SP Energy Networks
September / 2019

Charge

Method 2 (Phase 1): Results of analysis and identification of trial locations (SDRC3)

This document has been prepared for SP Energy Networks by Smarter Grid Solutions Ltd.

Level of confidentiality: **INTERNAL USE**

1 DOCUMENT ISSUE CONTROL

1.1 Version History

Version	Date	Comment	Author
1.0	06/09/2019	First Draft	Smarter Grid Solutions
1.1	20/09/2019	Updated based on feedback from SPEN	Smarter Grid Solutions
1.3	04/10/2019	Updated based on feedback from SPEN	Smarter Grid Solutions

1.2 Signatories

Version	Date	Role	Name	Signature
			Stephen Stewart	
			Scott Mathieson	
		Smarter Grid Solutions Director and Project Sponsor	Graham Ault	

2 CONTENTS

2.1 Figures

Charge

2.2 Tables

3 TABLE OF ABBREVIATIONS

ANM	Active Network Management
CBA	Cost Benefit Analysis
CPO	Charge Point Operator
DC	Direct Current
DER	Distributed Energy Resource
DNO	Distribution Network Operator
DSO	Distribution System Operator
EATL	EA Technology Ltd
ESS	Energy Storage System
EV	Electric Vehicles
FCO	First Circuit Outage
ICE	Internal Combustion Engine
ICP	Independent Connections Provider
LCNF	Low Carbon Network Fund
LCTs	Low Carbon Technologies
NCEWS	Network Constraint Early Warning System
NIA	Network Innovation Allowance
NIC	Network Innovation Competition
NPg	Northern Powergrid
NPV	Net Present Value
OHL	Overhead Line
SDRC	Successful Delivery Reward Criteria
SPD	SP Distribution Licence Area
SPEN	SP Energy Networks
SPM	SP Manweb Licence Area
SSEN	Scottish and Southern Electricity Networks
UCM	Unit Cost Manual
UKPN	UK Power Networks
WPD	Western Power Distribution

4 EXECUTIVE SUMMARY

This report is the first Successful Delivery Reward Criteria (SDRC) deliverable from the Charge project and presents the outcomes from the first phase of the Method 2 workstream: "Tactical Solutions to support EV connections".

The Charge project aims to advance SPEN and other DNO capabilities on addressing the charging needs of EV charge point customer groups. Specifically Charge aims to provide customers with better information on EV charge point network connections, to enable better EV charge point infrastructure planning based on cutting edge transport planning and to offer customers smart charging solutions as alternatives to network reinforced connections (with the cost and timescale issues associated with those).

The Charge project and this report studies the connection and DNO smart charging solutions for three different EV charging applications (or use cases):

- **On-street EV charging**: for domestic electricity customers without dedicated off-street parking such as in terrace, apartment and tenement dwellings.
- **Destination EV charging**: for charging at typical public destinations such as retail, entertainment, leisure and tourism sites.
- **En-route EV charging**: for charging while in transit between home, work and destinations including highway services and urban refuelling locations.

The analysis in this report consider 4 charger ratings and these are allocated to the different use cases according to the best information available at present:

- Slow single phase chargers: 3kW AC
- Fast single-phase chargers: 7kW AC
- Fast three-phase chargers: 22kW AC
- Rapid chargers: 50kW DC

The ultimate focus for Method 2 is to test DNO smart charging solutions that would complement and be coordinated with other smart charging initiatives including for charging equipment specifications and smart charging incentivised by Retail Suppliers and managed by Charge Point Operators (CPOs). This report analyses the application and operation of the smart charging solutions outlined in Figure 1.

Charge

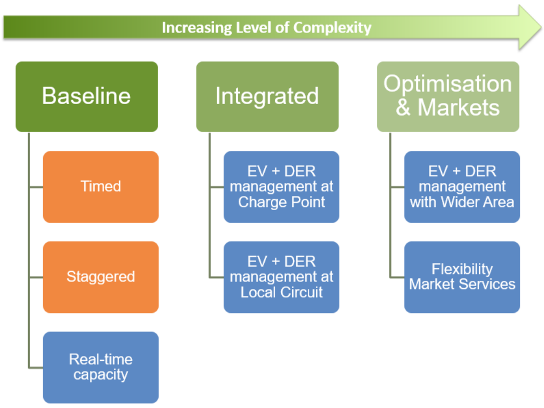

Figure 1: Overview of Smart Charging approaches.

The Method 2 workstream objectives for this first, now completed, phase of the project are to undertake connection studies of selected candidate areas of the SPM and SPD network to identify capacity headroom issues for a number of EV charge point modes and EV growth scenarios for a significant number of network types and locations. The EV connection studies programme and the selected network areas are intended to also identify potential smart EV charge point trial locations in the SPM network to be explored for the limited and broader trial phases of the Method 2 workstream. The stated objectives for this SDRC report and project milestone report[1] are:

- Completed assessments of candidate networks in SPM and other licence areas
- Updated Cost Benefit Analysis for each network study (each report detailing the impact of EV growth, the traditional reinforcement solution, smart solution options and the cost benefit analysis outputs of all solutions suitable at the network location)
- Stage Gate report which will determine the scope for trial deployment, and likely pilot trial locations.

This report presents the outcomes of the significant system analysis programme completed in this first phases of the project. The achievement of the milestone criteria in each of the three areas is presented below.

Headline Conclusions

The headline outcomes of the network and EV charging analysis in this first phase of Charge are:

- **A significant amount of network reinforcement would be required in both SPM and SPD LV networks to deal with a modest EV uptake.**
- **More than 50% of the identified reinforcement cases can be feasibly addressed with the Charge smart EV charging solutions.**

[1] https://www.ofgem.gov.uk/publications-and-updates/network-innovation-competition-project-direction-charge

Charge

- **The required LV network reinforcement investment compresses into the 2020-2030 period as the additional loading from EV charging creates a significant early investment requirement.**
- **Smart Solutions create significant CAPEX savings in the period 2020-2030 for the SPM license area, with a 55% reduction from £160m for conventional reinforcement to £70m for a reinforcement plus smart charging solutions investment strategy in the SPM license area.**
- **Indicative projections to the whole of GB reveal an estimated £3 billion of savings to upgrade LV networks to cope with the EV charging demand over the next 30 years.**
- **The targeted benefits of the application of smart EV charging solutions are in faster and cheaper connections to charge point developers and also in reduced load related reinforcement costs borne by all customers.**

Analysis Methods for EV Charging in the SPM and SPD Distribution Networks

An understanding of the existing and future network connection capacity headroom for EV charge points, the potential for smart EV charge point solutions to deliver benefits to the network and the avoided costs of reinforcing the network as a result of increasing EV penetration is gained from a substantial network analysis programme completed in this Phase 1 of the Charge Method 2 programme.

The network analysis programme has involved assessing several hundred LV and HV network sections in both SPM and SPD license areas, applying multiple EV growth scenarios to three separate use cases which represent the three main EV charge point use cases for the project (on-street, en-route, and destination).

The analysis methodology created and used sets of robust assumptions, applying time series loading profiles and assessed the technical and economic application and merits of multiple conventional network reinforcement and smart EV charge point solutions. Accessing LV and HV network data to build the network models for the analysis programme has been a challenge but aided by parallel SPEN initiatives on enhancing data sets and models. With all of these factors in play, the analysis programme has been a significant undertaking which has now produced two significant outcomes:

- A tried and tested analysis approach using existing and new tools, methods and data sets that can now be used for other large scale analysis campaigns (e.g. wider EV or other low carbon technology) in support of customer and network business objectives (e.g. investment planning), and
- Analytical results that shed light on the impact of EV charge points on the SPEN networks and the roles of conventional network reinforcement and smart EV charge point solutions.

