIPT system is the elimination of leakage flux. This was the main area of losses of preceding systems.

Losses remain greater than that of conductive recharging; whilst losses are dependent on a number of factors, initial tests have yielded losses of the order of 2% greater than conductive recharging. This assessment is based on the conductive system including the PiEV converter and battery charging being of the order of 90%. Note that excluding the PiEV converter and battery charging losses, the efficiency of a copper conductive cable and connector is greater than 99%. The HaloIPT system addresses the disparity of losses between conductive recharging by integrating the inductive recharging system into the PiEV converter.

To put the 2% additional losses of inductive recharging into context, the annual cost incurred due to 2% losses is £17.64. This is based on 2100 recharging hours at 3 kW on a tariff of 14p/kWh.

In addition to recharging losses, the inductive charging system has standing losses due to the system monitoring for vehicle presence. These losses are not known; it is therefore recommended that a trial be conducted to determine these losses and validate the recharging losses provided by HaloIPT.

HaloIPT presently provide single phase, 3 and 7 kW systems with a typical cost of £3,375 (excluding installation). However, the system is very much in a prototype stage and a significant reduction in cost is expected. Regardless, the inductive system requires additional equipment in comparison to conductive charging, so it is not expected that inductive charging systems will be greater in cost.

Usage of inductive charging systems may differ to that of conductive. For short durations of parking a user may not consider to connect a conductive system; whereas the recharging will automatically take place for inductive charging without any need for user intervention. This will maximise opportunity recharging, thereby reducing the transfer energy requirement for the primary recharge period.

Future developments for inductive recharging include three phase systems with 60 kW transfer capability, and dynamic recharging. Dynamic inductive recharging presents the opportunity of recharging whilst a PiEV is in motion (similar to an electric tram or train). Such systems will require significant lengths of recharge pads in the carriageway which will significantly increase infrastructure cost. At present there are challenges to address such are maintaining the air gap in the road, alignment of PiEV with the recharge pads and multi PiEV recharging on the same supply/ control area.

At present there is little information on dynamic inductive charging systems, and widespread adoption is not likely to be in the near term. The most appropriate adoption for such a system in the midterm would be PiEVs which utilise the same carriageway frequently, for example deployment on buses and common bus routes.

Inductive recharge systems are still in their infancy from which to gauge reliability and maintainability assessment. Connectors are subject to general wear and environmental conditions, the exclusion of these in inductive systems should improve reliability and maintainability over conductive recharging.

5.6.2 AC Conductive Recharging

Present PiEV power connectors utilise connectors that are presently used for general power applications, such as standard 3 pin plugs and sockets (BS 1363) and industrial connectors (IEC 60309). These connectors are not a long term solution for PiEV charging for reasons that are described in this section.

PiEV loads draw full load, continuously, over most of their recharge cycle, which can be as long as 8 hours. Therefore, compared to other domestic loads, there is an increased possibility of users disconnecting the plug under full load. This disconnection can result in arcing and consequent deterioration of the connectors (BS 1363).

Prolonged high current recharging also results in significant temperature rise of conductors, and subsequent disconnection will lead to risk of human contact with exposed hot plug pins.

In the case of domestic loads greater than 13A (e.g. ovens and showers), a connection method is not available, therefore such loads are hardwired directly to the consumer unit avoiding the disconnection under load issues mentioned in the previous paragraph.

Industrial connectors come in several forms and facilitate higher current connections (up to 32A) and higher voltage levels (phase to phase 415V as in three phase connectors). These connectors are intended for industrial applications and therefore to be operated by competent persons (significantly removing the possible operation by children). Some of the industrial connectors require significant force to part the connections and therefore would not be suitable for all possible PiEV users.

Emerging designs for PiEV connectors address some of the issues raised; incorporating the following design features:

- Control pilot circuit. Upon disconnection this circuit is broken before the power circuits, thereby signalling to the BMS to remove power before complete disconnection of the connector. This is achieved either through a manual button interlock or the configuration of conductor pins.
- Improved thermal capabilities.
- Safety interlock circuitry to determine connection of earth, control pilot and availability of PiEV and infrastructure prior to energy transfer.
- Charging capability interrogation. The maximum power transfer capability of the infrastructure and PiEV is determined avoiding the situation where the PiEV BMS may demand a higher current than the infrastructure is capable of. Present systems adopt a failsafe hardwired solution; however this could be carried out via a communications channel.
- Communication channels. A communication channel must be used for off-board charger control, however additional features such as smart grid interfacing, tariff optimisation, ancillary data services can be realised.
- Higher power transfer capabilities, through higher current capacities (32A) and three phase options.
- Proximity pin. Immobilises the vehicle while connected.

As described in Section 5.6.4.1, IEC working group TC69 is determining a standard for PiEV connectors addressing issues associated with PiEV recharging. Figure 5.6.2a shows a design proposed by Mennekes and pin descriptions. Note the inclusion of a control pilot pin which is shorter than the power pins and three power pins offering three phase recharging. The connector shown is also proposed for both the PiEV and infrastructure connector. A wall box is therefore required with associated control pilot functionality. This solution yields Mode 3 recharging and therefore the full capabilities of the connector may be utilised without the limitation of a standard infrastructure connector as is the case with Mode 2 recharging.

Figure 5.6.2a: A Proposed PiEV Connector (Mennekes Design)

Figure 5.6.2b shows two other designs put forward. The design offered by manufacturer Yazaki and adopted by the society of automotive engineers and standard SAE J1772 uses a button release for the control pilot disconnection function (as opposed to the shortened pins). This connector is offered only for the PiEV connection. The key feature of the SCAME connector is the cover which conceals the pins when disconnected.

Figure 5.6.2b: Further Proposed PiEV Connectors (Yazaki and SCAME Designs)

Connector manufactures Mennekes and Yazaki are considering recharge currents greater than 32A. The present standard BS EN 61851 does not consider AC charge currents greater than 32A and the future of currents greater than this has to be questioned. Practically a single phase 32A recharge has a significant impact on diversity of a 100A supply to properties; increasing this further will lead to a high probability of supply circuit breakers tripping. Additionally, Distribution Network Operators (DNO) may not accept such recharging due to the impact of imbalance of load between phases. The likely proposed solution would be to offer three phase recharging, yielding greater capacity.

Three phase recharging at greater than 32A is a significant load which leads to larger and heavier AC to DC converters. As space and weight is a premium in PiEV design, the likelihood is that an off-board AC/DC charger would be favoured; therefore resulting in a DC connector as opposed to an AC connector. Whilst it is accepted that there may be niche applications for recharge currents greater than 32A, this report will not consider AC recharge currents greater than 32A.

5.6.3 DC Conductive Recharging

Direct Current (DC) conductive recharging utilises an off-board power converter which converts an Alternating Current (AC) electrical waveform to a DC electrical waveform. Higher power transfers can be achieved as specified by standard BS EN 61581 with up to 240 kW capabilities. The high power transfers are achieved through controllable power electronic switching yielding voltages up to 600V dc and currents up to 400A dc.

Whilst 240 kW DC transfers are possible according to the BS EN 61581 standard, there are at present few batteries technologies that are able to accept such charge levels without significant battery degradation. These levels are therefore for future recharging as battery technologies advance. Such charge levels would require a non-standard LV grid connection (three phase, 400A MCCB). DC Chargers are available at lower power levels and individual units maybe controlled to operate at levels below their rated output.

A more practical maximum power rating for the near term is 69 kW. This rating yields a standard grid connection utilising a three phase 100A MCB. Whilst this rating is greater than can presently be accepted by batteries, the output can be controlled and allows for future expansion.

The power capacity threshold when DC charging is chosen over AC charging will be driven be PiEV manufacturers when considering the weight and space on the PiEV. Presently three phase 32A charging (23 kW) connectors are used for AC charging of large vehicles (electric vans), although smaller vehicles with less space may opt for DC charging at similar power levels.

Due to the high power ratings of DC chargers, instantaneous switching of full load could have a major impact on power systems. It is highly recommended that such systems have “soft start” functionality which ramps the power up at a controlled rate. This action will minimise voltage dips and allow for power system tap changers to react to the resulting reduction in voltage.

Figure 5.6.3 shows an off board charger; the weight and volume penalty if such unit where on-board vehicles would be significant. DC charging are of type Mode 4/case C, and therefore the interconnecting cable must be permanently connected to the off-board charger. No infrastructure connector is required as a result however the PiEV connector must be specific for DC coupling with a communication channel being mandatory. There are currently two DC connectors available produced by manufacturers Yazaki and Amphenol.

Off-board chargers are presently very expensive (£29,401) and there are few battery technologies that are able to accept such levels of power transfer without significant deterioration of the cells, battery manufacturers are not keen to warranty high transfers outside controlled laboratory conditions. The extra cost for recharging that would result for DC charging is generally not feasible for the present range of PiEVs. However, as the range of PiEVs increases and users adopt them for greater trip lengths, the constraining limits of domestic charging will be reached and therefore public rapid charging will become highly desirable. This is despite the expected increased cost of recharging to recover the additional infrastructure cost and maintenance of such chargers.

Figure 5.6.3: DC Fast Charger (AeroVironment)

5.6.4 Power Interface Standards

Standards relevant to PiEV recharging infrastructure are identified in this section. The scope of this report is the physical recharging infrastructure and thus standards related to PiEV components or intelligent infrastructure are not discussed.

Previous generations of PiEVs have yielded the standard BS EN 61851; this has defined a high level categorisation of recharging methods, addressed areas of safety and suggested connector configurations. Further developments in PiEV technologies have brought about new concepts and connection methods that have yielded new standards, or technical committees bringing together views from all stakeholders.

The main focus of recent developments in PiEV standards has been the physical connectors; whilst these do address the interfacing power system and PiEV, there are other standards to consider for the infrastructure, which are also covered in this section.

Table 5.6.4 provides a list of the fundamental standards that should be considered when undertaking any form of PiEV infrastructure design and installation.

Table 5.6.4: Overarching Standards

Standard Ref	Standards Relevant to PiEV Electrical Infrastructure
PiEV Interface	
BS EN 61851	Electric vehicle conductive charging system: Part 1 - General requirements. Part 21 - Electric vehicle requirements for conductive connection to an a.c./d.c. supply. Part 22 - AC electric vehicle recharging station.
BS EN 62196-1	Plugs, socket-outlets, vehicle couplers and vehicle inlets. Conductive recharging of electric vehicles. Recharging of electric vehicles up to 250 A ac and 400 A dc.
SAE J1772	Electric Vehicle Conductive Charge Coupler.
BS EN 61980-1	Electric Vehicle Inductive Charging Systems. Part 1: General Requirements.
Infrastructure	
ESQCR	Electricity Safety, Quality and Continuity Regulations 2002 (as amended).
BS 7671:2008	Requirements for electrical installations. IEE Wiring Regulations. Seventeenth edition.

5.6.4.1 Present PiEV Interface Standards

The requirements that have an impact on PiEV Interface Standards, as identified in Section 2, are repeated in Table 5.6.4.1a.

Table 5.6.4.1a: PiEV Interface Requirements

Req. ID	Requirements
SR1	The installation must be fit for purpose, suitable for the load and designed to withstand fault current characteristics.
SR2	Shall provide protection against over-current and thermal constraints.
SR3	Hazardous live parts must not be accessible (even after removal of parts that can be removed without a tool).
SR4	Exposed conductive parts must not become live under normal operating conditions and single fault conditions.
SR7	The PIEV recharging infrastructure shall be capable of supplying power to an electric PiEV such that equipment ratings are not exceeded.
SR10	Able to ensure safe connection of PiEV before energy is transferred.
SR11	A safety interlock shall prevent the cable connector from being removed from the recharge point socket whilst the system is energised.
SR12	Able to de-energise the system if unsafe operation is detected.
SR13	Current capacity limits of the charging infrastructure should be available to the charging control.
SR14	Must be designed to limit the introduction of harmonic, DC and non-sinusoidal currents that could impact the operation of protection devices and other equipment.
SR15	Shall minimise the injection of harmonic currents on to the power network.
SR16	The positioning of the recharging unit should consider the operation of the PiEV, e.g. reversing, and opening of PiEV doors.
SR21	Must provide the means to verify that the PiEV is safely connected.
SR22	Must provide the means to verify that the earth conductor is continuous.
SR23	A safety interlock shall prevent the PiEV connecter from being disconnected from the PiEV inlet whilst the system is energised.
SR24	The recharging cable should have increased visibility, considering periods and areas of low light. In addition there should be sufficient contrast between the cable colour and that of the backdrop.
SR25	Recharging cable should be flexible to minimise trip hazard.
SR26	Recharging cable must be able to withstand suitable impact and “drive-over” tests.
SR27	The PiEV cable length should be standardised.
SR28	Recharging cable design and installation should consider handling by a user.
SR29	The placement of a recharge point shall consider pedestrian access routes.
SR30	Shall adhere to traffic management orders for on-street sites.
BR2	Bi-directional power flow shall be accommodated to support V2G where required.
UR9	Interoperability (recharging capacity as well as connectors/hardware) is required to enable PiEVs to charge in multiple locations.

Req. ID	Requirements
ST1	Shall provide suitable protection against electric shock (IEC60364-4-41).
ST2	Protection against direct and indirect contact (IEC60364-4-41).
ST3	Stored energy after disconnection of the recharging equipment from the supply mains shall be below a required level (IEC61851).
ST4	Operating temperature of connectors must be according to regulations IEC 60309-1/2; IEC60884-1.
ST5	Connectors should be easy to connect and disconnect without excessive force IEC62196-1.

One of the most pertinent standards for electrical vehicle recharging infrastructure is BS EN 61851 (IEC 61851) *Electric vehicle conductive charging system*. This standard defines various topologies, modes of recharging, classes of recharging and safety requirements.

There are four defined modes of charging in standard BS EN 61581-1, the functions of which are summarised in Table 5.6.4.1b. The table shows a control pilot function which is a dedicated conductor used to check that the PiEV is connected and that there is a continuous protective earth conductor between the PiEV and protection zone of supply. The protective zone of supply boundary can be the infrastructure plug or infrastructure supply depending on the mode. After these conditions are met, then charging is enabled; conversely if the integrity of the control pilot circuit is interrupted by a fault or the initiation of disconnection, then the system is de-energised ensuring that there is no arcing during disconnection, or exposed live conductors.

The supply connection can utilise a present standard plug such as a UK 3 pin plug (BS 1363), or an industrial connector (IEC 60309). These connectors do not facilitate a control pilot and therefore a PiEV specific connector is required for Mode 3 charging; such connectors are presented in Section 5.6.2. Modes 1 to 3 are AC recharging, Mode 4 is specifically for DC recharging; in this case serial data communications are required to interface control parameters between the PiEV battery management system (BMS) and the off-board charger.

Table 5.6.4.1b: PiEV Recharge Mode Descriptions

Mode	Control Pilot	Supply Connection	Communication
1	No control pilot function	AC, via standard socket (eg BS 1363).	No serial data communication requirement.
2	Control pilot function between PiEV and the plug or in-cable control box.	AC, via standard socket (e.g. BS 1363).	No serial data communication requirement.
3	Control pilot function extended to equipment permanently connected to the supply.	The PiEV is connected directly to dedicated PiEV supply equipment.	No serial data communication requirement.
4	Control pilot function extended to equipment permanently connected to the supply.	AC/DC off-board charger, (DC interface). Fixed connection.	Serial data communication must be provided to allow vehicle to control off-board charger.

Mode 1 charging is presently the most common method used; however, Mode 2 solutions are available and becoming commonplace for new PiEVs entering the market. There are primarily three connector designs which offer Mode 2 recharging for which a common standard is yet to be finalised. Mode 3 charging solutions are also emerging with some manufacturers offering “wall box” solutions as presented in Section 5.5. This method will initially limit the number of locations available to recharge unless used in conjunction with a Mode 2 charge cable. The key benefit of Mode 3 recharging is that charge currents greater than 13/16A can be achieved as the control pilot function encompasses the supply as well as the PiEV. Note that some Mode 2 connectors have current ratings greater than 13/16A but the current would ultimately be limited by the supply point of connection.

In addition to modes of recharge, BS EN 61851 defines three recharge cases which detail the topology for PiEV connection to the recharging infrastructure as summarised below:

Case A: The recharging cable and plug is permanently attached to the PiEV, therefore no vehicle connector is required. This connection method is antiquated and not adopted for present PiEVs.

Case B: The cable assembly is detachable from the recharge point and PiEV. This method is widely adopted and offers flexibility in that a number of cables may be used with different connectors depending on the recharge point socket.

Case C: The recharging cable is permanently attached to the supply equipment. In the case of Mode 4 recharging, a case C connection must be adopted.

Parts 22 and 23 of standard BS EN 61851 go into more detail including testing and maintenance; these are considered too detailed for this high level report.