A baseline analysis was undertaken to create a reference case of EV load growth, headroom issue identification and conventional reinforcement requirements. Smart EV charging solutions are analysed with the same network conditions but with reinforcement offset by one or more of the smart charging solutions.

The analytical methods are described in detail in this report and supporting project reports. The methods and tools can now be used to analyse the EV scenarios from Charge Method 1 and to evaluate LV and HV network investment strategies as part of SP Energy Networks investment planning processes.

Charge

Results and Conclusions of Network Analysis of EV Charger Integration

The results of the network analysis studies provide an indication of the number of existing network assets that will be overloaded following an increase in demand as a result of installation of EV charge points on the network. The EV charger types and demand profiles are tailored for the three Charge EV charging use cases for on-street, destination and en-route locations in alignment with the overall Charge project goals and in order to complement the learning available through other completed and ongoing NIC and NIA projects.

These baseline analysis results inform the development of “smart solutions” that are expected to offset the need for network reinforcement in reaction to expected EV growth. The results of both the baseline and smart solution analysis allow the cost-benefit analysis to be undertaken to capture the financial benefits of applying smart solutions to offset the network reinforcement project in the baseline analysis.

Through modelling the application of innovative control techniques to EV charge point infrastructure, the smart solution studies have explored the value of such techniques in the deferment of EV-driven reinforcement and cost-effective connection of charge points. Importantly, the studies have highlighted the benefits of different solution types, reflecting the additional capacity that can be released as solutions grow in complexity.

By using the outcomes from the network analysis, scaling the results to provide a license wide view, the CBA has provided indicative cost comparisons between the use of conventional network reinforcements to upgrade the network in response to demand growth, and the use of smart solutions to manage demand at peak times and use the flexibility in the network to enable connections in a timely manner.

Building on the extensive connection study results, a Cost Benefit Analysis (CBA) of network reinforcement options provides a comparison between deploying conventional network upgrade solutions for identified capacity issues and the smart EV charge solution options selected for study throughout the Charge project.

The highlights from the analysis are:

- **Modest EV uptake can create large demand increases in some distribution network areas**: The uptake levels of EV charge points in urban areas (the scenarios based on Future Energy Scenarios assumptions model up to 1.5% of potential customers with dedicated and unmanaged access to an EV charging) results in an overall electrical demand growth of more than 50% compared with 2018 baseline levels. This shows that a relatively small uptake in EVs will have a significant impact on the electrical capacity required of LV distribution systems in the coming years.
- **The required LV and HV network reinforcement investment compresses into the 2020-2030 period.** A high proportion of the reinforcement comes in the form of new feeder solutions required in the first time period of the study (2020-2030) (See Figure 2 below). The characteristics of LV network reinforcement, while costly and inconvenient, create network capacity for further EV growth in later decades.

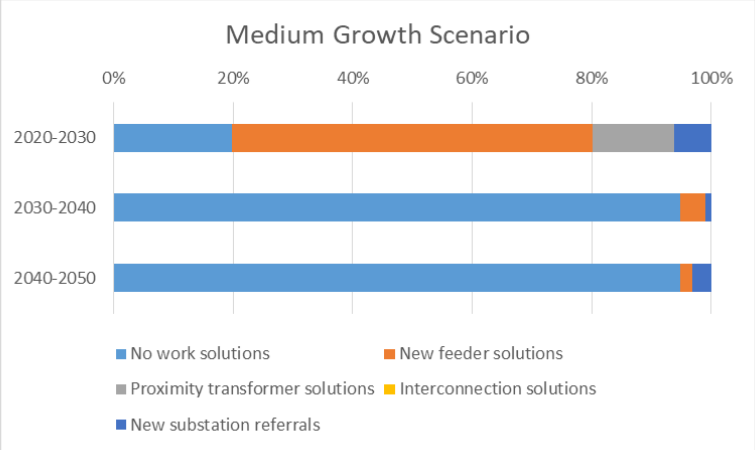

Figure 2: SPM On-street charging, Medium EV growth scenario, Baseline reinforcement solution requirements.

- **SPM On-Street, SPD On-Street and SPM Destination EV charge point cases create similar network headroom issues and investment needs**. There is a high degree of correlation between the SPM On-Street, SPD On-Street and SPM Destination EV charge point study cases in terms of the expected types and proportions of reinforcement solutions. This points to a general area-by-area requirement for network reinforcement in response to EV charger growth with specific local factors to be considered.
- Proportional allocation of EV chargers to car parking spaces and the relatively low baseline demand where **En-Route charging** is assumed to occur results in **demand growth as high as 119%** over the current baseline by 2050 (and up to 170% growth where a greater proportion of 50kW rapid chargers are modelled). However, there is **frequently sufficient capacity on existing HV/LV transformers** to accommodate this relatively modest level of growth. If more significant fast and rapid (22kW and 50kW) charger connections to a LV network occur (e.g. at a dedicated new EV en-route charging site) then a new HV/LV substation solution would typically be required and so a reinforcement solution would result. Only the integrated DER management would then be a logical smart charging solution addition to reinforcement since the immediate connection capacity issues would be resolved.
- The HV network analysis has assessed the growth of LV connected EV charge point across the EV growth scenarios and across decadal periods. There is a clear **impact to existing HV network capacity margins with some HV upgrades required** (Figure 3 shows the incremental erosion of HV headroom from the medium EV charging scenario across the decades to 2050). However, for the most part the **existing HV asset capacity headroom can cope with the forecast EV charge point load growth** approximated in these studies. This includes consideration of voltage regulation and fault level contribution (which is assumed to be low as a result of the EV on-board charge electronics and the impedance between LV connected charge points and the HV network.

Charge

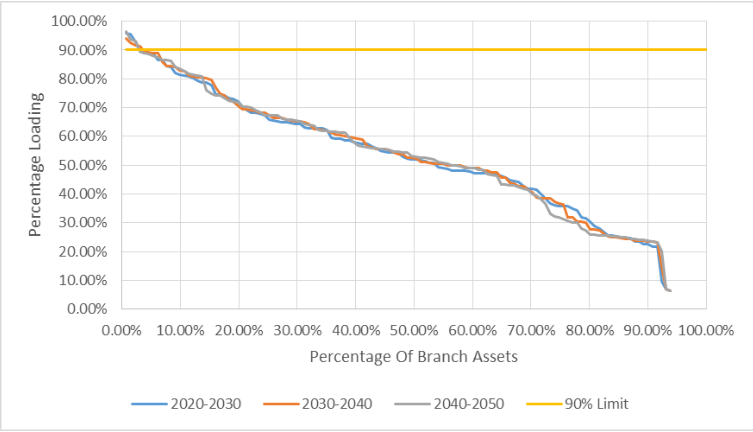

Figure 3: Medium Growth Scenario Worst Case Contingency Loading of Branch Assets (Baltic Triangle).