Safety requirements highlighted in BS EN 61851 are covered in detail in WP2.5 with additional comments considering possible scenarios.

Considering the potential issues relating to connectors as identified in Section 5.6.2. It is recommended that Mode 3 charging is required, thereby satisfying safety requirements SR10, SR11, SR12, SR13, SR21, SR22 and SR23.

5.6.4.2 Connectors Standards Development

Standard BS EN 61851 was formed from its IEC equivalent (IEC 61851). Part 1 is presently undergoing review by IEC technical committee (TC) 69. A final draft has been submitted to the European Committee for Electrotechnical Standardisation (CENELEC) with a forecast publication by the end of 2010.

The key issue being addressed is the method of connection to be adopted. Continued discussion of this matter will surpass the publication of part 1, through a European Commission mandate that the standard connector be in place by February 2012. Revisions of Part 21 and 22 shall follow.

The connector specific standard that is being addressed by TC69 is (IEC) BS EN 62196. The manufacturer Mennekes has adopted this standard in its present form. This solution has been adopted by German and other European PiEV manufacturers. A number of utility companies are involved in TC69 as well as PiEV manufacturers; as a result a recharge point solution is also being addressed. The present solutions consider using the same connector at both ends of the recharge cable and therefore offering Mode 3 recharging when utilising a wall box.

Additionally, standard BS EN 62196 is adopted by the EV Plug Alliance with their SCAME connector, which focuses on the recharge point connection, therefore requiring a wall box and offering Mode 3 recharging.

The Society of Automotive Engineers (SAE) International is leading the way for connector solutions from the automotive perspective. They have produced standard SAE J1772 from which connector manufacturer Yazaki has produced its version of the vehicle connector. This standard is presently the preferred option for North America and Japan, with the Japan Automobile Research Institute (JARI) aligning with the standard. Consequently PiEV manufacturers from Japan are adopting this standard, notably Mitsubishi with the iMiEV.

SAE and IEC are still developing DC recharging standards, meanwhile in Japan the CHAdeMo standard is gaining worldwide acceptance for DC charging with members globally and gaining experience from approximately 300 DC charging stations in Japan. Few PiEV manufacturers have adopted DC recharging, however those who have (Mitsubishi and Nissan) have adopted the CHAdeMo standard.

There is little information available publically on the CHAdeMo standard. However, one key finding is that the present CHAdeMO specification for quick chargers has a DC power rating of 100 kW (500V dc, 200A dc). This is significantly less than that indicated in the IEC standard 61851 which indicates 240 kW. It may be assumed that DC power ratings will increase as battery technologies develop such that they can accept such levels of charge.

A connector for DC charging has been developed by JARI and standardised by the Japan Electric Vehicle Standard (JEVS). This connector, named the JEVS G 105 or otherwise known as the TEPCO connector, has a number of dedicated control pins which are used for safety interlocks. In addition a CAN bus is used which allows the vehicle to control the voltage and rate of charge. This is essential due the various battery attributes which the on-board battery management system monitors and controls.

As indicated, DC charging standards and connectors are being driven by developments in Japan. Given that the DC interface is largely independent of the resident power system design, and are targeted at public recharging, this standard is likely to be adopted worldwide. Worldwide adoption of AC standards, however, is rather more complex due to the different designs of power systems and domestic wiring around the world. In areas of the United States domestic supplies utilise 110V systems which differs from European 240V LV supplies. Even within Europe there are relevant differences, for example, some European countries commonly adopt three phase supplies to domestic properties. The result is that large loads have lower phase current ratings. In the UK this is not the case and therefore the use of 32A and 40A single phase MCBs is common. These aspects lead to the desire for different connectors, and make the design of a common connector more complicated.

5.6.4.3 Present Infrastructure Standards

The Electricity Safety, Quality and Continuity Regulations (ESQCR) and BS 7671:2008 cover the fundamental requirements and principles of electrical installations. This includes considerations for the design, protection, selection of equipment and maintenance requirements. Currently these regulations and standards do not state any explicit requirements for electric vehicle recharge points. BS 7671:2008 addresses installations for caravans, caravan parks and similar sites as well as mobile or transportable units. Requirements for these installations could be referenced when installing PiEV infrastructure. However, it is expected that BS 7671:2008 will need to be modified to address the requirements for PiEVs explicitly.

All domestic, commercial and industrial electrical installations must comply with the IEE wiring regulations (BS 7671). This standard does not cover specifically PiEV installations; nevertheless it sets out requirements for general installations which include PiEV loads. Requirements that are covered by BS 7671 are as follows:

- Circuit design.
- RCD protection.
- Protection against electric shock.
- IP rating of equipment.
- Impact protection against mechanical damage.
- Isolation and switching.

The key aspect of circuit design is that the installation must be fit for purpose and suitable for the intended load whilst providing sufficient protection against thermal and current overloading and electric shock. The details of the standard need not be further elaborated as they are guidance for a qualified electrician who will consider each installation in its own right. Any PiEV recharge installation, be it new or a modification, must be carried out by a qualified electrician; however there are aspects of a PiEV load that a competent electrician may not be aware of due to their relatively new introduction.

- PiEV load profile: Present day PiEV models recharge with a current of approximately 12A continuously for typically 8 hours for a full charge. This is a load like no other domestic appliance and significantly reduces the circuit load diversity. As a result, a PiEV recharge installation should have its own dedicated circuit from the consumer unit.
- In cases where distribution supplies utilise a combined earth and neutral (Protective multiple earthing - PME) to a property, the ESQCR do not allow the protective conductor to be connected to the metalwork of a caravan or boat. This can be assumed to also apply to other external metalwork including a PiEV. This is to prevent risk of shock resulting from a voltage difference between the exposed metalwork and true earth. The IET during the course of 2011 will be addressing this issue to determine the true level of risk, regardless a solution would be to install a local earth system (type TT as per BS 7671).

There are numerous standards covering each system component within the recharging infrastructure; these are listed next to each component in Appendix A. These refer to well established standards and products, used widely in electrical installations, and hence are not elaborated on in this report.

5.6.4.4 Infrastructure Standards Development

The development of infrastructure standards addresses more than just PiEV loads. The nature of power systems is changing with embedded generation being commonplace and new technologies emerging besides PiEVs, such as heat pumps, solar PV, micro- generation, and general changes in standard domestic appliances (fridges, battery chargers, TVs).

One area of increasing change is the level of harmonics on power systems. Converters found in wind turbines, laptop chargers, phone chargers and PiEV recharging contribute to harmonic levels. At present Engineering Recommendation G5/4-1 (Planning levels for voltage harmonic distortion and the connection of non-linear equipment to transmission and distribution networks in the United Kingdom) sets out design criteria. This recommendation refers to British Standards for the connection of individual equipment/ connections. In light of the increasing background levels it is expected that these standards will soon be revised; this may impact directly on PiEV recharging.

5.6.5 Coupling Mechanisms Summary

On the recommendation from Section 5.6.4.1 that Mode 3 is required to meet the safety requirements, the coupling mechanisms are summarised in Table 5.6.5.

Table 5.6.5: Coupling Mechanisms Summary

Technology	Pros	Cons
AC Conductive Charging General	Cheap.	Safety Concerns.
Mode 3, 13A	Widely available. Limited network impact.	Slow (8hrs) for typical full recharge.
Mode 3, 32A	Fast (4hrs) for typical full recharge.	Dedicated electrical circuit (domestic).
DC Charging	Very Fast (20 mins) for typical full recharge.	Very expensive. Potentially large LV network impact. Only suitable for Commercial use.
Inductive Charging	Reduced user interface. No connector degradation.	Presently expensive. Not fully developed.

6 EVALUATION OF REQUIREMENTS, CONSTRAINTS AND SOLUTION OPTIONS

This section evaluates the solution options presented in Section 5 against the requirements and constraints identified in Sections 2 and 3.

It has been assumed that the charge point design and location selection has been conducted in accordance with the requirements UR1-UR9 and ST1–ST6 and that therefore these have been satisfied.

This leaves the safety, business and power transfer requirements and their constraints to evaluate.

Table 6a shows the summary of the solution options for domestic infrastructure. The main choice the user faces is the balance between costs and the charging power. Domestic users are unlikely to install charge posts due to the significantly higher costs than wall boxes. Some domestic users may prefer inductive charging over conductive charging, but again this is a personal choice based on the factors described in Section 5.

It is likely that energy storage solutions are too expensive for domestic consumers and perhaps also take up too much space, certainly when compared to load management or supply upgrade options.

Table 6a: Domestic Solutions Summary

Req. ID	**PR1.1**	**PR1.1**	**PR1.2**	**PR1.3**	**PR1.3**	**PR1.3**
Solution Options\ Power Requirements	**Domestic recharging infrastructure must support a minimum of 13A (3kWh) charging.**	**Domestic recharging infrastructure must support a minimum of 13A (3kWh) charging.**	**Some Domestic users will require infrastructure to support 32A charging.**	**Some Domestic users will require infrastructure to support 2 or more 13A or 32A recharging points.**	**Some Domestic users will require infrastructure to support 2 or more 13A or 32A recharging points.**	**Some Domestic users will require infrastructure to support 2 or more 13A or 32A recharging points.**
Constraint	100A fuse	80A fuse and Electric Heating	100A fuse, no electric heating	100A fuse, no electric heating	100A fuse, electric heating	100A fuse, electric heating
Solution Title	13A or 32A recharging	Supply Constrained	No electric heating, 13A or 32A recharging	No electric heating, 2 vehicle recharging	Electric Heating: 2 vehicles: Load Management	Electric Heating: 2 vehicles: Supply Upgrade
Supply Upgrade - single phase		Y				Y
Supply Upgrade - three phase						Y - depending on required load
Local Load Management					Y	
Energy Storage	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive
AC conductive Charging (13A or 32A)	Y (or inductive)	Y (or inductive)	Y (or inductive)	2 x 13A only (network constraint NC1.3)	Y (or inductive)	Y (or inductive)
Inductive Charging	Y (or conductive)	Y (or conductive)	Y (or conductive)	Y (or conductive)	Y (or conductive)	Y (or conductive)
DC Rapid Charging	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive
Wall Box	Y	Y	Y	Y	Y	Y
Charge Post	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive
Recommendation(s)	13A or 32A Mode 3 Wall Box (Appendix B)	13A or 32A Mode 3 Wall Box	13A or 32A Mode 3 Wall Box	Twin socket 13A Mode 3 Wall Box (Appendix C)	Twin socket 13A or 32A Mode 3 Wall Box, depending on load management system. (Appendix D)	Supply upgrade and twin socket 32A Mode 3 Wall Box

Table 6b: Commercial Solutions Summary

Req. ID	**PR1.4**	**PR1.4**	**PR1.4**	**PR1.5**	**PR1.5**	**PR1.5**
Solution Options\ Power Requirements	**Commercial recharging must support 13A recharging of a number of vehicles at the same time. Recharge rates of 32A are desirable.**	**Commercial recharging must support 13A recharging of a number of vehicles at the same time. Recharge rates of 32A are desirable**	**Commercial recharging must support 13A recharging of a number of vehicles at the same time. Recharge rates of 32A are desirable**	**Commercial recharging may need to support charging at greater than 50A; higher rates are likely to be desirable**	**Commercial recharging may need to support charging at greater than 50A; higher rates are likely to be desirable**	**Commercial recharging may need to support charging at greater than 50A; higher rates are likely to be desirable**
Constraint	100A fuse	100A fuse	Three phase supply (100A fuse)	Three phase supply (63A fuse) Low baseload	Three phase supply (100A fuse) High baseload	Three phase supply (100A fuse) High baseload
Solution Title	Small Commercial Premises, 2 PiEV recharging (16A)	Small Commercial Premises, 6 PiEV recharging (16A)	Large Commercial Premises, 6 PiEV recharging (16A)	3 three phase PiEV recharging (32A/ph)	3 three phase PiEV recharging (32A/ph)	DC Rapid Recharging
Supply Upgrade - single phase		Y				
Supply Upgrade - three phase					Y	Y
Local Load Management		Y	Y	Y	Y	
Energy Storage	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive	Could be considered
AC conductive Charging (13A or 32A)	Y (or inductive)	Y (or inductive)	Y (or inductive)	Y (or inductive)	Y (or inductive)	
Inductive Charging	Y (or conductive)	Y (or conductive)	Y (or conductive)	Y (or conductive)	Y (or conductive)	
DC Rapid Charging	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive	Viable Option
Wall Box	Y	Y	Y	Y	Y	N/A
Charge Post	Too expensive	Too expensive	Too expensive	Too expensive	Too expensive	N/A
Recommendation(s)	16A Mode 3 Wall Box (x2) (Appendix E)	16A Mode 3 Wall Box (x6) (Appendix F)	16A Mode 3 Wall Box (x6) (Appendix G)	32A Three phase Mode 3 Wall Box (x3) (Appendix I)	32A Three phase Mode 3 Wall Box (x3) (Appendix I)	DC charger up to 69kW (dedicated supply) (Appendix J)

Table 6c: Public Solutions Summary

Req. ID	**PR1.6**	**PR1.6**	**PR1.7**	**PR1.8**
Solution Options\ Power Requirements	**On street public recharging must support 13A recharging.**	**On street public recharging must support 13A recharging.**	**It is desirable for on street public recharging to support 13A or 32A recharging.**	**Public fast chargers (e.g. at motorway service stations) will require a three phase supply for DC charging**
Constraint	Local distribution network.	Local distribution network.	Local distribution network.	Local distribution network.
Solution Title	6 public PiEV 13A recharge bays.	18 public PiEV 13A recharge bays.	25 public PiEV 32A/ph recharge bays.	8 DC Rapid Chargers.
Supply Upgrade - single phase	New connection.			
Supply Upgrade - three phase		New connection.	New connection.	New connection Significant upstream upgrade.
Local Load Management	Y	Y	Y	Y
Energy Storage	Too expensive.	Too expensive.	Too expensive.	May be considered.
AC conductive Charging (13A or 32A)	Y (or inductive).	Y (or inductive).	Y (or inductive).	
Inductive Charging	Y (or conductive).	Y (or conductive).	Y (or conductive).	
DC Rapid Charging	Too expensive.	Too expensive.	Too expensive.	Viable Option.
Wall Box	N	N	N	N/A
Charge Post	Y	Y	Y	N/A
Recommendation(s)	16A Mode 3 Charge post (x6) (Appendix K).	16A Mode 3 Charge post (x18) (Appendix L).	32A Three phase Mode 3 Charge post (x25) (Appendix M).	8, 69kW DC chargers (dedicated supply) (Appendix N).

6.1 Potential System Solutions

There is a multitude of possible system design solutions depending on the specific requirements of each location, PiEV, and user utilising the recharge point. This section approaches the system design from a generic perspective identifying components and positioning within the infrastructure previously outlined in Figure 1.

Recharging scenarios and resulting power requirements for domestic, commercial and public locations identified in Section 2 are used in conjunction with system component ratings to identify typical system design solutions for each segment of the infrastructure. These segments are merged to yield a list of system designs for typical and limiting case scenarios.

The following sub-sections outline the installation segments identifying key components within each segment. Each component is listed in Appendix A.

6.1.1 Distribution Network Interface

The distribution network interface is the point at which the recharging infrastructure connects to the distribution network. A high level diagram of the distribution network interface and associated components is shown in Figure 6.1.1a.

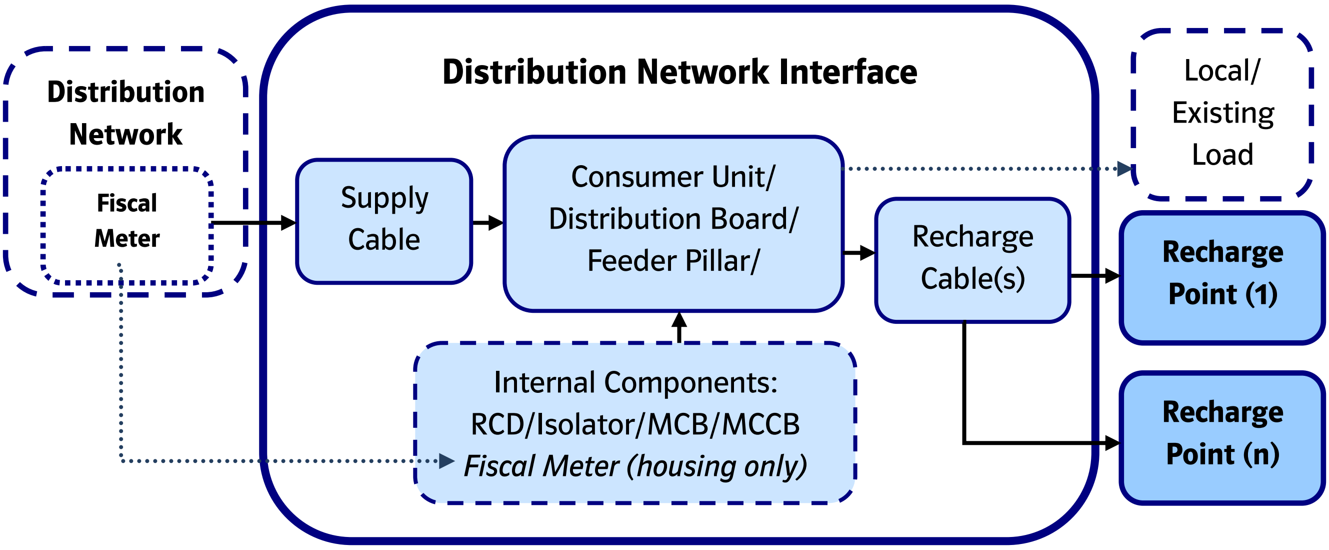

Figure 6.1.1a: Generic Component Layout for Distribution Network Interface Installation

The distribution network interface contains the supply cable to the distribution network where the financial meter and cut out fuse reside. This cable must be adequately rated for the total PiEV load, plus the expected peak power of other loads that use the same supply, such as those in the home. The supply cable is terminated in the consumer unit from where the individual circuits to each recharge point are connected via recharge cables.

A consumer unit is a term used for a plastic enclosure which houses the main isolator/RCD, MCBs and rails for installation, and is for single phase supplies in domestic and small commercial properties. A distribution board contains similar internal components; however, it has a more robust metal casing and is typically fed from a three phase supply. Both housings are wall mounted and suitable for indoor use. For external supplies such as public roadside charging a feeder pillar is used. This enclosure is floor mounted and designed to resist vehicle impacts, vandalism and is secure. In this case a distribution cut out fuse and financial meter may be housed within the unit.

Table 6.1.1a lists standard MCB and MCCB ratings. The MCBs are used for each circuit supplied from the distribution network interface; however, these ratings are also typical for the incoming supply isolation/RCD. Note the current limit of MCBs on single and three phase supplies is 100A, this equates to power limits of 23 kW and 69 kW respectively. MCCBs facilitate greater capacities up to a limit of 800A (552 kW). These capacities are in line with the ratings of feeder circuits from secondary substations containing typically an 11 kV to 415V step down transformer. This transformer is generally part of the distribution network and therefore outside the scope of this document, however the use of MCCBs may require significant network upgrade and high capacity supply cables which will have significant associated costs.

Table 6.1.1a: Standard MCB & MCCB Current and Power Ratings

MCB Current Rating (A)	Number of Phases	Power Rating (kW)
16	1	3.7
20	1	4.6
32	1	7.4
40	1	9.2
50	1	11.5
63	1	14.5
100	1	23.0
16	3	11.0
20	3	13.8
32	3	22.1
40	3	27.6
50	3	34.5
63	3	43.5
100	3	69
MCCB Current Rating (A)	**Number of Phases**	**Power Rating (kW)**
100	3	69
160	3	110.4
250	3	172.5
400	3	276
630	3	434.7
800	3	552

Appendix A contains a list of component options and associated standards relevant to the distribution network interface.

Table 6.1.1b shows how many recharge bays may be installed for the three supply limits previously identified. The number of bays is determined by the maximum recharge level as limited by the PiEV interface connectors. These limits are based on all bays recharging at full load current as would be a worst case design condition. In practice, diversity of connections and local load management systems will facilitate a greater number of bays. Figure 6.1.1b shows the load levels of the previously identified recharging scenarios; in the majority of these conditions a recharge rate lower than the connector rating is required, therefore accommodating more recharge bays.

Table 6.1.1b: Maximum Number of PiEV Recharge Bays

Connector Rating	**Maximum Number of Recharge Bays**		
	Single Phase Supply (100A/ 23 kW)	**Standard 3 Phase Supply (100A/ 69 kW)**	**High Capacity 3 Phase Supply (800A/ 552 kW)**
Single Phase 16A	6	18	150
Single Phase 32A	3	9	75
Three Phase 16A	N/A	6	50
Three Phase 32A	N/A	3	25
DC, 69 kW	N/A	1	8
DC, 240 kW	N/A	N/A	2

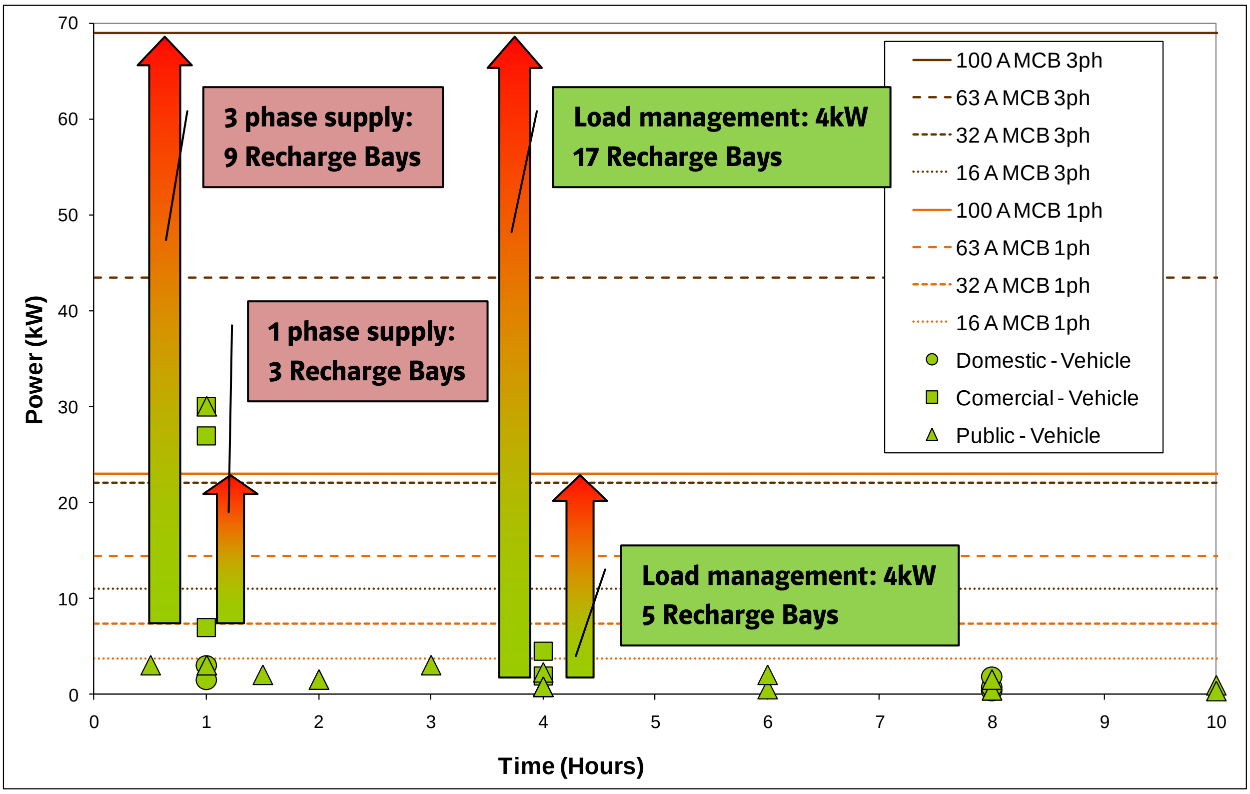

Figure 6.1.1b: Recharge Scenarios and Application of Local Load Management

Figure 6.1.1b demonstrates how more bays may be installed with the integration of local load management for a particular scenario. This scenario has been chosen for demonstration purposes and the merits of such systems will vary from one location to another and the range of user requirements at each single location. Indeed load management systems may be tailored to suit the particular requirements of each location. Table 6.1.1c has been produced to show the number of recharge bays considering an algorithm which considers that 50% of recharge scenarios require 100% of the connector rating, and the remaining 50% recharge at 50% of the connector rating.

Table 6.1.1c: Maximum Number of PiEV Recharge Bays utilising a Local Load Management System

Connector Rating	**Maximum Number of Recharge Bays**		
	Single Phase Supply (100A/ 23 kW)	**Standard 3 Phase Supply (100A/ 69 kW)**	**High Capacity 3 Phase Supply (800A/ 552 kW)**
Single Phase 16A	8 *(+2)*	25 *(+7)*	200 *(+50)*
Single Phase 32A	4 *(+1)*	12 *(+3)*	100 *(+25)*
Three Phase 16A	N/A	8 *(+2)*	66 *(+16)*
Three Phase 32A	N/A	4 *(+1)*	33 *(+8)*
DC, 69kW	N/A	1 *(nc)*	10 *(+2)*
DC, 240kW	N/A	N/A	3 *(+1)*

6.1.2 Recharge Point

The recharge point shall be located within the proximity of the PiEV recharge bay such that the PiEV interface cable length is minimised to reduce the tripping hazard and provide a convenient interface to the user. Figure 6.1.2a shows how the recharge point fits into the recharge infrastructure and identifies key components.

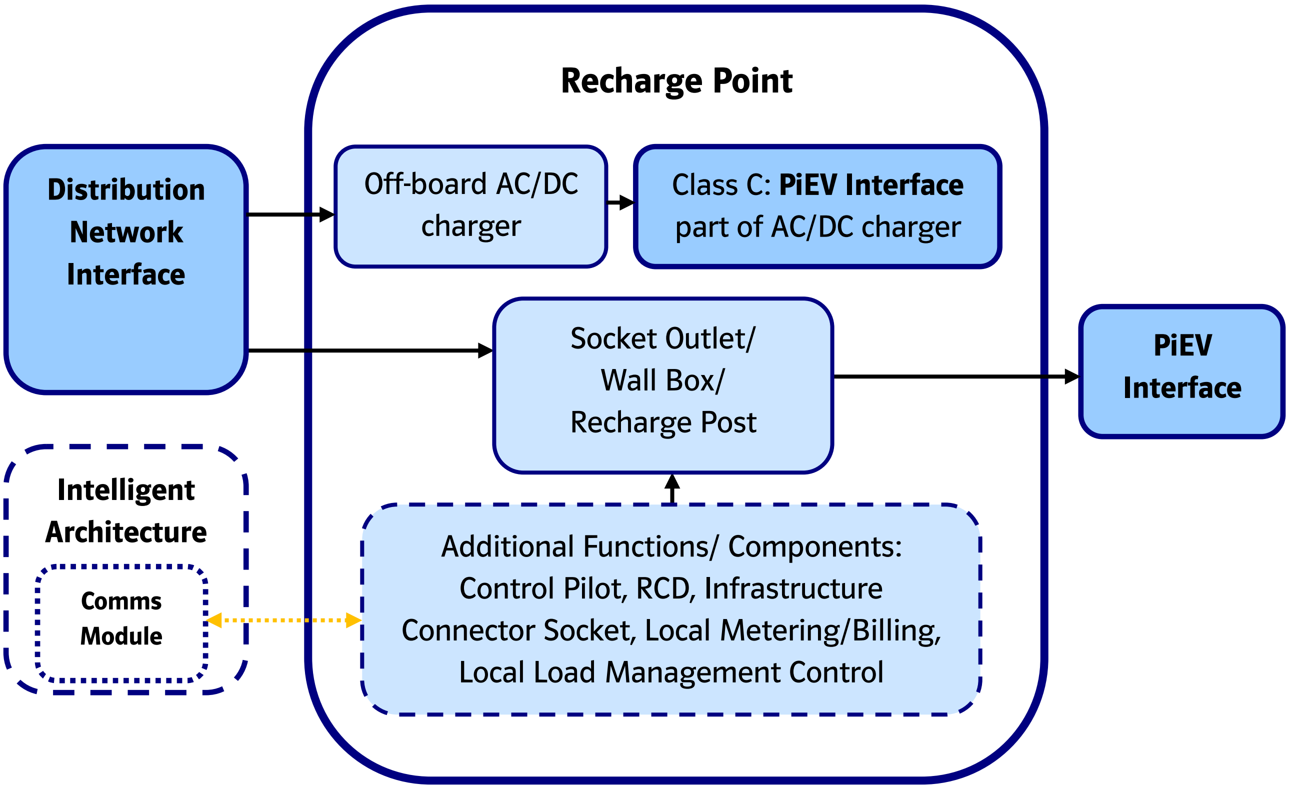

Figure 6.1.2a: Generic Component Layout for Recharge Point Installation

The recharge point is the point of connection to the recharge infrastructure. In its most basic form it is a simple socket outlet such as a three pin socket (BS EN 1363) or industrial connector (IEC 60309); suitable for Mode 1 and 2 recharging. Mode 3 charging will require specific connectors for the recharge infrastructure which require control pilot functionality within the recharge point. Domestic and commercial solutions include the wall box whereby greater capacities may be achieved. For external PiEV connection points remote from buildings or in the public domain a recharge post will be required. These will develop to include control pilot functionality and greater capacities. Wall boxes or recharge posts may provide additional space for metering, communications, local load management or even a simple timer switch.

Figure 6.1.2b shows identified scenarios from Section 2 that exceed the limits of a three phase 32A PiEV connector, and therefore require a DC off-board charger. This resides in the recharge point segment due to the Mode 4, class C categorisation. Note that a maximum DC recharge capacity of an off-board charger is 240 kW as indicated in Section 5. Given the maximum supply limit (~550 kW) shown in Table 6.1.1a a maximum of two chargers could be installed. There are however lower capacity DC chargers available leading to a range of up to typically 10 recharge bays before AC recharging should be considered.

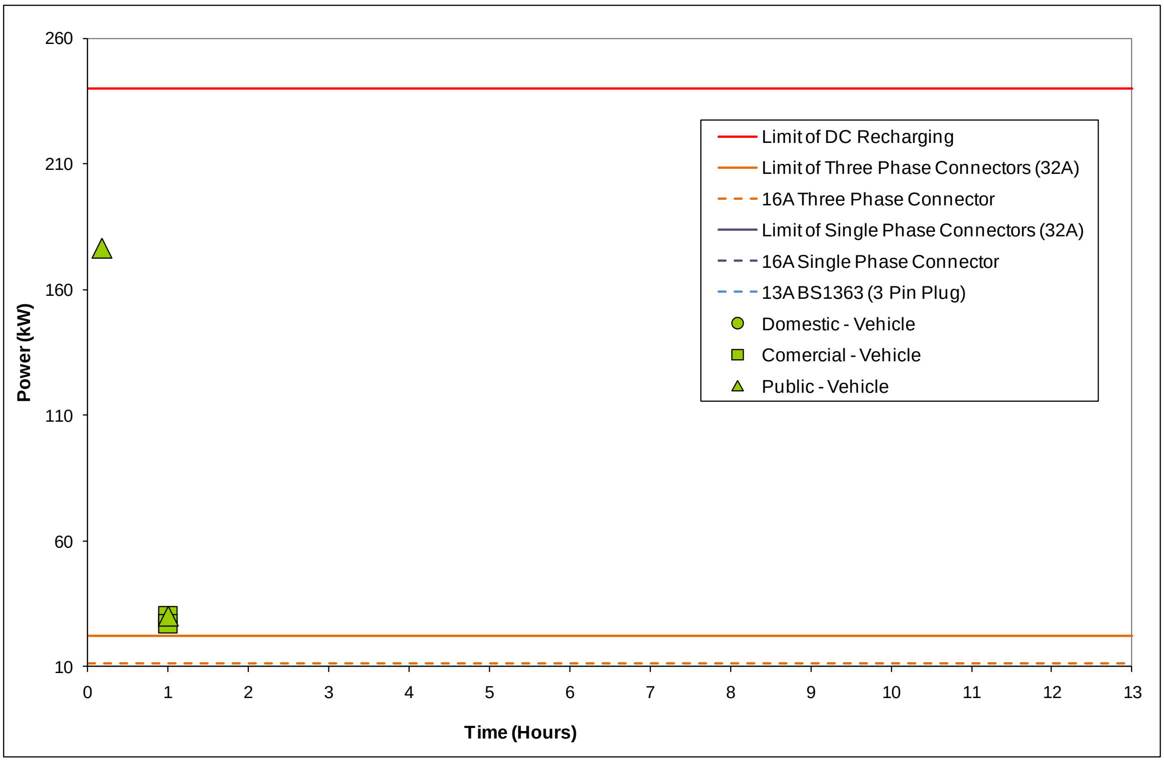

Figure 6.1.2b: PiEV Requirements and Connector Limits (Fast Charge)

6.1.3 PiEV Interface

The PiEV Interface is simply a cable with connector plugs at each end for connection to the infrastructure and PiEV, as presented in Figure 6.1.3a.