- **Real-time EV charging controlled smart solutions can avoid reinforcement in more than 50% of all cases that observe constraint conditions**. In all cases that study the Real-time smart charging solution (and the equivalent combined with DER coordination), the number of sites that are feasible for smart solutions deployment is higher than the number of sites where greater than 10% charge time interruption would be required and so where it is judged that network reinforcement would be the best solution to EV charge point connection. The issue of charge interruption and shifting with the smart solutions required further analysis and thought, and will be explored as part of the trials in the next phase.
- **There is a significant increase in applicability of 'active' over 'passive' smart solutions**. The real-time smart solutions, which provide real-time control of EVs based on real-time measurements of network loading, can be applied usefully to over twice as many sites as the 'passive' approaches (i.e. Timed and Staggered charging) that apply fixed limits in the planning timeframe using offline observations of historical loading conditions. In the on-street study case for the 2020-2030 period, this is reflected in the Real-Time solution being applicable to around 13% of studied feeders (shown in Figure 4 below), in comparison to the Timed/Staggered smart solution being fund applicable to only 5.5% of feeders. This outcome is evident across the On-street and Destination use cases with the en-route use cases having particular characteristics that narrow the scope of smart charging solutions as discussed above.

Charge

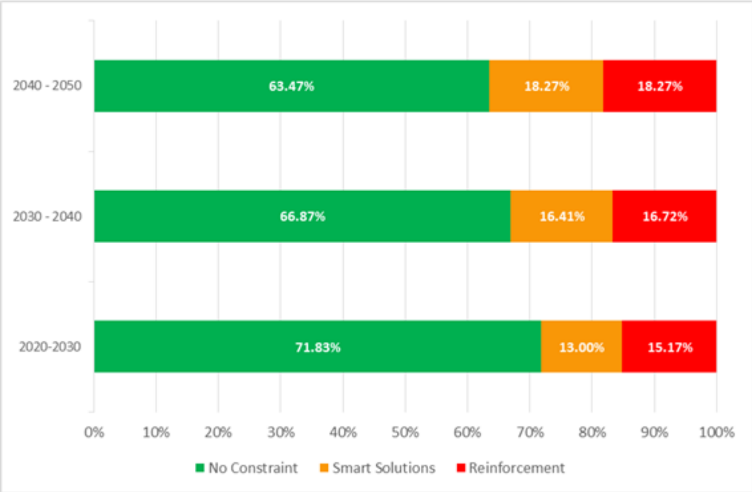

Figure 4: Proportion of Cases Suitable for Real-Time EV charge point – On-street charging.

- **The deployment of DER with the smart charging solutions provides additional gains in network capacity headroom or reinforcement deferral.** The real-time control plus DER smart charging solution defers reinforcement at additional study locations by offsetting EV charger interruption through use of on-site energy storage devices. A further 2-5% of reinforcement cases are addressed through the addition of DER in addition to the 12-18% of reinforcement cases dealt with by real-time controlled smart charging for the on-street and destination charging cases between 2020 and 2050. This DER integrated solutions might be better suited to marginally-constrained cases where the deployment of energy storage can provide a greater percentage reduction in charge point interruption or else where the customer has other DER value streams or objectives anyway.
- **When Smart Solutions are introduced as an option, there are significant CAPEX savings in the first 10 year period (2020-2030)**. The installation of smart solutions provides 'breathing space' for DNO investment needed to support LV network demand growth from EV charge point connections and EV charging. With the analysis outcome showing a significant reinforcement need in the 2020-2030 decade, the early capital investment reduction or deferral benefits of smart charging are very clear.
- **A hybrid investment strategy of conventional reinforcement and smart solutions provides the lowest combined CAPEX and OPEX outcome for EV connections and the associated demand growth.** Figure 5 shows a clear reduction of CAPEX from £190m for conventional reinforcement for EV charge point connections to £70m (so a 63% reduction) for the hybrid reinforcement and smart charging solutions in the SPM license area in the decade 2020 to 2030. There is a trade off with annual OPEX rising marginally.

Charge

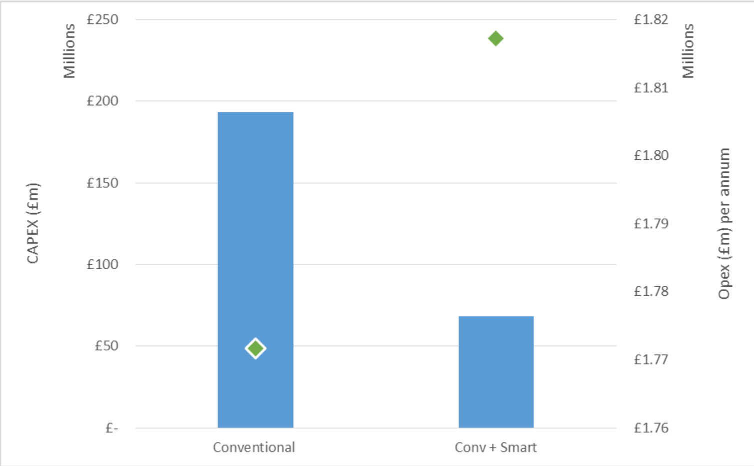

Figure 5: CAPEX (blue bars) and OPEX per annum (green diamonds) for conventional and real time control smart solutions – SPM license area.

- **The GB-wide costs to upgrade LV networks to cope with the EV charging demand increase is estimated at £3 billion over the next 30 years.** Based on the analysis of the selected network areas in SPM and SPD, an indicative projection of the cost reduction benefits for integrating EV charging in across the GB distribution networks shows a significant target for DNO investment and regulatory arrangements. This estimate is indicative of the scale of work that is required to upgrade the LV network but also the potential scale of benefits from EV smart charging.

Smart Charging Trial Scope and Locations

The LV and HV networks connection analysis of the selected areas in the SPM license area are a key input to the selection of network trial areas. The network analysis shows that additional network loading from EV growth and EV charger connection would ordinarily require network reinforcement and SPM stakeholders have informed SPEN of their intentions to install public charging infrastructure in these areas.

Based on the EV charge point connection studies, the network locations listed in Table 1 are recommended for potential trials – these are all in the Baltic Triangle area of Liverpool as it was in this area that combined LV and HV network capacity headroom issues along with expensive reinforcement solutions is most prominent in all of the studied SPM (and SPD) networks.

Table 1: Candidate EV Smart Charging Trial locations meeting LV and HV analysis selection criteria.

	HV/LV Substation Name	Charging Type
1	CHANDLERS WHARF BLOCK A	On-Street
2	105 DUKE STREET	On-Street
3	CORNHILL	On-Street
4	BLUNDELL STREET	On-Street
5	NORTH HILL STREET	Destination
6	GRENVILLE ST SOUTH COMMUNITY COLLEGE	On-Street
7	SUFFOLK STREET	Destination
8	CHANDLERS WHARF	On-Street
9	HENRY STREET NO 2	On-Street
10	LETITIA STREET	Destination
11	KENT ST BLOCK D	On-Street
12	THE CINNAMON BUILDING	Destination

In addition to the analysis work performed in Method 2, SPEN has engaged with key EV charge infrastructure customers and stakeholders in the SPM region to understand the needs, potential and appetite for participation in the Charge trials.

The studies have identified parts of the SPM, Liverpool Baltic Triangle network area as strong candidates for **Phase 2 EV smart charging trial locations**.

Ultimately the decision on trial locations will be dependent on stakeholders and their ability and desire to fund elements of smart solutions and trial them. If alternative locations are proposed by stakeholders the methodology developed in this initial phase of Method 2 will enable the suitability of those new sites for smart EV charging solutions to be assessed.

Potential Further EV Charging and Network Analysis

The analysis tools and methods will be utilised to support the final trial decisions and to provide a more detailed baseline of expected trial outcomes.

The platform of methods, tools, data, network models and configurations for analysis of EV charge point integration to distribution networks created for the Charge project present the opportunity for further detailed analysis of this important area.

The potential further analysis requirements within Charge and beyond the project have been identified and are summarise below:

- **Analysis of additional scenarios and EV charge point assumptions**: This analysis has created a very valuable foundation of understanding of the impacts of EV charge point on the SPEN distribution networks. In a fast moving area such as EV growth and smart charging solutions it is expected that analysis will be required for additional scenarios for EV growth, testing of the assumptions of how this translates into EV charge point requirements (e.g. locations, ratings, types), specific approaches to smart charging, what level of flexibility in EV charge point will arise from third party action (e.g. energy retail supplier incentives and tariffs, Charge Point Operator action) and other emerging questions. The EV charge point integration analysis tool chain created in Charge can be readily adapted to build on the assumptions made in each of these areas so far and test a wide spectrum of additional issues. Specifically, the outputs of the Method 1 EV charging scenarios will be integrated into further analysis to provide a more focused assessment of the impact of EV charging on the SPM network than the more general and even distribution of charge point penetration according to the high level parameters of the Future Energy Scenarios.

- **Network investment planning in ED1 and ED2**: Assessment and exploration of roles, preferences, volumes, costs and benefits of conventional and smart solutions for EV network integration will underpin network investment planning for EV integration. Analysis for investment planning should include the additional commercial implications of network capacity dependency on EV charge point flexibility connection methods and flexibility services. Several of the possible analysis enhancements noted above (e.g. additional scenarios, extending the coverage of the models to whole or more representative portions of the SPM, SPD and other DNO areas) along with building on the EV charge point integration CBA will be necessary to feed these Charge outcomes into network investment planning for the remainder of ED1 and in preparation for ED2. Study of the 'intra-decadal' (e.g. annual granularity) growth of EV charging and requirement for reinforcement and smart solutions would add additional detail and value to the investment planning analysis, especially in the 2020-2030 decade.

- **Detailed assessment of smart charging operations**: When the smart charging solutions are developed further from the existing concepts (e.g. once the design of the Charge trials begins) then analysis of their expected operation and performance can be undertaken in a more detailed manner using the same analytical tools and methods utilised in the analysis presented in this report. This analysis will provide useful information for comparison with the actual smart charging operation in trial as well as providing insight into the implications of smart charging for potential trial participants.

Next steps for Method 2 in the Charge Project

The outcomes of the analysis will support the decision on pilot and trial scope, locations and design.

- **Additional analysis** of network reinforcement and smart charging application to trial areas and wider SPM and SPD network areas to enhance the understanding of the applicability, benefits, costs and customer implications of the conventional and smart solutions. This will include analysis of the EV and charging scenarios produced in Method 1.

- The **scope of the trials** should be broad to maximise the learning captured on applicability and value to customers from the range of smart EV charging solutions. The trials will provide a much deeper understanding of the assumptions made in the network analysis and CBA as well as the technological, integration and customer impacts of the smart solutions.

- The **trial locations** identified in the analysis will now be considered by SPEN, the Charge partners and project stakeholders and decisions made to finalise the trial locations.

Charge

- The **trial design** will be informed by completed analysis and some new analysis to configure the smart solutions, including charge time window and staggering parameters, baseline of expected curtailment or shifting of charging under real time control.
- **Smart solution design** will follow a structured process of requirements, specification and design with focus on the most applicable and value adding smart charging solutions for the trial locations and participating customers.

Charge

5 INTRODUCTION

This section provides an overview of the Charge project and the 'Tactical Solutions to support EV connections' (Method 2) workstream with an overview of this report. This creates the context to understand fully the significance of the methods, results and outcomes presented in this report.

5.1 Charge Project Overview

The Charge project aims to accelerate the connection of and planning for public EV charge point infrastructure, at lowest possible cost to GB electricity customers. Charge aims to develop methods to maximise the use of existing distribution network assets, and develop and deploy innovative approaches to connecting and managing EV charge point infrastructure across a broad geographical area. It will combine learning from other EV charge point and integration projects with expertise from the world of transport planning. This learning will be coupled with a targeted selection of innovative EV charge point connection trials for a range of practical EV charge point requirements and network situations.

Charge merges the disciplines of transport planning and electricity network planning to create an overarching plan of where EV charge points will be required and how the network will be impacted by charge point connections. This will facilitate better planning of electricity networks and will provide vital information for all sectors involved in facilitating and supporting the transition to low carbon transport in the UK.

The project will use driver behaviour and journey statistics to create a view of the likely electrical demand from multiple charge point installations in various uses (e.g. car park, forecourt, destination), helping the DNO to assign more appropriate design assumptions during the connection process.

The main legacy of the project will be an online self-service tool 'ConnectMore' for EV connection customers, to allow them to understand whether their connection requirements can be met by the existing network and understanding potential EV charge point utilisation. The service will also alert customers to planned reinforcement work, or what network flexibility options could be adopted, which may be a factor in whether they proceed with their connection, when that happens and at which selected location.

Charge includes three methods:

- Method 1: Strategic transport and network planning led by PTV which will create a geographic plot of the likely location of charge points and typical EV usage in these locations;
- Method 2: Tactical solutions to support EV connections, led by Smarter Grid Solutions which will carry out targeted trials to determine the lowest lifecycle cost options for charging solutions for on-street, destination and en-route use cases. ;
- Method 3: The development of the 'ConnectMore' software tool led by EA Technology which will enable non engineering stakeholders to assess optimum locations for connection of EV charge points.

5.2 Charge Method 2 Overview

Smarter Grid Solutions (SGS) is responsible for delivering Method 2 which defines and trials smart EV charge point solutions that enhance the flexibility of EV charge point and support the improved hosting of charging infrastructure in distribution networks without expensive reinforcement and avoidable delays. Method 2 is summarised in Figure 6.

Charge

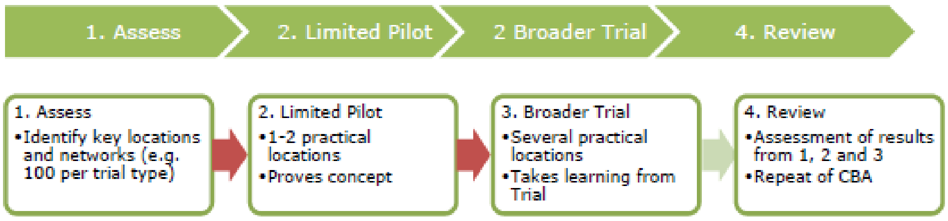

Figure 6: Overview of Method 2 Approach

During the first phase of Method 2, SGS was tasked with undertaking desktop screening and analysis of case study networks in both the SP MANWEB (SPM) network area and cases from other Distribution Network Operator (DNO) license areas (the SPEN SPD license areas was selected). The desktop analysis was to begin with a screening process to classify typical LV networks, against a set of characteristics relevant for the EV charge point types to be explored in the Charge trials (i.e. on-street charging, en-route charging, and destination charging). The screening was to feed into a baseline analysis, studying the impact of EV charger growth on the candidate networks and with the aim of identifying the conventional reinforcement required to accommodate the EV charger infrastructure.

A 'smart solutions toolbox' of flexible charging solutions was to be defined, with the intention of demonstrating the developed methods during a Limited Pilot and Broader Trial phase. Following on from the initial baseline studies, the smart solutions were to be modelled within analytical studies to explore the impact of smart EV charge point solutions as an alternative to reinforcement.

The outputs of the baseline and smart solution studies was planned to feed into a Cost Benefit Analysis (CBA) of conventional versus smart EV charge point solutions.

The smart solution toolbox definition, analytical study outputs and CBA were planned to feed into a Modelling Report with recommendations for trial locations in the Broader Trial phase. The approaches described for Method 2 have now been implemented and the reporting of outcomes is reported in this SDRC milestone report.