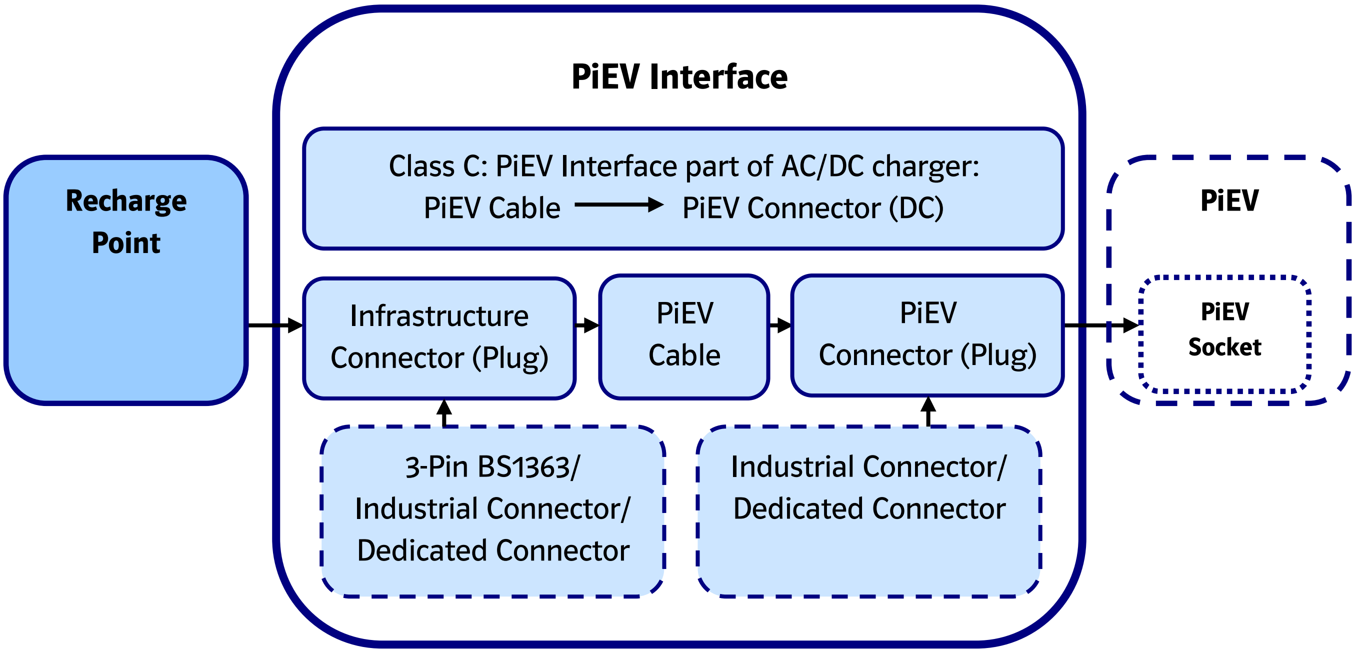

Figure 6.1.3a: Generic Component Layout for PiEV Interface

The PiEV interface in its simplest terms is the cable including connectors which connect the infrastructure and PiEV. Present infrastructure connector options utilise plugs commonplace in domestic and industrial installations (BS 1363 and IEC 60309). However, PiEV duty cycles and expected increased current ratings shall require Mode 3 recharging and result in the requirement for dedicated PiEV infrastructure connectors. Section 5.6 on technology options further details connector considerations and designs expected in the future. PiEV plugs are also discussed in Section 5.6 and primarily associated with the PiEV socket which is outside the scope of this report.

The concept of having plugs at both ends of a cable is unique to PiEV recharging. General rules dictate that a plug should belong to a load and a socket to a supply source. This avoids the situation of mating two sources together and the resulting safety aspects. With the possibility of V2G a PiEV may be a load or supply. These aspects of PiEV connectors are being addressed by IEC TC69.

Figures 6.1.3b and 6.1.3c show the limits of present and emerging PiEV connectors in relation to the previously identified recharging scenarios (Figures 2.4.2 and 2.4.3). Figure 6.1.3b shows the DC charging connector limit; this method of recharge is Mode 4/case C and therefore the cable is hardwired to the charger with no infrastructure connector.

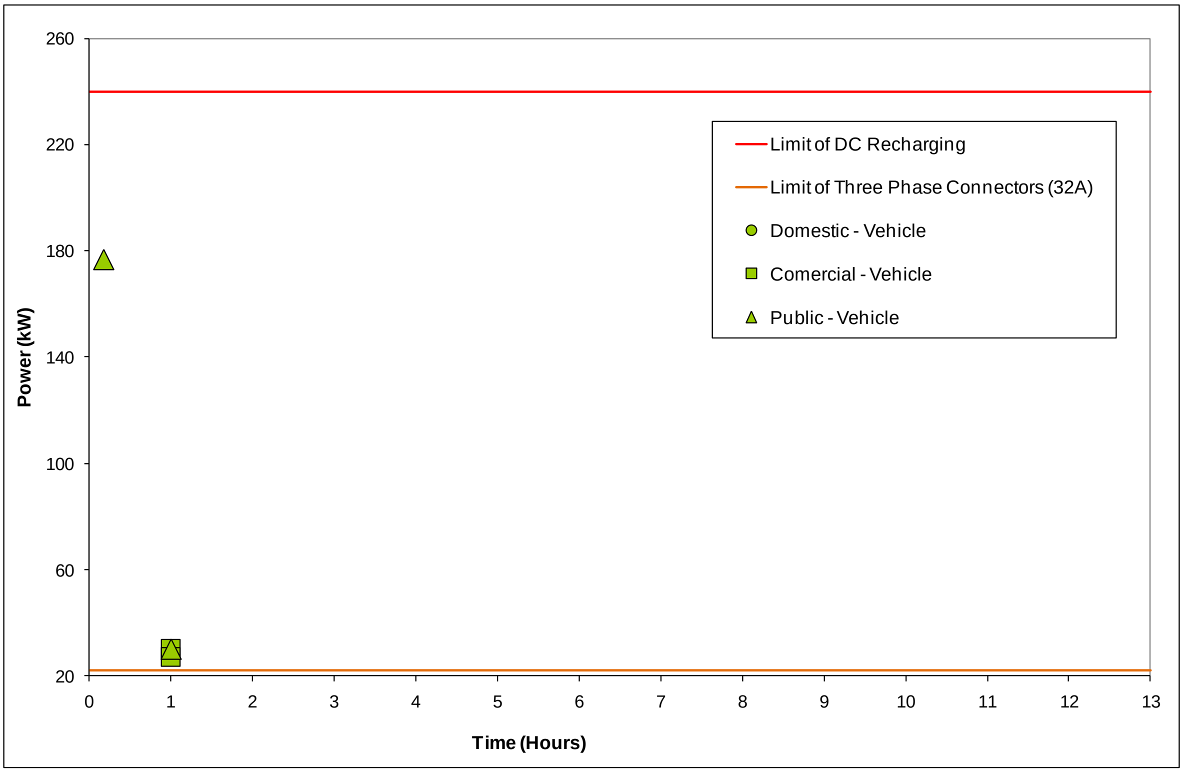

Figure 6.1.3b: PiEV Requirements and Connector Limits (DC Charging)

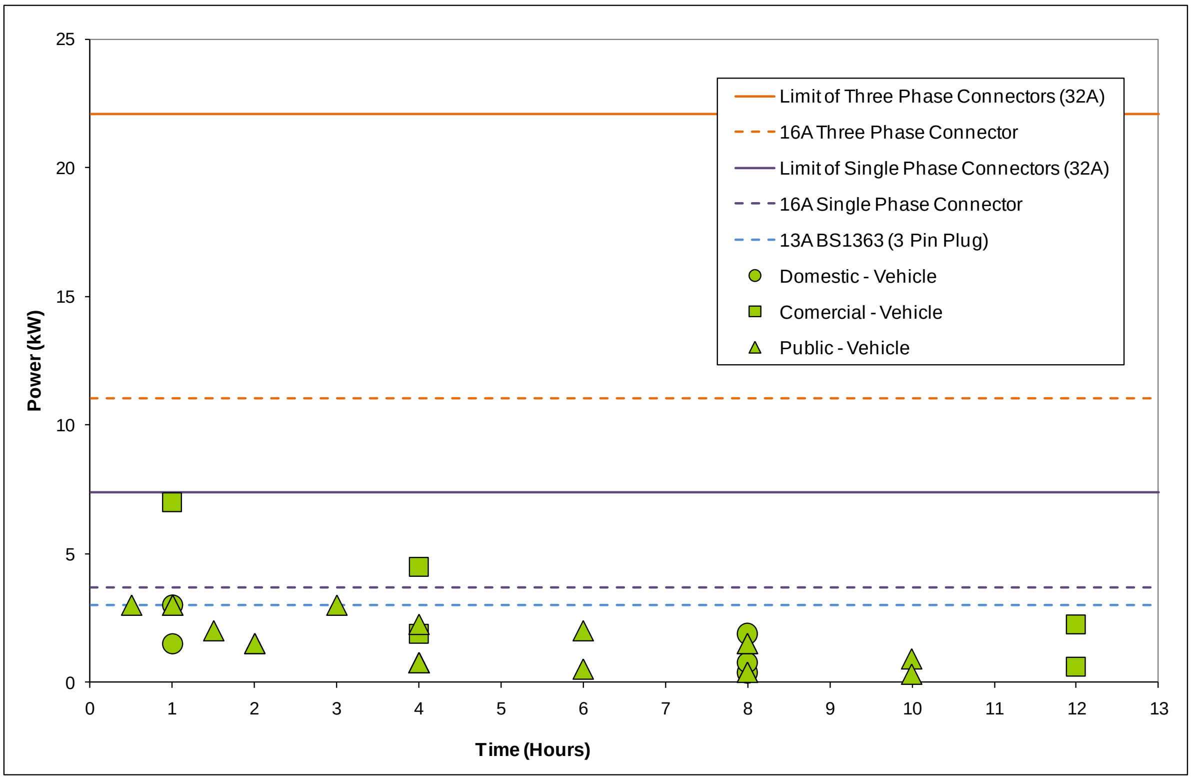

Figure 6.1.3c: PiEV Requirements and Connector Limits (AC Charging)

6.1.4 Selected System Designs and Component Variations

Appendices B to N present the system designs as listed in Table 6.1.4. These designs have been selected to demonstrate system design solutions for domestic, commercial and public recharging scenarios. Also included are designs for significant power requirement threshold levels whereby additional capacity would lead to significant increase in infrastructure cost.

The system designs aim to demonstrate a range of PiEV charge levels, technologies and components. Appendix A shows the details of components used in the system designs, including any relevant standards.

Table 6.1.4: Selection of System Designs as Presented in the Appendices

Appendix	Location	PiEV Recharge	Infrastructure Supply	Further Comments
B	Domestic	1ph, 13A	1ph, 100A	Integration into existing wiring
C	Domestic	1ph, 16A	1ph, 100A	Mode 3 recharging, 2 PiEVs
D	Domestic	1ph, 32A	1ph, 100A	Mode 3 recharging
E	Commercial	1ph, 16A	1ph, 100A	2 Recharge Bays
F	Commercial	1ph, 16A	1ph, 100A	6 Recharge Bays (limit case)
G	Commercial	1ph, 16A	3ph, 100A	6 Recharge Bays
H	Commercial	3ph, 16A	3ph, 100A	6 Recharge Bays (limit case)
I	Commercial	3ph, 32A	3ph, 100A	3 Recharge Bays (limit case)
J	Commercial	DC, 69kW	3ph, 100A	1 Recharge Bay (limit case)
K	Public	1ph, 16A	1ph, 100A	6 Recharge Posts (limit case)
L	Public	1ph, 16A	3ph, 100A	18 Recharge Posts (limit case)
M	Public	3ph, 32A	3ph, 800A	25 Recharge Posts (limit case)
N	Public	DC, 69kW	3ph, 800A	8 Recharge Bays (limit case)
O	Public	DC, 240kW	3ph, 800A	2 Recharge Bays (limit case)

6.1.4.1 Component Costs

Deliverable SP2/E.ON/05 reports the analysis on the cost and supply chain for components within the PiEV recharging infrastructure. Using the component costs taken from SP2/E.ON/05, the system designs presented in Table 6.1.4 and Appendices B to O are priced and listed in Table 6.1.4.1 for 2011 costs.

Table 6.1.4.1: 2010 Estimated Costs of System Designs Presented in the Appendices

Appendix	Number of Bays	Component and Installation Cost	Cost/Bay	Cost/kW
B	1	£ 707	£ 707	£ 186
C	2	£ 3,087	£ 1,544	£ 401
D	1	£ 1,731	£ 1,731	£ 225
E	2	£ 3,201	£ 1,600	£ 416
F	6	£ 8,787	£ 1,464	£ 382
G	6	£ 9,038	£ 1,506	£ 393
H	6	£ 9,239	£ 1,540	£ 134
I	3	£ 5,142	£ 1,714	£ 75
J	1	£ 33,816	£ 33,816	£ 490
K	6	£ 35,818	£ 5,970	£ 1,557
L	18	£ 106,695	£ 5,928	£ 1,546
M	25	£ 152,006	£ 6,080	£ 1,583
N	8	£ 266,564	£ 33,320	£ 483
O	2	£ 173,326	£ 86,663	£ 314

A significant proportion of per bay costs are due to the recharge point technology adopted; such as the wall box, recharge post or off-board charger. Wall box and recharge post costs per bay are relatively constant regardless of recharge capacity; with costs at around £1,500 and £6,000 respectively. Costs of off-board chargers, as shown in Appendices J, N and O, are significantly higher with entry level 69MW units costing around £33,000; however, costs significantly increase as recharge capacity increases.

Figure 6.1.4.1a shows the effect of increasing the number of recharge bays for single phase 16A PiEV recharging. Whilst there is a visible step in costs when moving from a single phase supply to a standard three phase supply, and then to a high capacity three phase supply, the cost per bay remains relatively small.