5.3 Document Objectives and Structure

This completed first phase of the Method 2 workstream was the Assessment Phase (Figure 6), the quantitative assessment of EV charge point demand growth on the LV and HV network in selected areas of the SPM and SPD networks. The assessment was aimed at identifying capacity

This document:

- Presents results from the completed assessments of selected networks in SPM and SPD which details the impact of EV growth on network capacity headroom, the applicable conventional reinforcement solutions and the potential for smart charging solutions.
- Provides a CBA comparison of conventional network reinforcements compared with smart EV charge point solution deployment.
- Presents options for potential pilot and trial locations in the next phase of the project (and Method 2).

headroom issues, the applicability of conventional and smart EV charge point solutions and the potential locations for a trial of smart solutions during future phases of the project.

The document achieves the above objectives through the following structure:

Section 6 presents the current EV smart charging landscape that the project sits within, describes relevant projects within SP Energy Networks and other projects supported by NIC and NIA funding in other DNO license areas and their relevance to this project.

Section 7 describes the solutions available to connect EV charge infrastructure to the distribution network, both conventional and ‘smart’. These solutions are then used in the connection studies to understand the impact they have on facilitating connections to the network.

Section 8 and Section 9 present the methodology and results of the baseline analysis and the smart solutions analysis respectively. The baseline analysis captures the level of reinforcement required on the LV and HV networks as a result of EV growth projections. These results are then used to assess if smart EV charge point solutions can reduce the need for conventional reinforcement on the network.

Section 10 provides a comparison of baseline and smart solutions through a CBA.

Section 11 brings all of the analysis together and highlights potential locations for the smart EV charge point trials.

The report concludes in Section 12 with a summary of the main conclusions from this phase and identifies the next steps for the Method 2 workstream.

6 EV SMART CHARGING LANDSCAPE

This section presents an overview of the EV smart charging landscape, highlighting the policy, market and DNO innovation context for this Charge project. This enables the appropriate links to be made between the Charge project, the analysis of EV smart charging connection to distribution networks and the wider EV and EV charge point market.

6.1 Government Consultations and Policy

In the last six months, a number of consultations have been published on the deployment of EV charge points, for public and commercial use.

The BEIS EV Smart Charging consultation[2], launched in July 2019, presents a proposed specification and approach to ensure that all 'at home' charge points have 'smart' functionality. The aim is that once the smart charge specification has been agreed and adopted, the market will develop to ensure all new charge points meet the specification, and that with the required smart functionality, they can be used to help ensure better electricity network planning and operation i.e. through the collection and analysis of charge point data. Implementing smart charging functionality is essential for both at home, and public charge points in order to ensure there is visibility and control of these assets. This is helpful for distribution network planning and operations as the smart charging specification enables relevant and valuable visibility and the potential for control of EV charge point. The smart charging trials in Charge Method 2 can usefully align with, utilise and create learnings from the proposed smart charging specification in public charging settings.

A second consultation published in July 2019[3] is proposing to alter building regulations for all new builds to include EV charge points (in residential buildings) and EV charge point infrastructure (in non-residential buildings), as well as introducing requirements for existing non-residential buildings to install charge points. Again, outputs from the Charge project can help to support this change in building regulations through the use of the ConnectMore tool under development in Method 3 of the project.

In addition to these open consultations, the UK Government announced in August 2019 that an extra £2.5 million funding[4] will be available for charge points on residential streets to allow those without off-street parking to have better access to EV charge point infrastructure near to home. This funding has the objective of helping the UK government achieve net zero emissions by 2050. It is hoped that the outcomes from the Charge project will provide local authorities, who will be using funding to install charge points, with the ability to understand the EV charger connection options available to them and to facilitate those connections at a reasonable cost and timescale.

6.2 Relevant activity in SP Energy Networks

SPEN has publicly committed to enabling the growth of EVs on their networks in order to allow the government and local authorities to meet carbon reduction targets and to facilitate the electrification of transport. SPEN expect EVs to have grown to 198,000 in the SPT license area

[2] https://www.gov.uk/government/consultations/electric-vehicle-smart-charging

[3] https://www.gov.uk/government/consultations/electric-vehicle-chargepoints-in-residential-and-non-residential-buildings

[4] https://www.gov.uk/government/news/government-doubles-funding-for-on-street-electric-car-charging

by the end of the RIIO-T2 price control period and have factored this and other significant demand changes into the draft T2 submission[5].

The Scottish Government announced in August 2019 a £7.5million strategic partnership project to deliver more EV charge point points across Scotland and ensure the infrastructure needed to support EV charge points is in place. This strategic partnership includes Transport Scotland, SPEN and Scottish and Southern Electricity Networks (SSEN). SPEN and SSEN will work with Transport Scotland to identify the best locations for charger deployments under a new joint approach in 2020 – 2021.

Currently in SPEN, there are three flagship projects which address some of the challenges the network will have as a result of the uptake of EV: Charge; LV Engine; and EV-UP.

LV Engine is a flagship £8.3m innovation project funded via Ofgem's Network Innovation Competition (NIC). The project will carry out a globally innovative network trial of Smart Transformers to facilitate the connection of Low Carbon Technologies (LCTs). The project will design and trial a number of Smart Transformers within the UK Electricity Grid. Its application will be within distribution substations, and provide the first functional specifications and control strategies for the smart functionalities of a Smart Transformer in different deployment situations and under different network conditions. In relation to EVs, the project will demonstrate a low voltage Direct Current (DC) connection for low carbon technologies including EVs.

EV UP[6] will contribute to the development of data sets to improve SPEN's understanding of customers' ability to transition to Electric Vehicles (EVs) based on off-street parking opportunity and customer demographics. This will enable improved understanding on the likely network areas which will see increased domestic demand and better inform future investment programmes. The dataset will complement existing work being carried out in other innovation projects such as Network Constraint Early Warning System (NCEWS) and Charge. The project is being delivered in partnership with Field Dynamics and is due for completion in Spring 2020.

6.3 Other Relevant NIC/NIA projects

6.3.1 My Electric Avenue

My Electric Avenue was awarded LCN funding in November 2012. EA Technology (EATL) were the lead project partner, with Scottish and Southern Electricity Networks (SSEN) and Northern Powergrid (NPg) participating as DNO partners. The project looked at both commercial and technical aspects of domestic EV charge point. Of relevance to Charge are the technical aims of learning customer driving and EV charge point habits, trial equipment to mitigate the impact of EV charge point and the network benefits of such technology.

The project recruited 'clusters' of EV owners i.e. residential streets across the UK which would participate in the managed charging trial and have their EV charge point behaviour monitored. An 'Esprit' device was used to monitor and control EV 'at home' charging to manage EV cluster network impacts. Esprit curtails charging on a rolling basis for 15 minute periods to avoid LV network overloading. Results from the trial showed that an additional 10% of customers on the feeder were able to connect where Esprit was deployed. While the project has focused on domestic off street EV charge point, this was one of the first projects to explore the potential for smart charging of EVs.

[5] https://www.spenergynetworks.co.uk/pages/riio_t2.aspx

[6] https://www.smarternetworks.org/project/nia_spen_0037

6.3.2 Electric Nation

The Electric Nation project launched in 2015 and was funded directly from Western Power Distribution's (WPD) Network Innovation Allowance (NIA). The recently completed project was led by WPD with support from EA Technology, DriveElectric, Lucy Electric Gridkey and Transport Research Laboratory.

The objectives of the project were to increase the understanding of the impact on distribution networks of 'at home' charging based on diverse vehicles, battery sizes and charger ratings. The project also addressed the impacts of differentiated customer interaction and issues such as acceptability of charge restrictions, preferences, information, incentives, fairness and charging control.

Smart charging services were provided by CrowdCharge[7] and GreenFlux through web interface or smart app:

- **GreenFlux** allows users to select to override the default 'demand management allowed' for any charge session using an app, so enabling opt-out on a session by session basis.
- **CrowdCharge** bases charging (and any curtailment) on a web interface pre-submitted journey plan by customers.

Results from the trial have shown that there is flexibility in charging of EVs, but without an incentive, the demand in the evening peak will require management. Trial participants found management of EV charge point acceptable, and the use of a Time of Use tariff showed to be highly effective at moving demand away from the evening peak particularly when supported by a smart charging app to make it easier for the user. Data collected as part of the trial can provide a key reference source for all future EV charge point developments.

Charge will build upon the learnings from the trial in this project, and the learning from My Electric Avenue to provide new examples of different smart charging approaches and data collection, across new use cases – on-street, destination and en-route.

6.3.3 Optimise Prime

Optimise Prime is an industry-led electric vehicle innovation and demonstration project that brings together partners from leading technology, energy, transport and financing organisations, including Hitachi Vantara, UK Power Networks, Centrica, Royal Mail, Uber, Scottish & Southern Electricity Networks, Hitachi Europe and Hitachi Capital.

The project will gather data from up to 3,000 electric vehicles driven for commercial purposes within London and the South East of England. Optimise Prime will also implement a range of technical and commercial solutions with the aim of accelerating the transition to electric for commercial fleet operators while helping the UK's DNO's to plan and prepare for the mass adoption of electric vehicles. Through cross-industry collaboration and co-creation, the project aims to ensure security of energy supply while saving money for electricity customers and helping the UK meet its clean air and climate change objectives.

The project will conduct three trials, of which the Depot trial is of greatest relevance to Charge Method 2 as it will also explore the use of 'smart charging' to manage the EV charge infrastructure connection to the network. The Charge and Optimise Prime projects will work together to ensure the learning from both projects is maximised, and there is no unnecessary duplication.

[7] https://crowd-charge.com/

7 CONVENTIONAL & SMART EV INTEGRATON SOLUTIONS TOOLBOX

This section sets out the solutions that are available to SPEN as part of the Charge project. This includes both conventional/traditional network reinforcement options, and the smart EV charge solutions proposed for demonstration in the trial phases of the project (Phase 2 and Phase 3).

This section provides a summary of the solutions that can be applied to the networks to relieve issues caused by increased EV charge point demand and the important factors for their analysis in the connection studies programme.

7.1 Conventional network reinforcement solutions

When network capacity limits are reached in planning timeframes with appropriate look ahead, the conventional approach is to upgrade the capacity or number of distribution network assets. This typically involves the replacement of existing cables, overhead lines (OHL), or transformers on the network. By upgrading network assets the thermal and voltage capacity of that part of the network is increased and it can therefore accommodate greater levels of demand growth.

This solution can be costly and can cause lengthy periods of development, design, permitting, construction and outage on the network, which in some cases can temporarily decrease the capacity available to network users. Where works are required in dense urban areas (e.g. Liverpool city centre) then there is a large cost and inconvenience associated with the disturbances cause by the network upgrade works.

The advantages of installing new network assets are that they can significantly increase the capacity of the network in a single installation providing sufficient headroom for future demand or generation connections.

Specific reinforcement options are summarised in Table 2. These reinforcement options match the reinforcement screens applied to the connection analysis (discussed in more detail in Section 8).

Table 2: Summary of conventional upgrade solutions.

LV Upgrade	**Connect to existing feeder to nearest Tx**	Construction of new network circuits or upgrading existing cables to enable connection to the nearest Tx
	Connect to proximity Tx	If the nearest Tx is at capacity, connect in to next closest Tx
	Interconnection between closest Tx and Proximity Tx	Provide interconnection between nearest Tx and Proximity Tx to enable load sharing
	New 500kVA substation	Construction of new 500kVA substation
HV Upgrades	**New Circuits or upgrade existing circuit**	Adding new feeder to existing substation
	New Substation	Construction of new HV Primary substation

7.2 Smart Charging Solutions

There are several different approaches that could be used to defer or avoid network reinforcement, and these range in terms of complexity and cost to the developer or user (and DNO). Following an initial market and literature review of technologies, solutions, business models, stakeholders and user perspectives from relevant, UK-focused, EV smart charging projects, a number of 'smart' solutions have been proposed for assessment in the Charge project. Desktop analysis (reported in this report) and demonstration through the trial phase of the project will provide valuable knowledge to the wider industry, and build on previous EV projects noted in Section 6.

The seven proposed smart solutions are shown in Figure 7. The solutions can be divided into three categories of solutions and these categories are described in the subsections below.

The purpose of setting out the smart charging solutions in this way, is to demonstrate an increase in complexity and allow progression towards a full market approach, integrated with future Distribution System Operator (DSO) capabilities and business models.

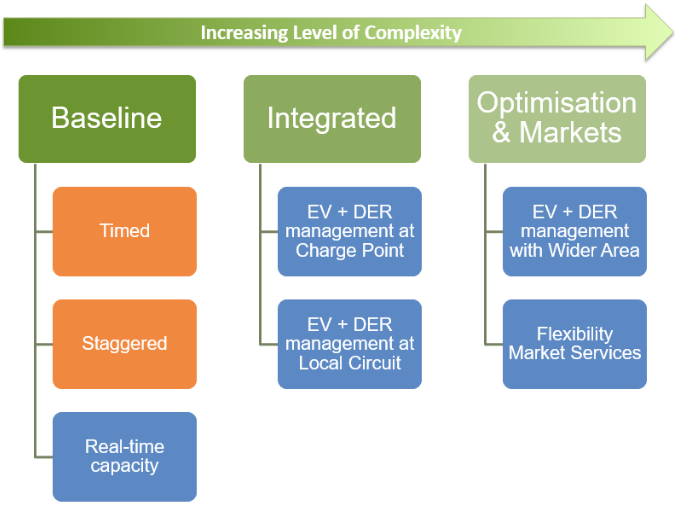

Figure 7: Smart Solutions increasing in level of complexity – with those in orange being passive, and those in blue being active.

7.2.1 Baseline Smart Charging Solutions

Baseline charging solutions are the more straightforward solutions to deploy for smart EV charge point. In these approaches, the management strategies are similar to those used for DER under Active Network Management (ANM) control in schemes across the UK with timed, staggered and real-time network limits based controls.

Timed and staggered solutions can be considered to have a passive operational mode, with the DNO able to fix schedules ahead of time and pass this information on to chargepoint operators. The real-time solution is a more active operational mode, with regular polling of measurement point data informing the available capacity at constrained parts of the network.

Advantages of this group of solutions are that they are technically the least complex, with a good understanding of how these approaches have been applied to other controllable assets (wind power, solar power, and energy storage) in other ANM schemes in SPEN license areas.

Disadvantages are that the solutions do not take advantage of integration of other DER such as storage to maximise the capacity available, and some lack the flexibility to provide availability for EV charge point to users on demand.

7.2.2 Integration of DER and EV Groups

By aggregating EV charge points, and integrating them with other available DER assets (including energy storage systems), there is the potential to increase the capacity available to charge points on the network at times of constraint, and to be used to facilitate balancing within local areas of the network.

The two solutions proposed within this category integrate EV and DER at the point of connection (e.g. behind the meter storage and EV chargers) and integrate within a local circuit area (e.g. at the head of a feeder). Adhering to network limits is achieved by aggregated control of the smart EV chargers and available DER units at the charger site or within the feeder.