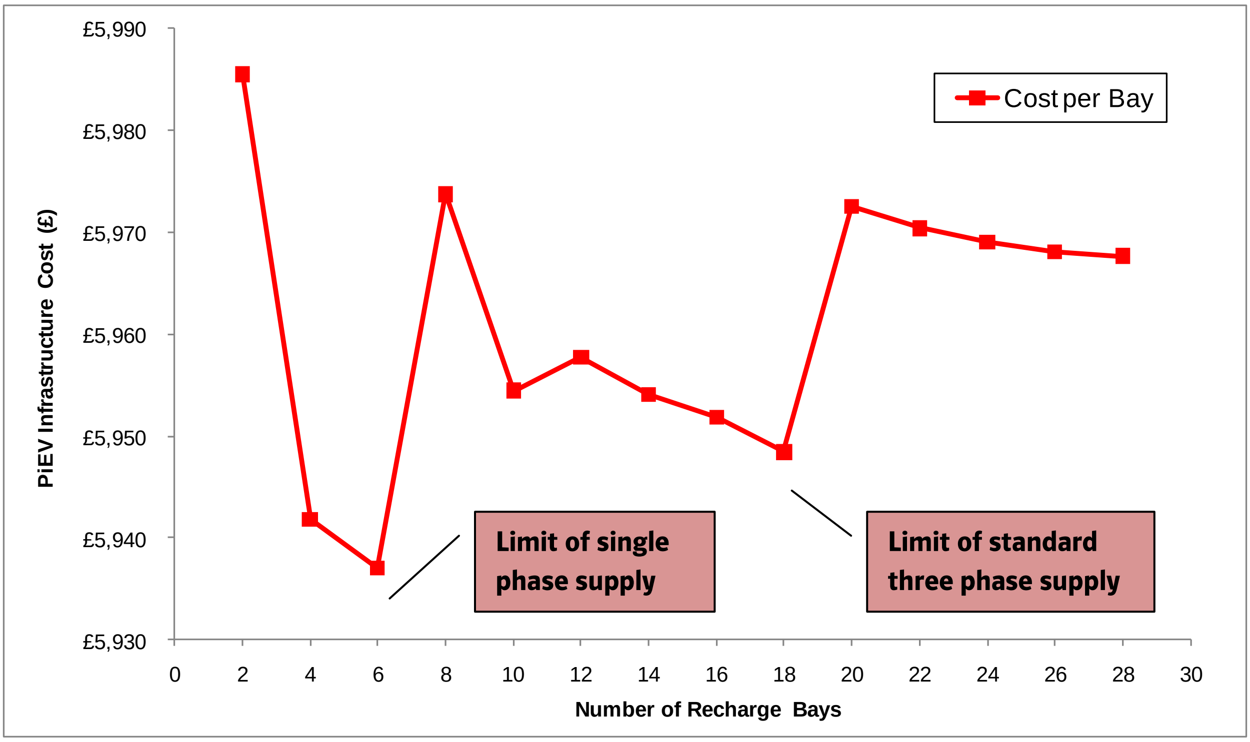

Figure 6.1.4.1a: PiEV Infrastructure Cost per Bay for Increasing Number of Bays

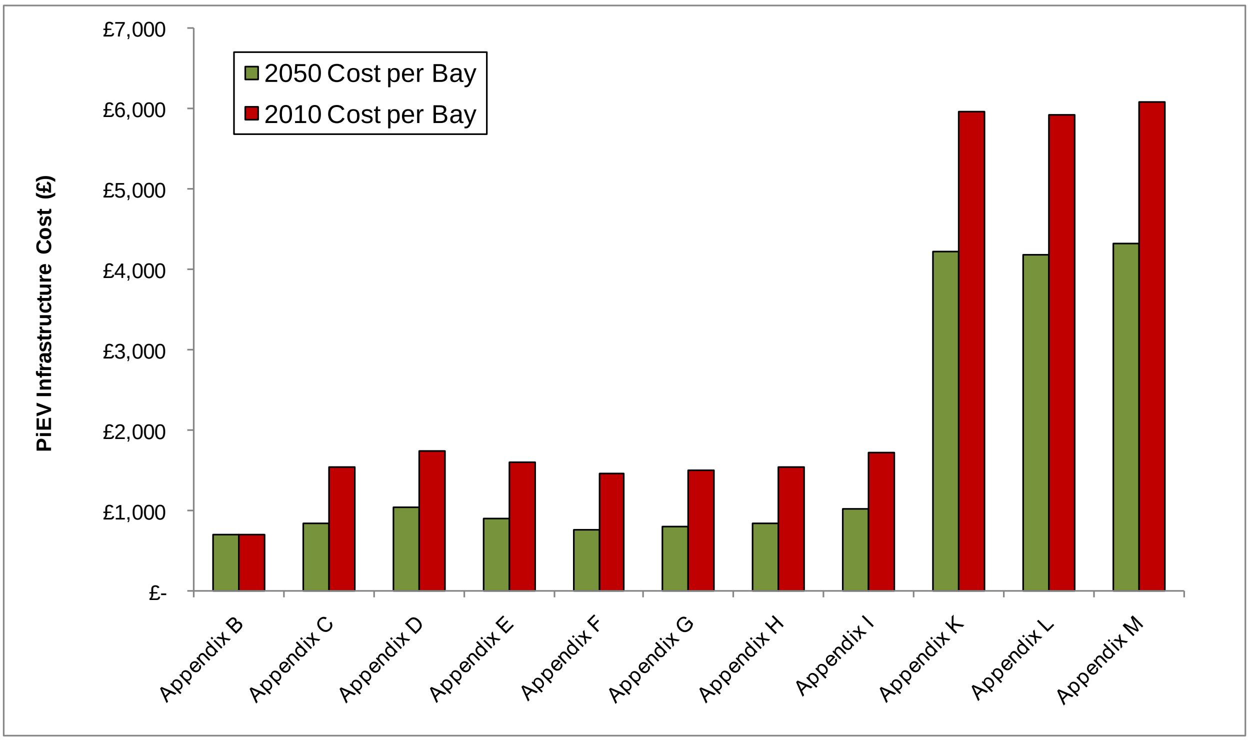

Figure 6.1.4.1b: 2010 and 2050 System Design Costs per Bay (AC Recharging)

Figure 6.1.4.1b shows the 2010 costs for system design listed in Table 6.1.4.1 (excluding DC recharging) and how they are projected to reduce by 2050. The reduction is realised through the establishment of the dedicated PiEV components and competition of suppliers. As these components are a large proportion of the overall cost, three tiers of costs are evident in Figure 6.1.4.1b: Appendix B with no dedicated PiEV component (excluding PiEV connector) where there is no margin for cost reduction; Appendices C to I where wall boxes lead to circa £1,500 per recharge bay reducing to circa £800; and Appendices K to L where recharge posts with 2010 costs of circa £6,000 reducing to circa £4,200.

The high cost of recharge posts is due to costs associated with the posts being located in public highways. This includes creating a product that can withstand vehicle impacts, security systems and a large proportion of cost due to the installation.

7 CONCLUSIONS

This report has presented the attributes and developments of PiEV recharging infrastructure in domestic, commercial and public locations and proposed design solutions. For each location, an assessment of PiEV parameters and typical PiEV / recharge point usage has been used in conjunction with an energy transfer assessment. The resulting charge point usage requirements yield power requirements for recharge point installations.

A broad assessment of the power network constraints has been carried out and correlated to the PiEV power requirements. An appraisal of technology options, which may be adopted to address charge point usage requirements, constraints and compliance with standards, has been carried out.

Given the number of variables associated with recharging infrastructure, a structured design approach has been presented to reveal potential system solutions. The design structure composes of three segments; distribution network interface, recharge point and PiEV interface. This structure has been complemented with a range of system design examples, demonstrating technologies and components in each segment, and designs for multiple PiEV recharging.

The PiEV interface is the primary design consideration which transpires from the requirements of the user and PiEV capabilities. Examples of energy and recharging durations have been presented for domestic, commercial and public locations; this yields a power capacity requirement for individual PiEVs.

Individual PiEV connection power requirements are sized against present, emerging and expected future ratings of PiEV connectors. These developments are based around standard BS EN 61851 which has been presented identifying modes, classes and power level of recharging as shown below.

- 3.8 kW, 16A single phase AC recharging (Slow)
- 7.7 kW, 32A single phase AC recharging (Fast)
- 11.5 kW, 16A three phase AC recharging (Fast)
- 23 kW, 32A three phase AC recharging (Rapid)
- 240 kW, DC recharging (DC-Rapid)

A practical limit for domestic recharging is a single 7.7 kW PiEV connection or two 3.8 kW PiEV connections. This is subject to a suitable assessment of the local load and some engagement with the user to avoid multiple loads at the same instance. Commercial and public locations vary so much that a generic practical limit cannot be concluded.

In addition to AC connector developments, PiEV interface technology options are presented for inductive and DC recharging, identifying the merits of each. Technology options for the recharge point are also presented, including developments in recharge posts and wall boxes.

The distribution network interface ultimately determines the number of recharge points that may be accommodated depending on the supply capabilities. This report has identified the following power thresholds and limits of the supply infrastructure.

- 23 kW, limitation of components for a single phase supply
- 69 kW, limitation of components for a standard three phase supply
- 552 kW, limitation of components for a dedicated LV three phase supply from a secondary substation.

Disregarding any local load on the same supply, the maximum number of recharge bays may be determined by a simple division of the supply capacity, over the PiEV interface requirement determined for a particular location. It follows that the above supply limitations yield a maximum of is 6, 18 and 150 recharge bays respectively, for single phase 16A recharging. This is based on all bays being utilised at the same instance in time, which is a reasonable assumption given the relatively long durations of recharge. There is however scope to implement a local load management system, which could be used to increase the number of bays for a given infrastructure capacity.

8 RECOMMENDATIONS

The use of a standard 13A, 3-pin plug for PiEV recharging is an enabling technology for early adoption of PiEVs. However, as technologies are emerging for Mode 3 recharging (i.e. control pilot functionality encompassing the infrastructure connection), it is recommended that all PiEV infrastructure system designs adopt Mode 3 recharging on safety grounds. Connectors, wall boxes and recharge posts are developing to accommodate Mode 3 recharging which facilitates safe, interoperable recharging of future systems incorporating higher power levels. A common standard for connectors is mandated in early 2012.

Table 8 details high level recommendations which have been deduced for requirement through-out this report.

Table 8: High Level Recommendations

Recommendation ID	Requirements
RN1	The distribution network interface should implement a control system for local load management of multiple recharge points or local load where appropriate.
RN2	Power system and local load data should be available in real time to any recharging control system. This should be used to determine available capacity.
RN3	Flexible load current management should be adopted for multiple charge points.
RN4	PiEV recharging unit must be supplied by a dedicated circuit from the consumer unit.
RN5	PiEV recharging installations should consider the diversity of other loads on the domestic network.
RN6	Charge rates greater than 3 kW should have a domestic load management system installed with interface to the PiEV recharge control.

Recommendation ID	Requirements
RN7	Properties with electric latent heating systems to take advantage of reduced off-peak tariffs should have a domestic load management system installed with interface to the PiEV recharge control.
RN8	Homes with multiple PiEVs should have a domestic load management system installed with interface to the PiEV charge control.
RN9	The recharge cable or connectors should clearly indicate that extension cables and adaptors should not be used.
RN10	Common modes of failure should be notified.
RN11	A means of communication should be implemented between the PiEV and the infrastructure.
RN12	Power indicator – recognition of current rating of recharge point.
RN13	The user or operator can specify the upper limit recharge rate.
RN14	Operation of a load management system should be clearly indicated to the user.
RN15	Where recharging is billed, the costs of recharging should be clearly visible and understandable.
RN16	A contact number for 24 hour charger post service should be clearly visible.
RN17	The recharging post should have communications to facilitate remote operation and failure notification.

It is recommended in domestic and small commercial locations, that PiEV installations are supplied from a separate feed from the consumer unit. It is recommend that where 16A single phase recharging is installed; that a cable sufficient for 32A recharging is installed, thereby catering for future upgrades at little expense.

Inductive recharging offers a number of safety advantages, both electrically and practically, such as removal of cable trip hazards. Recharging takes place with reduced user intervention, minimising situations of “forgetting to connect”. These benefits can be offset by the cost of such systems and reduced efficiency compared with conductive recharging. It is recommended that an inductive recharge system be trialled to determine recharge efficiencies in comparison to conductive recharging. Such assessments should focus on the efficiency of individual segments in the system and deduce how incorporating the inductive recharging within the PiEV converter improves overall recharging efficiency and cost saving.

The high load level capabilities of DC recharging can have significant voltage step implications on the distribution network. It is therefore recommended that all DC chargers have soft start control implemented which incorporates a slow charge level ramp in co-ordination with the distribution network voltage.

Diversity of load within properties is reduced as a result of PiEV recharging, resulting in increased risk of overloading and tripping of the main incoming circuit. It is recommended that a load management system which monitors the local load and controls the PiEV recharging, be adopted to avoid such situations.

Similar local load management systems are recommended for large car parks where expected PiEV connection durations are significantly longer than the recharge duration. In these cases the distribution network interface capacity may be significantly reduced which could result in a reduced infrastructure cost.

In the early stages of PiEV uptake, the duty of recharge duration to connection duration is not known, and will vary from one location to another. It is therefore recommended that PiEV trials include equipment installed to determine these duties, thereby informing future developments of algorithms to adopt within the local load management system.

In all cases a local load management system must have a margin to allow for adverse cases, (for example large groups of employees leaving work early on Friday half day working, significantly reducing the recharge window).

The scope of local load management systems can be extended to other areas, for example distribution networks (smart grids) and energy suppliers, the benefits being network support or tariff and environmental optimisation.

9 REFERENCES

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[7] SP2/EDF/06 Vehicle-to-Grid (V2G) & Vehicle-to-Home (V2H) Evaluation.

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[9] British Standard BS 7671 – Requirements for Electrical Installations; the IEE wiring regulations.

[10] The Electricity at Work Regulations 1989.

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[13] SP2/IMP/09 Report on potential reinforcement / mitigation options.

[14] SP2/EDF/05 Intelligence Upgrade Cost Report.

[15] Profile Class 1 – unrestricted customers as defined by ELEXON.

[16] From Meetings with Central Networks design engineers, October 2010.

[17] Central Networks Design Manual.

[18] Meetings with Central Networks design engineers, October 2010.

[19] Engineering Recommendation P28 - Addendum 3.

[20] Ofgem, Standard Licence Conditions http://epr.ofgem.gov.uk/index.php?pk=folder100992.

[21] Source: DNO Connection Charges Methodology documents.

[22] Source: UK Power Networks, Average DNO cost of installing 600 public charge posts in 2010.

[23] Source: Central Networks, January 2011.

[24] SP2/EDF/06 Vehicle to Grid (V2G) & Vehicle to Home (V2H) Evaluation.

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[26] Engineering Recommendation P2/6, 2005.

[27] OFGEM Quality of Service Requirements.

[28] Central Networks Design Manual.

APPENDIX A

Component Details

Cable Options (415kV -3 phase, 240V- 1 phase)		
Component	**Options**	**Standard**
External Cable (Suitable for supply and recharge cable)	SWA (Steel Wire Armoured). Single Phase. 2-core twin and earth cable. Three Phase. 3 or 4 Core depending on earthing arrangement (See BS 7671). Cable sizes/ratings. (Insulated wall installation): 1.5mm^2, 14.0A, 3.3kW 2.5mm^2, 18.5A, 4.4kW 4.0mm^2, 25.0A, 6.0kW 6.0mm^2, 32.0A, 7.6kW 10.0mm^2, 43.0A, 10.3kW	BS 5467 BS 6724
Internal Cable (Suitable for supply and recharge cable)	2-core twin and earth cable, Insulated and Sheathed. Cable sizes/ratings (Insulated wall installation): 1.5mm^2, 14.0A, 3.3kW 2.5mm^2, 18.5A, 4.4kW 4.0mm^2, 25.0A, 6.0kW 6.0mm^2, 32.0A, 7.6kW 10.0mm^2, 43.0A, 10.3kW	BS 6004 Follow BS 7671 for the de-rating of cables according to installation.
PiEV Cable	3 core cable, High visible coiled cable. Resistance to oil, weathering, hydrolysis, microbes, high abrasion and impact. 3.5 metre cable reduced to 1 metre by coiled arrangement.	VDE 0293 IEC 60245-4

Supply Enclosure and Internal Components		
Feeder pillar (External)	4 to 24 Way 100A to 200A Max Incomer Rating Single or Three Phase DIN Rail Mounting Lockable door	
Consumer Unit (1 Phase)	4 to 8 Way. 100A Max Incomer Rating. Single Phase. DIN Rail Mounting.	BS EN 61439-3
Distribution Board	4 to 24 Way. 125 to 200A Max Incomer Rating. Single or Three Phase. DIN Rail Mounting. Lockable door. IP41 internal/ IP20 Open door. Typical Dimensions: H:500 mm to 1040 mm. W:450 mm, D:150 mm.	BS EN 61439-3
MCCB Panel Board	400 to 800 A Max Incomer Rating. 6 to 12 Way	BS EN 60429-1
Disconnector/ Isolator	100 to 200 A (DB) / 250 to 800 A (PB)	BS EN 60947
RCD	High sensitivity (30mA), type A, group G. Latching. Single phase: 2 pole. Three phase: 4 pole.	IEC 61008-1; IEC 61009; IEC 60364-4-41 IEC 60755
MCB	DIN rail mount, Single pole, Type B. See Table 13 for range of ratings. Single and Three phase available.	BS EN 608989 BS EN 60947
MCCB	See Table 13 for range of ratings.	

Recharge point/ Off-board Chargers		
External Socket	UK 3 pin switchable socket with integrated RCD. Industrial socket single phase. IP rating according to installation, Blue, 240V, 16A or 32A rating. Industrial socket three phase. IP rating according to installation, Red, 415V, 16A/phase rating.	BS 1363 IEC 60309
Wall box (Future development)	Future developments for PIEV specific connectors. Integrated RCD/ Timer control. PWM/ Control pilot test circuit. Continuous earth test circuit. Communication channels. IP rated for external installation	
Recharge post	- UK 3 pin socket with integrated RCD. - Public kerb side/ bay wall mount recharging post, integrated payment and locking mechanism.	BS 1363
Off board charger	AC to DC Rectifier (Future- Inverter capability). Three phase connection. 100 kW to 250 kW units. Dedicated fixed PiEV cable/ connector.	

Connectors and PiEV Cable		
Infrastructure Plug	13A fused, UK 3 pin plug. Industrial plug (Blue, 240V, 16A rating)	BS 1363 IEC 60309
PiEV connector	To be determined by the PiEV manufacturer	
Future connector (Infrastructure and PiEV)	Compatible with Wall box/ PiEV / off-board chargers	

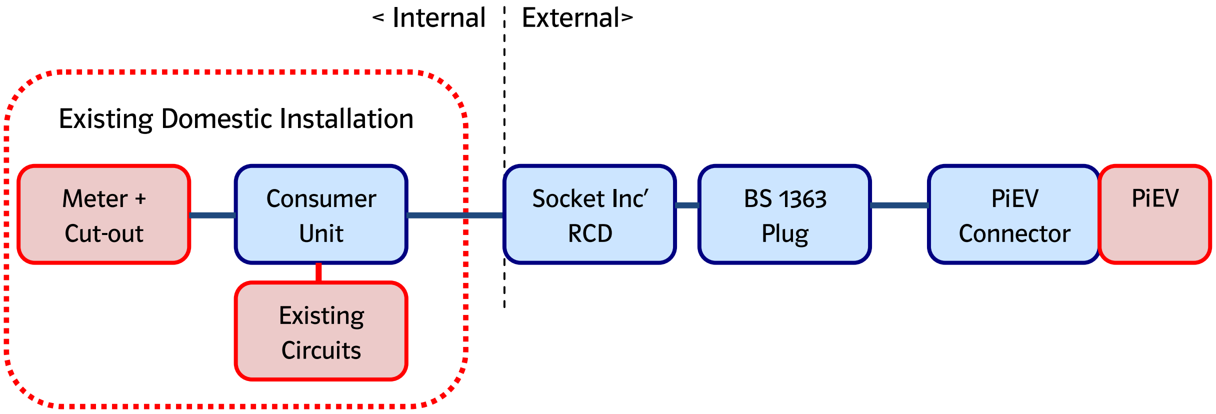
APPENDIX B

Domestic System Design Option 1

Domestic System Design Option 1

Standard 13A recharging. Installation added to existing domestic wiring (Assuming spare way within the consumer unit).