The main advantage of this group of solutions is that by integrating with other types of DER asset, there is the ability to add diversity to charging profiles and shape demand profiles locally through effective management. This also provides an opportunity for certain customer types who have an interest in operating the other DER along with EV chargers as part of their operating model (e.g. community or local authority owned solar PV and charging hubs).

Disadvantages of these solutions are that they are relatively focused at the point of connection, and do not make the best use of larger aggregations of DER and flexible load on the network to make full use of network flexibility.

7.2.3 Optimisation and Markets

Building on the integrated solutions, this category increases the sophistication and complexity of the smart EV charge point solution by applying optimisation and market participation to EV smart charging. The integration of solutions happens over a wider network area e.g. several substations or a whole Bulk Supply Point area.

By increasing the level of optimisation and aggregation, there is a greater level of flexibility within the group of smart EV chargers and DER assets to be able to accommodate charging requests from users, and offer a valuable flexibility service to or respond to instructions from the DSO, maintaining the network within its limits.

These are more complex solutions, and therefore require more sophisticated commercial arrangements to be in place. The commercial arrangements depend on other external factors such as development of DSO services, and the use of forecasting and optimisation software in addition to real-time constraint management approaches and the direction of network tariffs and markets. There is an added complexity of future local management signals interacting with flexibility market signals – and issue currently being discussed as part of future DSO market models.

Charge

8 BASELINE EV CHARGER INTEGRATION ANALYSIS

This section presents baseline network analysis to assess the impacts of EV charge point connections on existing network infrastructure and where networks constraint issues are created. The assumptions and predictions made in this report are for the purpose of determining a comparison of smart and conventional network reinforcements on the network. More detailed scenarios of EV uptake will be produced by the Method 1 workstream, led by PTV.

The aims of this section are to:

- Define possible EV charge point connection types and the criteria used to select areas to apply different connection types.
- Address the issues that scale of charging infrastructure and connection application characteristics have on the network for analysis.
- Define initial network area selection criteria and search methodology.
- Describe analysis methodology when applied to LV network areas.
- Describe analysis methodology when applied to HV network areas.
- Present the method for identifying constraints associated with EV charge point connection applications per EV charge type, and the escalating network interventions to facilitate the connections.
- Present the outcomes of the analysis when applied to the selected SPEN LV and HV network areas.
- Identify the SPEN network areas more likely to see immediate impacts of EV infrastructure growth.
- Set out the criteria for and search the analysis results for candidate trial locations.

The LV and HV study results presented in this report will be used to determine factors such as potential future network reinforcement costs, network impacts for different predicted future EV growth scenarios, and provide a baseline to explore how smart solutions may defer network impacts and costs caused by EV charge point connections.

8.1 Characteristics of EV charge point types

This following table provides a short description of the EV charge point types allocated to each use case and the anticipated capacity associated with each type[8]. This is used to identify which transformers would host each type of EV charge point, and is a key factor in creating study cases and scenarios for analysis.

It is possible that distribution transformers will consist of more than one EV charge point type, however, the dominating type associated with the transformer will determine the designation as

[8] 50kW rapid chargers have not been considered in this analysis to date, but based on stakeholder engagement as part of this process, updates will be made to destination and en-route modelling in future iterations of the modelling work.

an on-street, destination, or en-route transformer. This principle will be defined in greater depth when selecting study areas, and full details of the area search is provided in the Appendix.

Table 3: EV charge point types.

Use Case	Description	Charging Infrastructure
On-Street Charging	On-street charging will be public (shared) charger infrastructure, located in areas with high-density domestic housing such as tenement flats or terraced housing where vehicle owners may not have a dedicated space to charge their vehicle. The density of chargers will be limited by the physical space and installation designs. It is assumed that a charge point can supply a single car space. Power ratings, sharing factors and driver parking/charging behaviours are expected to emerge and change with EV growth. The assumptions made in this analysis are reasonable at the time but subject to change with time.	On-street charging will likely be single-phase chargers rated at 7 kVA (single phase fast chargers).
Destination Charging	Destination charging consists of public chargers installed in locations such as cinemas, shopping centres or supermarkets, allowing customers to charge EVs while they are at the location.	Destination charging will likely consist of a combination of 7 kVA and 22 kVA (three phase fast) chargers.
En-Route Charging	En-route charging infrastructure is expected to be found in locations on the route of major trunk roads, including motorways. This infrastructure provides fast-charging for EVs when en-route from their home or starting location to a destination. Customer behaviour for this usage is similar to motorway services locations and petrol stations. In the first instance, this form of charging is expected to be located at the site of existing motorway and trunk road services and petrol stations.	Similarly to destination charging, en-route charging will comprise a combination of 7 kVA and 22 kVA charging, the relative proportions of which can be tailored in the analysis.

8.2 Summary of EV Connection Application methods

It is anticipated that Independent Connection Providers (ICPs) would approach SPEN with a bulk/batch connection application for multiple charge points, possibly covering each of the above types. For the purpose of this analysis, this approach is defined as a connection application.

A batch connection application method is required to vary study parameters for individual EV charger connections to SPEN network models for this analysis, and test the outcomes for different scenarios.

For all EV charge point types (i.e. on-street, destination, and en-route), the maximum number of car parking spaces associated with the customers present on a feeder in the case of on-street charging or the capacity of a car park for destination and en-route charging determines the maximum number of EV charger connection applications for a feeder. Further details of this analysis can be found in Appendix B.

8.3 EV Charger Growth Scenarios

A projection of total residential demand growth percentage was taken from National Grids 2019 future energy scenarios: namely: community renewables, given a growth of 36% over the network 50 years[9]. A worked example of EV growth projections is provided in Appendix D.

Using this a sensible projection for medium growth each network case, three different magnitudes of EV connection application are considered:

- Low – a case where a percentage of possible car parking spaces that results in a relative low demand growth, in the area under analysis, are fitted with EV charge point infrastructure.
- Medium – a case where a percentage of possible car parking spaces that results in a relative medium demand growth, in the area under analysis, are fitted with EV charge point infrastructure.
- High – a case where a percentage of possible car parking spaces that results in a relative high demand growth, in the area under analysis, are fitted with EV charge point infrastructure.

The magnitudes, once determined, are applied to give the total growth of EV demand over the full period 2020-2050. To sensibly stagger this growth over a 30 year period, the total growth is then split into three bulk connection applications.

The analysis for each area takes place across three time periods (2020-2030, 2030-2040 and 2040-2050). The EV growth in each time period is set as a percentage of the original loading (not the cumulative loading) and is therefore assumed to be linear across the time periods (i.e. the total connection application will be the same for each decade–long period 2020-2030, 2030-2040 and 2040-2050).

Any reinforcements or upgrades which are performed in a given time period (e.g. 2020-2030) are captured and implemented as input data to the next time period (2030-2040), in order that the same piece of work is not duplicated.

For the Liverpool On-Street study, these assumptions result in total demand growth, of the distribution substation assessed by 38%, 45% and 54% respectively between 2020 and 2050. The EV% was held across all areas for consistency.

8.4 EV charge point Connection Application Impacts

When connection applications appear for each of the EV charger types there will be an acceptable degree of network enabling works required to facilitate the new connection. However, when

[9]http://fes.nationalgrid.com/media/1432/fes-data-workbook-v30.xlsx Tab: ED1, Data Item: Total Residential Demand, Community Renewables.

connection applications are sufficient to require network reinforcement, understanding lowest cost options creates customer value.