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Cut out Fuse	Existing	0
Meter	Existing	0
Supply Cable	Existing	0
Consumer Unit	Existing with a spare way/ Isolator/ RCD	0
MCB	16A, Type B	1
Recharge Cable	1.5mm^2, 2-core twin and earth cable	~10m
Recharge Point		
Socket	IP44, Integrated RCD – 30mA, Single gang	1
PiEV Interface		
Infrastructure Plug	BS 1363	1
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m
PiEV Plug	PiEV connector to be determined by PiEV Manufacturer	1

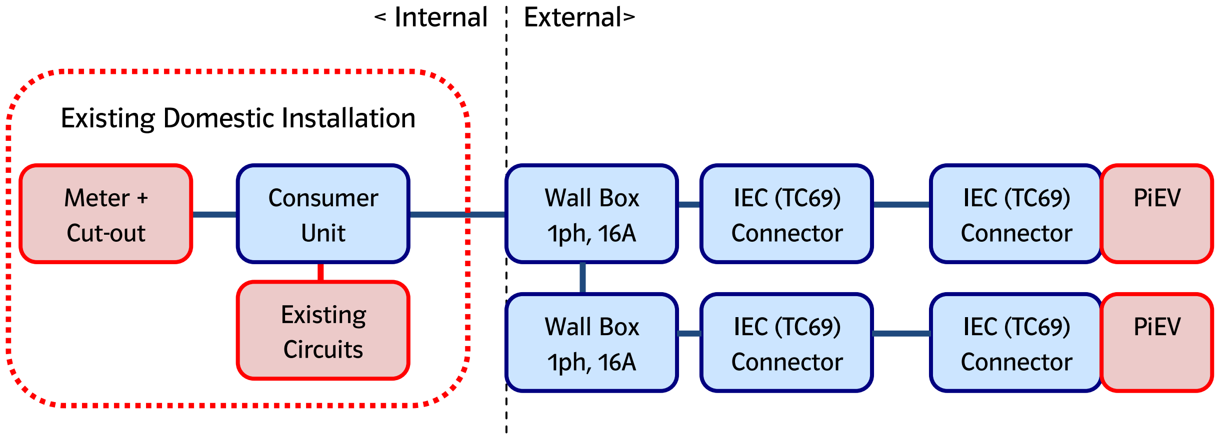
APPENDIX C

Domestic System Design Option 2

Domestic System Design Option 2

16A Mode 3 recharging with provision for 2 PiEVs. Installation added to existing domestic wiring (Assuming spare way within the consumer unit).

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Cut out Fuse	Existing	0
Meter	Existing	0
Supply Cable	Existing	0
Consumer Unit	Existing with a spare way/ Isolator/ RCD	0
MCB	32A, Type B	1
Recharge Cable	$6mm^2$, 2-core twin and earth cable – Radial feed.	~12m
Recharge Point		
Wall Box	1ph 16A rating, integrated RCB/MCB/Control Pilot function	2
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	2
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m x2
PiEV Plug	IEC connector as determined by TC69	2

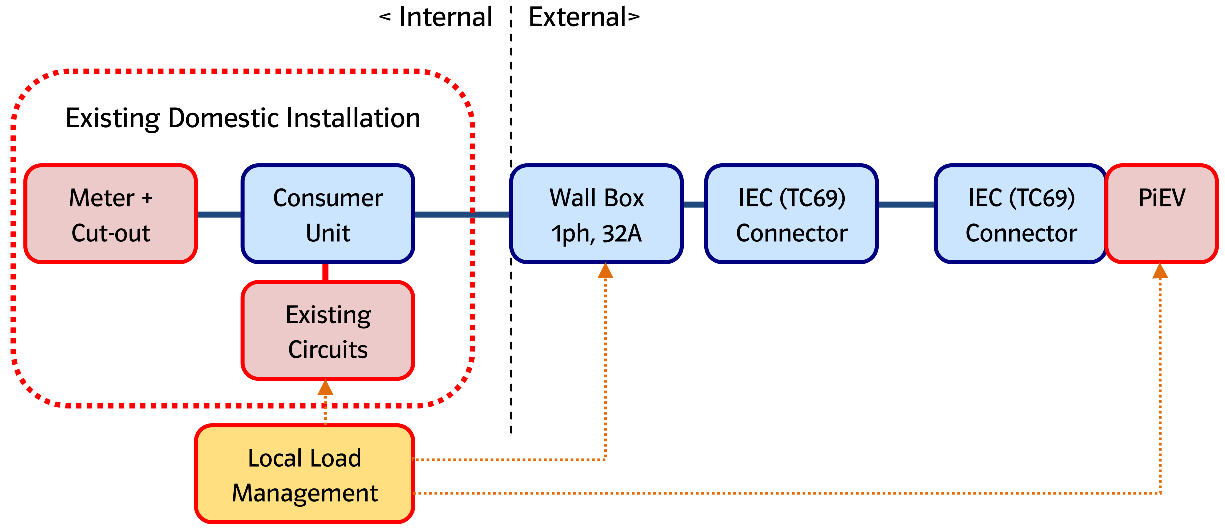
APPENDIX D

Domestic System Design Option 3

Domestic System Design Option 3

32A Mode 3 recharging with provision for 1 PiEV. Installation added to existing domestic wiring (Assuming spare way within the consumer unit).

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Cut out Fuse	Existing	0
Meter	Existing	0
Supply Cable	Existing	0
Consumer Unit	Existing with a spare way/ Isolator/ RCD	0
MCB	32A, Type B	1
Recharge Cable	6mm^2, 2-core twin and earth cable – Radial feed.	~10m
Recharge Point		
Wall Box	1ph 32A rating, integrated RCB/MCB/Control Pilot function	1
Local Load Management (Future)	Future technology presented in Section 3 for time shift recharging in harmonisation with existing loads. NB: Not used for costing in Section 6.	-
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	1
PiEV Cable	3 core, At least 32A rated, Yellow coiled cable,	3.5m
PiEV Plug	IEC connector as determined by TC69	1

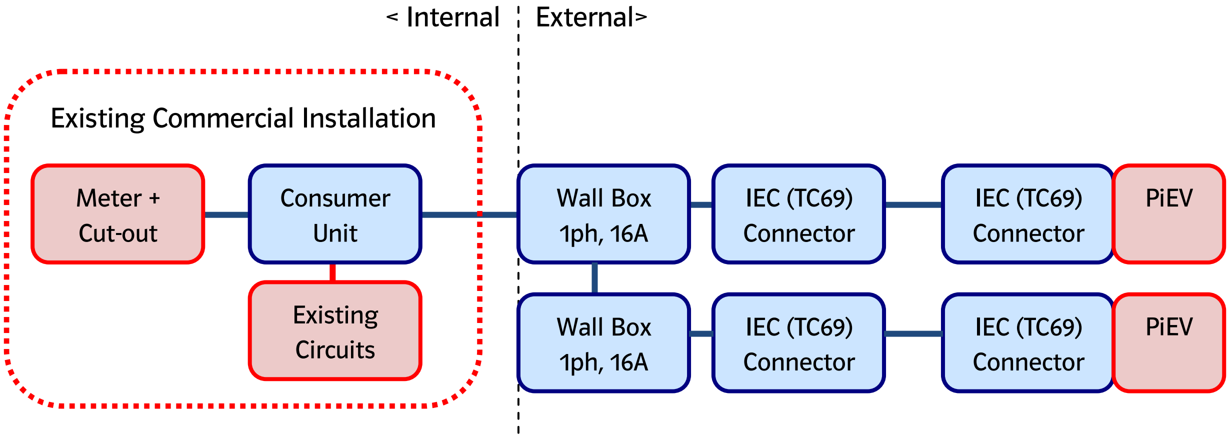
APPENDIX E

Commercial System Design Option 1

Commercial System Design Option 1

16A Mode 3 recharging with provision for 2 PiEVs. Installation added to existing commercial wiring (Assuming spare way within the consumer unit).

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Cut out Fuse	Existing	0
Meter	Existing	0
Supply Cable	Existing	0
Consumer Unit	Existing with a spare way/ Isolator/ RCD	0
MCB	32A, Type B	1
Recharge Cable	6mm^2, 2-core twin and earth cable – Radial feed.	~20m
Recharge Point		
Wall Box	1ph 16A rating, integrated RCB/MCB/Control Pilot function/ Metering functionality	2
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	2
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m x2
PiEV Plug	IEC connector as determined by TC69	2

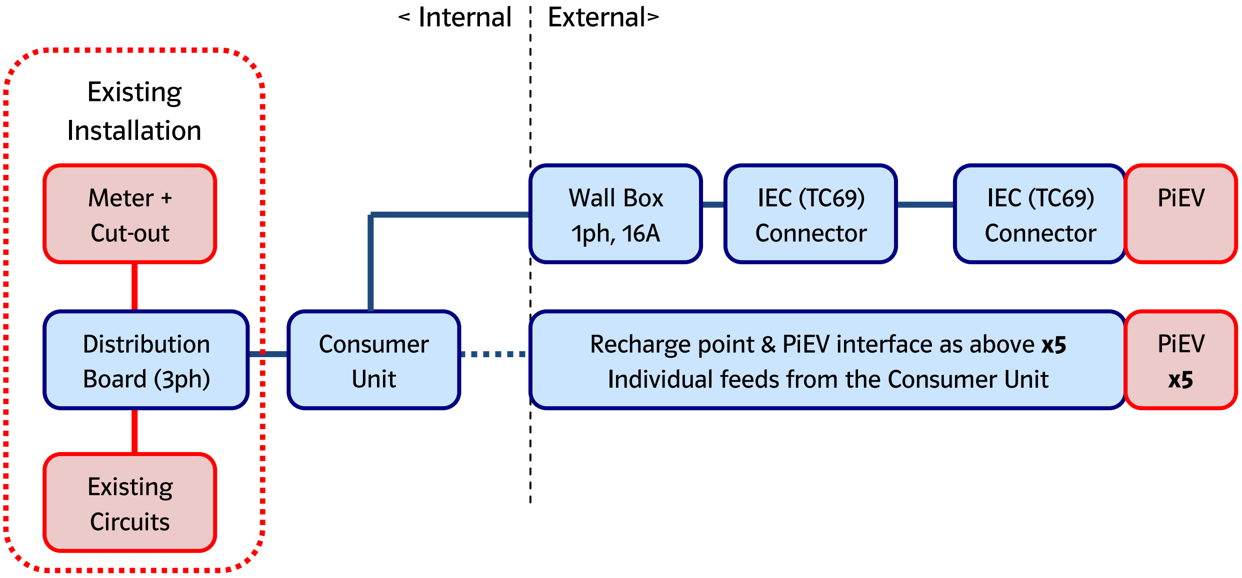
APPENDIX F

Commercial System Design Option 2

Commercial System Design Option 2

16A Mode 3 recharging with provision for 6 PiEVs. Installation added to existing supply (Assuming 3 phase distribution board).

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Distribution Board	Existing 3ph 100A/ph. 2 phases used for existing installation, third phase dedicated to PiEV infrastructure	0
MCB	100A, Type B. For supply to PiEV installation	1
Supply Cable	2 Cables, single phase, 25mm^2 each	2m x2
Consumer Unit	Single phase unit including Isolator switch and at least 6 ways.	1
RCD	2 pole, 30mA, type A.	1
MCB	16A, Type B	6
Recharge Cable	1.5mm^2, 2-core twin and earth cable – Radial feed.	~20m x6
Recharge Point		
Wall Box	1ph 16A rating, integrated RCB/MCB/Control Pilot function/ Metering functionality	6
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	6
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m x6
PiEV Plug	IEC connector as determined by TC69	6

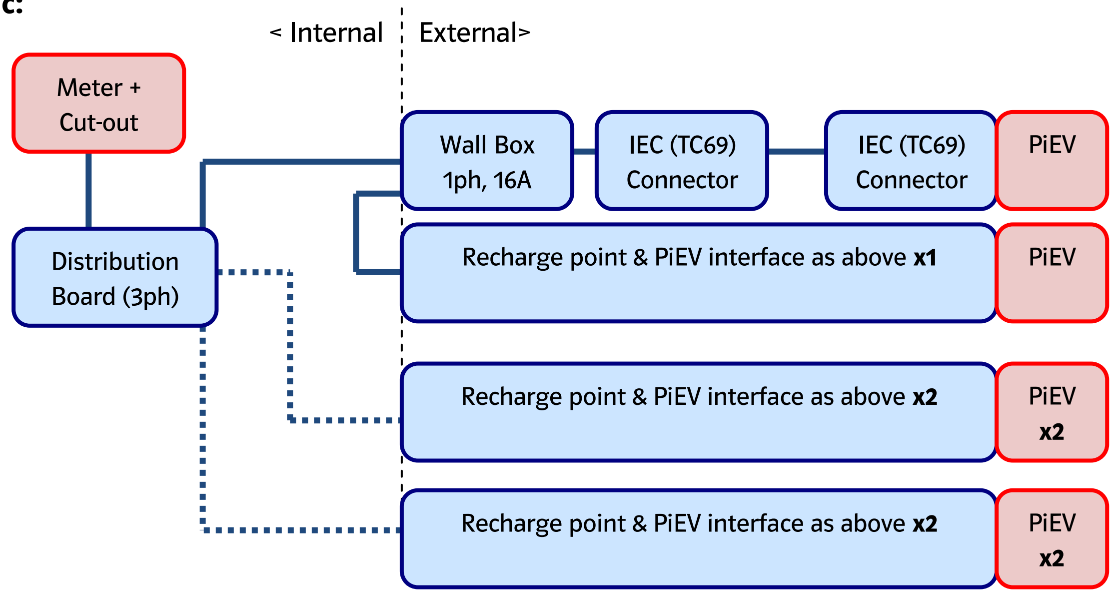
APPENDIX G

Commercial System Design Option 3

Commercial System Design Option 3

16A Mode 3 recharging with provision for 6 PiEVs. Installation of three phase distribution supply with PiEV load evenly distributed across the phases.

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Supply Cable	6mm^2, 4-core cable (3 phase).	10m
Distribution Board	3ph 100A/ph. PiEV load distributed evenly across phase (2 PiEVs per phase). Note spare capacity for other loads.	1
RCD	4 pole, 30mA, type A.	1
MCB	16A, Type B	3
Recharge Cable	6mm^2, 2-core twin and earth cable – Radial feed.	~10m x3
Recharge Point		
Wall Box	1ph 16A rating, integrated RCB/MCB/Control Pilot function/ Metering functionality	6
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	6
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m x6
PiEV Plug	IEC connector as determined by TC69	6

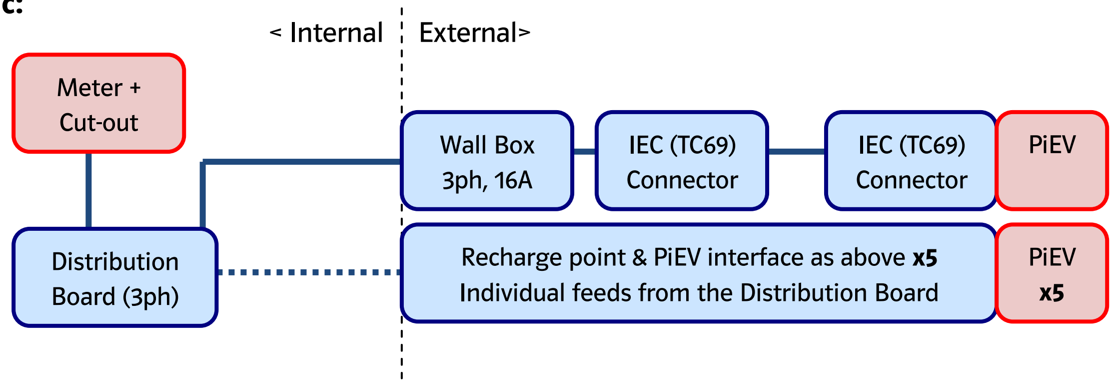
APPENDIX H

Commercial System Design Option 4

Commercial System Design Option 4

16A three phase Mode 3 recharging with provision for 6 PiEVs. Installation of three phase distribution supply with PiEV load evenly distributed across the phases.

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Supply Cable	35mm^2, 4-core cable (3 phase).	10m
Distribution Board	3ph 100A/ph. PiEV load distributed evenly across phases (dedicated 3ph supply to each wall box). Note no spare capacity for other loads.	1
RCD	4 pole, 30mA, type A.	1
MCB	3ph, 16A, Type B	6
Recharge Cable	1.5mm^2, 4-core cable (3 phase).	~10m x6
Recharge Point		
Wall Box	3ph 16A rating, integrated RCB/MCB/Control Pilot function/ Metering functionality	6
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	6
PiEV Cable	5 core, At least 16A rated, Yellow coiled cable,	3.5m x6
PiEV Plug	IEC connector as determined by TC69	6

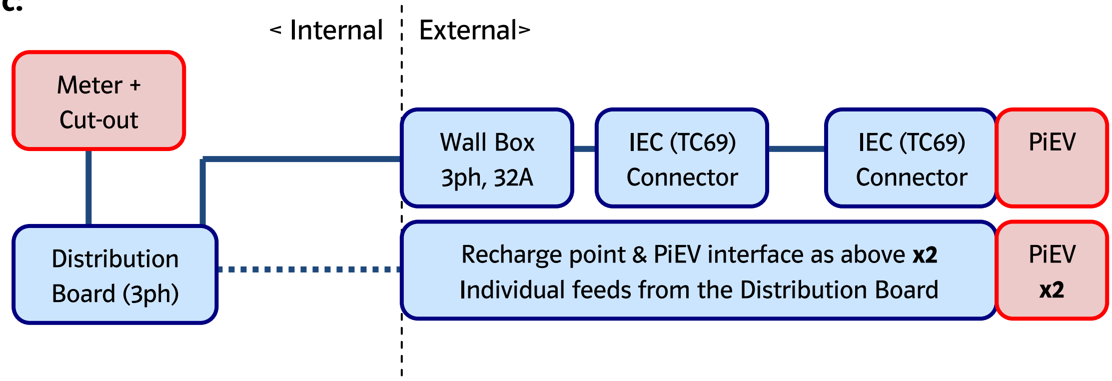
APPENDIX I

Commercial System Design Option 5

Commercial System Design Option 5

32A three phase Mode 3 recharging with provision for 3 PiEVs. Installation of three phase distribution supply with PiEV load evenly distributed across the phases.

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Supply Cable	35mm^2, 4-core cable (3 phase).	10m
Distribution Board	3ph 100A/ph. PiEV load distributed evenly across phases (dedicated 3ph supply to each wall box). Note no spare capacity for other loads.	1
RCD	4 pole, 30mA, type A.	1
MCB	3ph, 32A, Type B	3
Recharge Cable	6mm^2, 4-core cable (3 phase).	~10m x3
Recharge Point		
Wall Box	3ph 32A rating, integrated RCB/MCB/Control Pilot function/ Metering functionality	3
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	3
PiEV Cable	5 core, At least 32A rated, Yellow coiled cable,	3.5m x3
PiEV Plug	IEC connector as determined by TC69	3

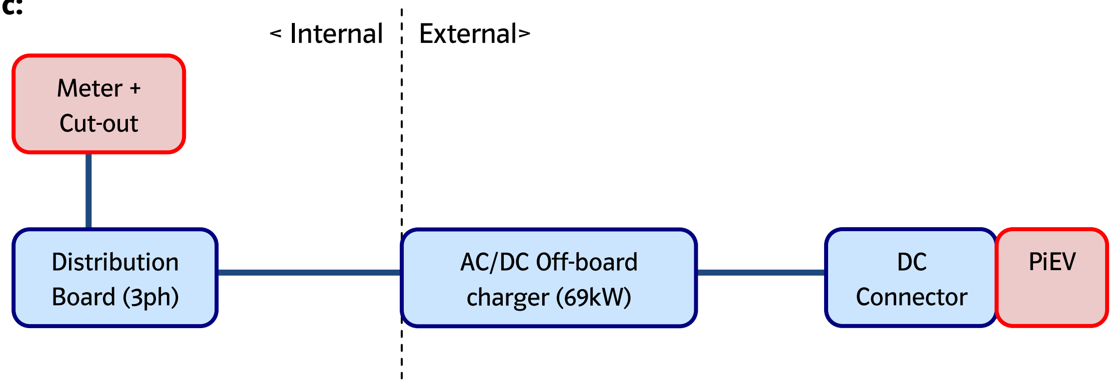
APPENDIX J

Commercial System Design Option 6

Commercial System Design Option 6

69kW off-board charger. Installation of three phase distribution supply dedicated for PiEV load.

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Supply Cable	35mm^2, 4-core cable (3 phase).	10m
Distribution Board	3ph 100A/ph.	1
RCD	4 pole, 30mA, type A.	1
MCB	3ph, 100A, Type B	1
Recharge Cable	35mm^2, 4-core cable (3 phase).	~10m x6
Recharge Point		
Off board Charger	69kW AC/DC converter, with fully integrated control and protection	1
PiEV Interface		
PiEV Cable	Part of the off-board charger	3.5m
PiEV Plug	Part of the off-board charger	1

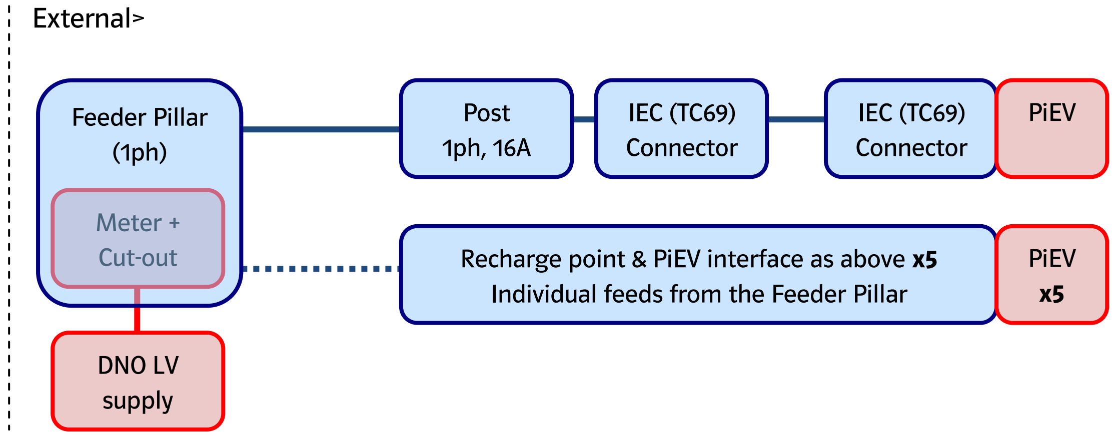
APPENDIX K

Public System Design Option 1

Public System Design Option 1

16A Mode 3 recharging with provision for 6 PiEVs. Kerbside installation.

Schematic:



Component	**Details**	**Quantity**
Distribution Network Interface		
Cut out Fuse	DNO equipment installed within the feeder pillar	0
Meter	DNO equipment installed within the feeder pillar	0
Feeder Pillar	Including single phase board including isolator. Housing may contain temperature/moisture control equipment.	1
RCD	2 pole, 30mA, type A. 100A	1
MCB	16A, Type B	6
Recharge Cable	1.5mm^2, SWA, 2-core twin and earth cable – Radial feed.	~10m x6
Recharge Point		
Recharge Post	1ph 16A rating, integrated RCB/MCB/Control Pilot function/ Metering and billing functionality	6
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	6
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m x6
PiEV Plug	IEC connector as determined by TC69	6

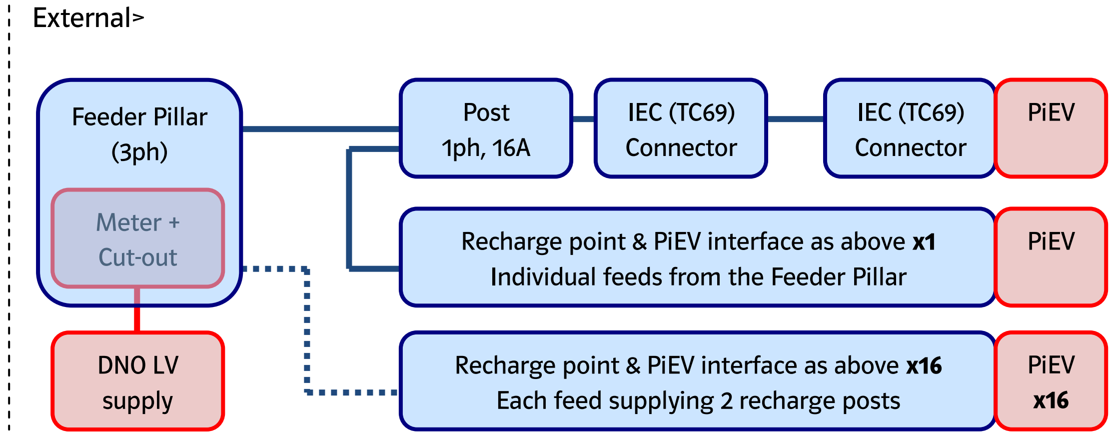
APPENDIX L

Public System Design Option 2

Public System Design Option 2

16A Mode 3 recharging with provision for 18 PiEVs. Carpark installation with 6 recharge post per supply phase.

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Cut out Fuse	DNO equipment installed within the feeder pillar	0
Meter	DNO equipment installed within the feeder pillar	0
Feeder Pillar	Including three phase board including isolator. Housing may contain temperature/moisture control equipment.	1
RCD	4 pole, 3 phase, 30mA, type A.	1
MCB	32A, Type B	9
Recharge Cable	6mm^2, SWA, 2-core twin and earth cable – Radial feed.	~15m x9
Recharge Point		
Recharge Post	1ph 16A rating, integrated RCB/MCB/Control Pilot function/ Metering and billing functionality	18
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	18
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m x18
PiEV Plug	IEC connector as determined by TC69	18

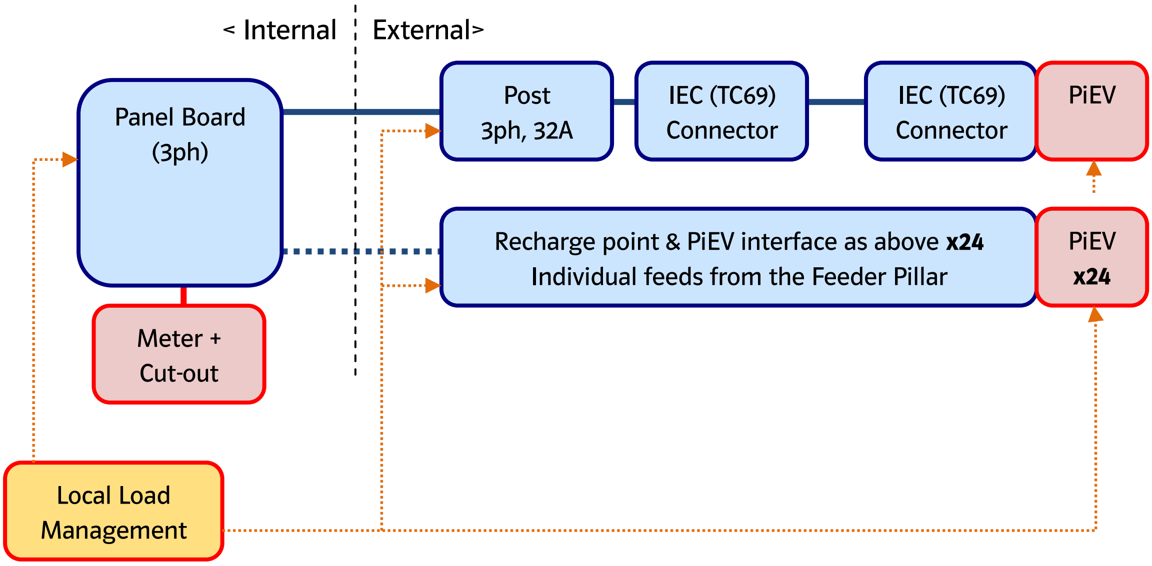
APPENDIX M

Public System Design Option 2

Public System Design Option 3

32A Mode 3 recharging with provision for 25 PiEVs. Eg Multi-storey car park installation.

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Panel Board	Three phase, capacity for 25 way (3ph)	1
MCCB	Three phase, 800A	1
MCCB	Three phase, 400A to split the load	2
MCB	Three phase 32A, Type B	25
Recharge Cable	6mm^2, 4-core cable (3 phase).	~20m x25
Recharge Point		
Recharge Post	1ph 16A rating, integrated RCB/MCB/Control Pilot function/ Metering and billing functionality	25
Local Load Management (Future)	Future technology presented in Section 3 for staged/ controlled recharging in harmonisation with all PiEV load. NB: Not used for costing in Section 6 and infrastructure capacity could be reduced.	-
PiEV Interface		
Infrastructure Plug	IEC connector as determined by TC69	25
PiEV Cable	3 core, At least 16A rated, Yellow coiled cable,	3.5m x25
PiEV Plug	IEC connector as determined by TC69	25

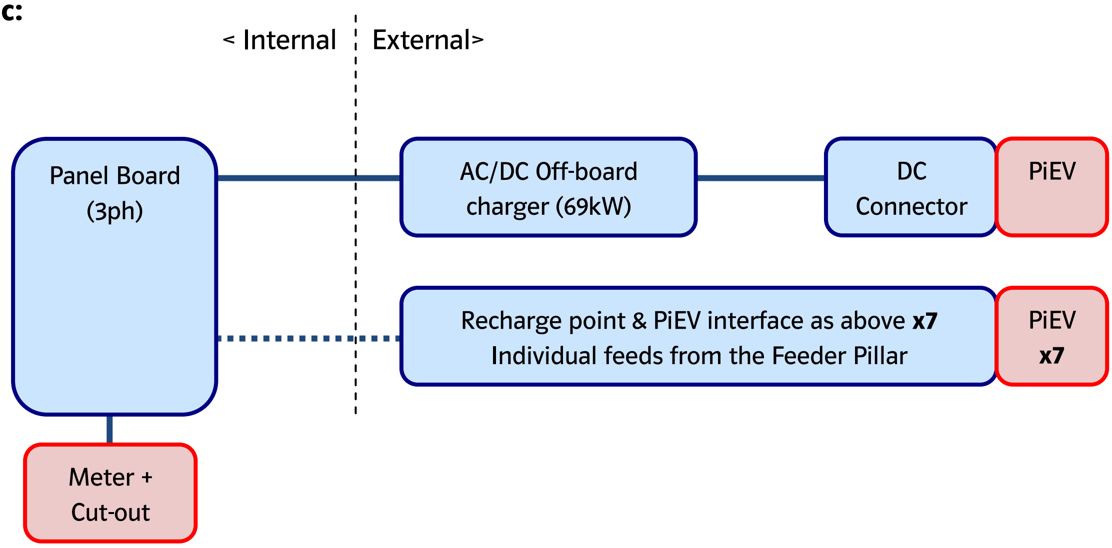
APPENDIX N

Public System Design Option 4

Public System Design Option 4

69kW off-board charger for 8 recharge bays. Installation of three phase distribution supply dedicated for PiEV load.

Schematic:



Component	Details	Quantity
Distribution Network Interface		
Panel Board	Three phase with MCCB /split load capacity	1
MCCB	Three phase, 800A	1
MCCB	Three phase, 400A to split the load	2
MCB	Three phase 100A, Type B	8
Recharge Cable	35mm^2, 4-core cable (3 phase).	~10m x8
Recharge Point		
Off board Charger	69kW AC/DC converter, with fully integrated control and protection.	8
PiEV Interface		
PiEV Cable	Part of the off-board charger	3.5m x8
PiEV Plug	Part of the off-board charger	8

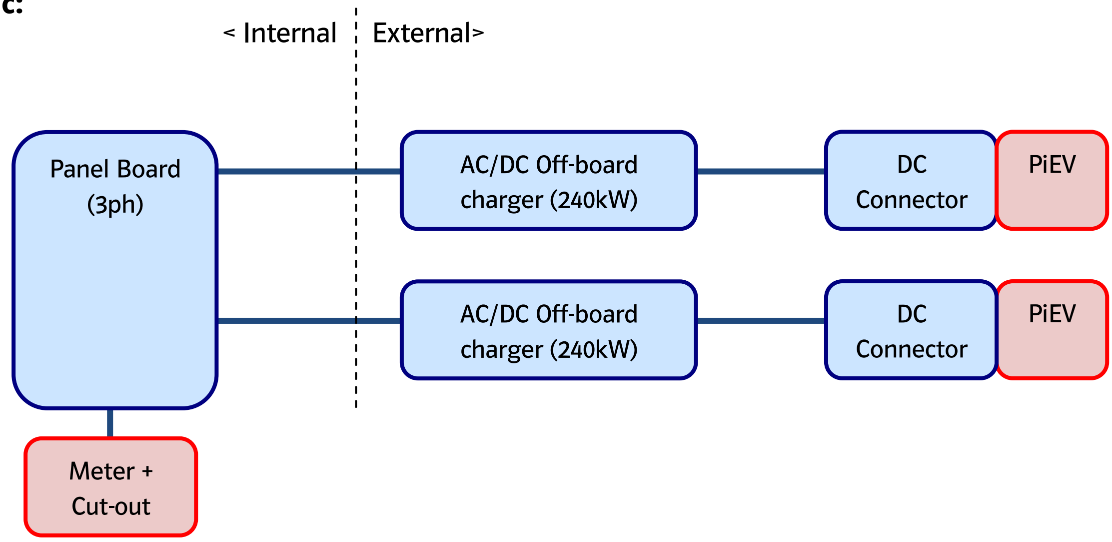
APPENDIX O

Public System Design Option 5

Public System Design Option 5

240kW off-board charger for 2 recharge bays. Installation of three phase distribution supply dedicated for PiEV load.

Schematic:



Component	**Details**	**Quantity**
Distribution Network Interface		
Panel Board	Three phase capacity	1
MCCB	Three phase, 800A	1
MCCB	Three phase, 400A	2
Recharge Cable	300mm^2, 4-core cable (3 phase).	~10m x2
Recharge Point		
Off board Charger	240kW AC/DC converter, with fully integrated control and protection.	2
PiEV Interface		
PiEV Cable	Part of the off-board charger	3.5m x2
PiEV Plug	Part of the off-board charger	2

APPENDIX P

Low Voltage Network Overview

P Introduction

This section reviews present electrical design procedures and requirements for low voltage network design, it is included to set the background for the locations specific analyses found in Section 3.1.

P.1 General Network Design Requirements

P.1.1 Low Voltage Networks

Low Voltage (LV) networks comprise of three phase underground cables or overhead lines on wood poles, normally arranged as multi branched radial feeders. A typical arrangement of an LV network supplying domestic properties is shown in Section 3.1.1.

The number of customers connected to an LV circuit varies from one circuit to the other. Most DNOs have a standard maximum number of customers that can be connected to an LV circuit which is typically of the order of 100 customers per circuit.

Currently, it is a general practice that the supplies to groups of new customers are provided by underground cables and only exceptionally overhead lines are used. Selected LV circuits interconnect with adjacent transformers via underground link boxes or overhead fuse-gear to provide back-feeds during routine and emergency work ensuring compliance with the security of supply requirements of Engineering Recommendation P2/6 and Regulator's customer service targets[26 & 27].

The majority of domestic properties have single phase services which are distributed across the phases of the mains cable as evenly as possible to balance load. Some electrically heated properties have three phase services to meet the local network requirements. Blocks of flats have a three phase supply installed at a central service metering position, and lateral connections to flats are provided and owned by the owner or occupiers. Commercial and industrial properties normally have three phase services; however, small commercial properties can have a single phase service.

P.1.2 Factors that Influence Low Voltage Network Design

The major factors that influence LV network design are electrical loading, voltage drop, earth loop impedance and protection. In selecting mains or service cables, electrical loading will be the first factor which defines the minimum cable size. Higher capacity cables may be required to meet the voltage drop and loop impedance criteria set by DNOs.

Service cables are selected based on the potential maximum loading that the cable will be subjected to. Mains cables are selected based on the arithmetic sum of after diversity maximum demands (ADMD) of all the customers connected to that mains. Diversity is a term used to indicate that the maximum total load of a group of loads is less than the sum of the individual maximum loads because these individual maximums do not all occur simultaneously.

Voltage drop occurs along the mains and service cables as the loads draw current. The statutory voltage drop limits on LV networks in the UK are +10/-6%. DNOs have a set of

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[26] Engineering Recommendation P2/6, 2005

[27] OFGEM Quality of Service Requirements

standard voltage drop limits from HV/LV transformer to cut-outs, which are generally lower than the above limits. As the load increases on a circuit the voltage drop also increases. Hence, addition of PiEV load will influence voltage drop characteristics.

Earth fault loop impedance is the impedance of the intended path of an earth fault current, starting and ending at the point of the fault to earth (known as the earth fault loop). This impedance comprises of transformer impedance, LV mains and service cable impedances and protective devices impedance. Loop impedance influences quality and safety of supplies. DNOs have a set of standard loop impedance limits (typically 0.24Ω)[28].

Low voltage circuits are protected by high rupturing capacity (HRC) fuses such that phase to neutral faults on mains and service cables are cleared within a certain time (typically 100s). This limits the length of the mains and service cables according to the combined loop impedance of the transformer, mains and service cables and the substation fuse size.

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[28] Central Networks Design Manual

APPENDIX Q

Identification of Hazards, Risks and Likely Consequences

Identification of Hazards, Risks and Likely Consequences

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
Design & Specification	1	Equipment and associated accessories are under rated for the prospective short circuit current (fault level) of the electricity supply.	1) Fire or explosion at recharge point caused by an electrical fault with the potential to kill or seriously injure the user or member of the general public. 2) Fire or explosion causing damage to equipment and nearby property, including vehicles.	The prospective short circuit current (fault level) may vary at commercial locations and at different locations within the electricity distribution network. Fault levels may also vary at domestic properties with installed generation sources (diesel etc.)	1) A fault level study at the point of supply should be undertaken prior to the design and specification of equipment. 2) Recharging equipment and accessories should be rated above the prospective short circuit current at all foreseeable charge locations.	1) Public and commercial recharge point owners and designers 2) Approved installation contractors for domestic locations
	2	Equipment and associated accessories are under rated for the nominal load or overload current required by the PiEV.	1) Electrical fire at the recharge point or accessory with the potential for injury or death. 2) Fire at the recharge point causing damage to equipment and nearby property, including vehicles.	Without preventative measures in place, a cable with a low current rating could potentially be connected to a high power recharge point.	1) Installed recharging equipment and all supplied accessories should be rated above the nominal current required by the vehicle with an allowance made for potential overload conditions. 2) Power interrogation electronics to determine power requirements of PiEV and maximum rating of electric vehicle supply equipment (EVSE) - Does not apply to Mode 1 charging. 3) Mechanical measures such as standardised plug and sockets, to prevent connection of a PiEV to an under rated supply point. 4) Automatic Disconnection of supply 5) Recharge point is installed in compliance with BS 7671	1) System owners, designers and suppliers of equipment (commercial and public locations). 2) Approved installation contractors for domestic locations

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
	3	Installation of a domestic charge point de-rates (overloads) existing household mains circuits.	Risk of household fire	Typically applies to domestic properties whereby the recharge point is connected to an existing 13A or higher mains circuit	1) A dedicated 16/20A circuit should be installed in the property with a dedicated overload protective device. 2) Automatic disconnection of supply in accordance with BS7671	Approved installation contractors for domestic locations
Environment	4	Ingress of water	1) Electrical fault at recharge point or PiEV causing fire resulting in injury, death or property damage. 2) Electrocution resulting in serious injury or death	Ingress of water is foreseeable during periods of heavy rain, washing of the PiEV and at domestic properties utilising sprinkler systems.	1) Recharge point enclosures and accessories should have a minimum ingress protection (IP) rating as specified in BS EN 61851-1 2) Automatic disconnection of supply in accordance with BS7671	1) Public and commercial recharge point owners 2) Manufacturers and suppliers of equipment and accessories 3) Approved installation contractors for domestic locations
	5	Recharge point equipment and accessories exposed to extreme temperatures	Degradation and breakdown of electrical insulating materials resulting exposed, live conducting parts. Risk of electric shock or electrocution in the event of human contact.	High temperatures may be present within the EVSE during normal operation.	Thermoplastic and rubber materials should be designed to withstand temperatures and fire (increasing resistance to ageing) as specified in BS EN 62196-1	Manufacturers and suppliers of equipment and accessories
	6	High speed vehicle impact with recharge point	Damage to recharge point resulting in exposed, hazardous live parts. Risk of electric shock or electrocution in the event of human contact.		1) Recharge points fitted with impact detection are de-energised in the event of a collision 2) Installation of overload and fault current protective devices such as a circuit breakers, fuses	1) Recharge point owners 2) Manufacturers and suppliers of equipment (commercial and public locations).

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
					which automatically disconnect the supply in the event of a fault. 3) RCD for electric shock and additional earth protection	2) Approved installation contractors for domestic locations
	7	Vehicle drive-over of recharging cable	Damage to external cable sheath and/or cable insulation resulting in exposed, hazardous live parts. This presents the risk of electric shock or electrocution when the system is energised.		1) Recharging cables and connectors should be designed to withstand the impact force of the tyre on a slow moving vehicle (approximately 5000N) as specified in BS EN 61851-1 and BS EN 62196-1. 2) Fault protection devices for automatic disconnection of supply 3) Pilot circuit and protective conductor detection (Modes 2, 3 and 4 only)	1) Manufacturers and Suppliers of the PiEV, equipment and accessories 2) Recharge point owners 3) Approved installation contractors for domestic locations
	8	Potentially explosive atmospheres	Sparking or arcing during normal operation ignites the gas within an explosive atmosphere resulting in an explosion causing property damage, injury or death.	Explosive atmospheres may be present within fuelling stations which supply LPG	1) Recharging points installed with a minimum degree of separation from potentially hazardous zones 2) EX rated equipment installed at recharge point as defined by the Dangerous Substances and Explosive Atmosphere Regulations (DSEAR).	1) Recharge point owners 2) PiEV and equipment manufacturers and suppliers

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
	9	Exposure to chemicals and other hazardous substances	Degradation and breakdown of electrical insulating materials resulting in exposed, live conducting parts. Risk of electric shock or electrocution in the event of human contact.	Substances such as brake fluid, diesel, petrol and engine oil may be present at recharge point locations.	The inlet, plug, connector and cable is designed to resist the effect of normal automotive solvents and fluids appropriate to the application as defined in BS EN 61851-1	PiEV and equipment manufacturers and suppliers
Fault	10	Undetected third party damage to recharging cable or accessory	Exposed cable conductors present the risk of electric shock or electrocution when the system is energised.	Damage to cable or recharge point from a third party (theft, misuse or vandalism) may expose conductive parts without damaging the protective earth or pilot cable.	1) Additional protection against electric shock and earth fault provided in the form of a MCB / RCCB (residual current circuit breaker)/ Residual Current Device (for sockets with a rated current not exceeding 20A) 2) Regular inspection and maintenance of recharge point locations 3) Supervision of recharge location by trained and competent person	1) Recharge point owner 2) Approved installation contractors for domestic locations
	11	An overload condition resulting in an excess current flowing through an intended path.	Over heating of recharging cables, equipment and accessories resulting in fire.	This could be caused by a fault or a vehicle drawing more current than the recharge point equipment and accessories are rated to carry.	1) Installation of an overload protection device such as a Miniature Circuit Breaker (MCB) or Fuse for automatic disconnection of supply 2) Installation in accordance with BS7671	Recharge point owners, designers and installers.
	12	A short circuit condition resulting in an excess current flowing through an unintended path (with no exposed, hazardous live parts	Fire or explosion	A typical cause would be a charger cable insulation failure.	1) Installation of an overload protection device such as a Miniature Circuit Breaker (MCB) or Fuse for automatic disconnection of supply. The protective device should have a rated Breaking Capacity greater	Charge point owners, designers and installers.

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
		as a result).			than the largest potential short circuit (fault) current. 2) Installation compliance with BS7671	
	13	Exposed live parts as a result of an insulation failure	Indirect contact with conductive parts which have become hazardous live parts resulting in electric shock which can cause serious injury or death	Protection against indirect contact should consist of one or more of these measures as specified by BS EN 61815-1 and detailed within IEC 60364-4-41 (Clauses 411 to 413). One or more of these protective measures are also required to comply with BS7671: 'Requirements for Electrical Installations' - The IEE Wiring Regulations.	1) Reinforced or supplementary insulation 2) Protective equipotential bonding 3) Automatic disconnection of supply in the event of a fault (MCB or Fuse) 4) Simple separation of live parts 5) Installation of a Residual Current Device (mandatory supplementary protection) 6) For separated and isolated EVSE, an insulation monitor, that monitors the electrical isolation from earth of an isolated circuit, should automatically disconnect the supply under fault conditions. 7) double insulated equipment where possible	Charge point owners, designers and installers.

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
	14	Exposed live parts as a result of an insulation failure - supplementary measures	Indirect contact with hazardous live parts resulting in an electric shock causing serious injury or death.	These are mandatory supplementary measures for modes 2, 3 and 4 which will enhance protection during charging	A control pilot circuit which comprises a control pilot conductor, the protective earth conductor, supply equipment control electronics and further electronics aboard the electric vehicles. The circuit should be capable of performing the mandatory functions as described in BSEN 61815-1 sections 6.4.1.1 to 6.4.1.5	Charge point owners, designers and installers.
	15	Loss of the main DNO protective conductor to a domestic premise.	The loss of main protective conductor (combined neutral & earth) from the electricity distribution network could result in the vehicle chassis potential rising to 230V AC, while the surface beneath the user remains at 'true ground'. This presents a serious risk of electric shock should the user come into contact with the PiEV metalwork.	This scenario is most prevalent within a domestic property whereby the main protective conductor into the property (taken from the electricity distribution network) has been used to earth the charge point and subsequently the electric vehicle (common for a TN-C-S type earthing arrangement). A neutral fault in the supply network would mean a loss of protective conductor to the property and vehicle. This may also prevent an earth fault protective device, such as an RCD, from operating.	While there are no specific requirements for electric vehicles or charge points within the IEE Wiring regulations (BS 7671), it is reasonable to assume that the requirements for a caravan park installation would apply to a vehicle. In this case a TT earthing system (as defined in BS7671) could be employed for earthing vehicle charge points in domestic and industrial premises. This system requires a local earth electrode at the charge point and an RCD at the charge point for earth fault clearance. In the event that the main protective conductor is lost, the vehicle and the ground below the user will rise to the same potential.	Approved installation contractors for domestic locations

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
General Use	16	Continual use of charge point, PiEV inlet or equipment accessory (including cable)	Damage to recharge point equipment or accessories resulting in exposed, live conducting parts. Risk of electric shock or electrocution in the event of human contact.	Recharge point equipment must be able to withstand the demands of normal 'everyday' use.	1) The inlet/connector and plug/socket outlet should be designed with a service life as specified in BS EN 61851-1 2) Plugs and connector should be designed and manufactured such that they withstand impact of dropping and normal use as defined in BS EN 62169-1 and BS EN 61851-1 3) The recharging cable should be designed and manufactured such that the flexibility and mechanical characteristics should conform to the requirements of IEC 60245-66 and BS EN 61851-1	Vehicle and equipment manufacturers and suppliers
	17	Driving the PiEV while connected to a charge point at nominal current	Damage to recharging equipment or the PiEV with subsequent exposure of hazardous live parts presenting the risk of electric shock.		1) Control pilot circuit with protective conductor detection (modes 2, 3 & 4) 2) PiEV traction interlock preventing driving PiEV when connected to a recharge point is detected (Modes 2,3 and 4) 3) Automatic disconnection of supply	1) Public and commercial charge point owners and installers 2) Approved installation contractors for domestic locations
	18	Manual disconnection of the recharge cable while the recharge point is in operation	Arcing at the plug or socket causing degradation and eventual failure of insulating materials. Subsequently exposed, hazardous live parts present the risk of electric shock causing injury or death.		1) The plug, socket outlet, inlet and connector should be designed with sufficient breaking capacity as specified in BS EN 61851-1 2) For Mode 2 and 3 recharging systems, the pilot conductor should be disconnected before	PiEV and equipment manufacturers and suppliers

Safety Issue	Hazard ID.	Hazard	Risks / Consequences	Additional Information	Mitigation	Responsible Parties
					the live and neutral conductors. This action will de-energised the EVSE, thus preventing an electrical arc.	
	19	Stored Energy in capacitors and equipment with an inherent capacitance	A residual voltage, after de-energisation, between any accessible conductive parts or an accessible conductive part and earth presents the risk of electric shock.		As detailed in BS EN 61851-1: The equipment should be designed such that one second after having disconnected the EV from the supply, the voltage between any accessible conductive parts shall be less than 42,4V peak, 60V DC and the stored energy shall be less than 20J.	Manufacturers and suppliers of equipment (commercial and public charge locations).
Inspection & Maintenance	20	Inspection, Test & Maintenance of live equipment	Contact with hazardous live parts resulting in electric shock causing injury or death		1) A point of electrical isolation should be installed at all recharge point locations 2) Regular inspection and test of the installation in accordance with BS7671	Recharge point owners, designers and installers.