Where connection applications exceed existing network capacity, a series of LV design solutions are assessed for the lowest cost solution, where a connection progresses through each stage as it fails to satisfy the network requirements surrounding the stage. These are presented in Figure 8 encapsulate a generalised approach to upgrades and typically represent an approximation of escalating level of expense, where stage 1 in a baseline superficial "no work solution", representing the no or limited cost. After the discrete LV impacts are considered, the aggregate HV impacts of the wider areas connections would also be covered. A typical connection application would escalate through these design options based on increasing connection capacity as each lower-cost design option was ruled out. Full details of planning principles are provided in Appendix E.

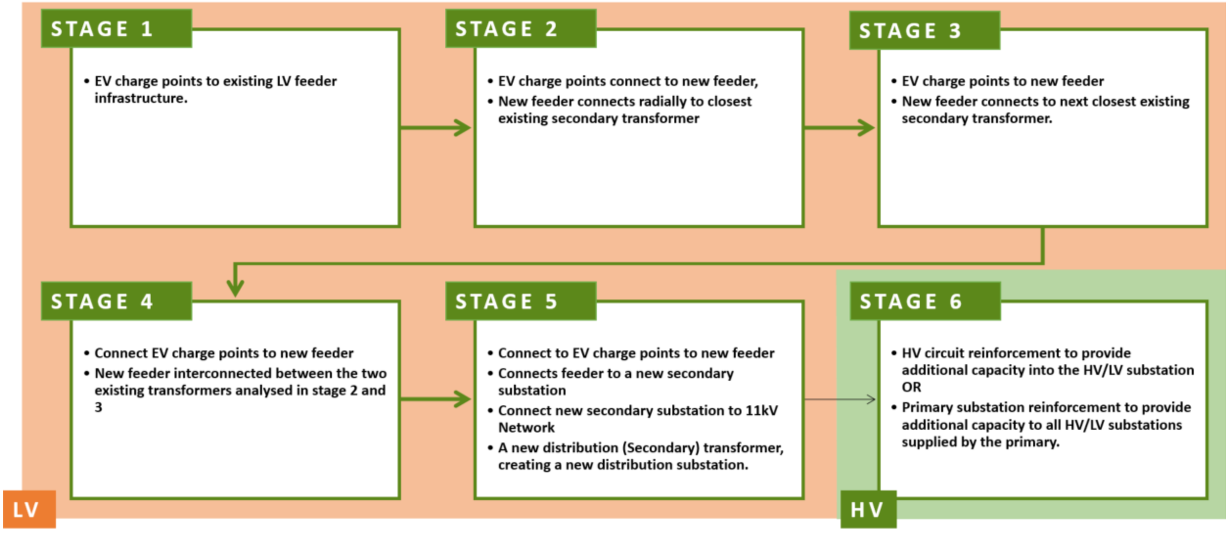

Figure 8: Escalating actions for EV charger connection reinforcements.

8.5 Network Area Selection Criteria

The Charge project explores the impact of EV charger growth for use cases presented in Section 8.3 to accurately understand these impacts, there is a requirement to create a reference network case representative of the areas where each EV charge point type is most likely to emerge. A method of case study identification and screening is proposed to identify areas of greatest likelihood of emergence of the EV charge point types in focus. Both of SPENs licence areas, SPM and SPD, have been considered as part of this analysis. Full details of the substation search are provided in Appendix C.

8.5.1 Charger Type, Customer Type and Uptake/Usage Filtering

Internal Combustion Engine (ICE) application of the Customer Type and EV uptake/usage activity can be used to filter for the identification and prioritisation of areas, and substations, to perform EV charger growth impact analysis.

This methodology was used as a first pass to identify areas of expected high EV growth in the cities of Liverpool and Glasgow.

Charge

The filtering criteria in Table 4 is used to inform the first pass area identification:

Table 4: Network Selection Criteria.

Charging Type	Customer Type	Uptake/Usage Filters
On-street	Identifying the areas where on-street charging types will emerge is achieved by reviewing the substations found in the previous section by eyeball and google maps review, determining "flat" and "terraced" housing types.	Where a high turnover of car registrations is present in the U.K. it can be assumed these areas will replace their combustion engine cars with EVs sooner, resulting in a faster requirement for EV charge point infrastructure. This can be used as an early indicator of candidate areas in which to focus attention. For the Merseyside area (SPM), this data is provided by UK Government Statistics[10] and highlighted in Figure 9, and for the Glasgow area (SPD) in Figure 10.
Destination Charging	Identifying destination charging types can be achieved by defining the customer types, for example: • Supermarket; • Shopping Centre/Retail Park; and • Cinema. Although it may be possible to search for customer types as part of the GIS database, using an internet search to find the relevant destination associated with the area under analysis was used for initial identification of prospective sites.	Destination charging can be filtered in order of popularity in the region, where popularity is indicated by the number of car visits over a period of time. Many data sources such as council data can be used to supply statistics for these criteria[11]. This might only be required if the previous criterion produce too large a candidate pool. Due to the reduced set of destinations by type, this criterion may be enough on its own without the first criterion of customer type.
En-Route	En-Route charging can be filtered by customer type "petrol station/service station" from the GIS database or the transformer substation database.	En-Route charging can be filtered in order of convenience on the busiest routes in the region, the more used a route is the more the amenities along that route will be utilised. This is determined by government traffic data.[12] Finally, in all cases, where stakeholders have identified specific locations of interest, these have also been considered.

[10] https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01

[11] https://www.liverpoolvision.co.uk/wp-content/uploads/2014/07/Liverpool-City-Centre-Main-Retail-Area-Review-June-2014.pdf

[12] https://www.dft.gov.uk/traffic-counts/area/regions/North+West

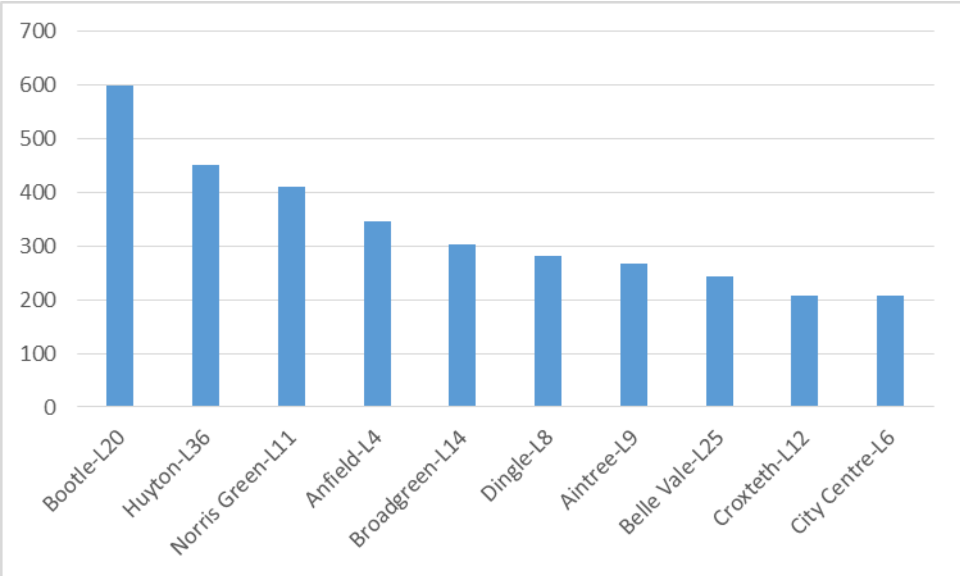

Figure 9: Annual New Car Registrations per Area (Merseyside).

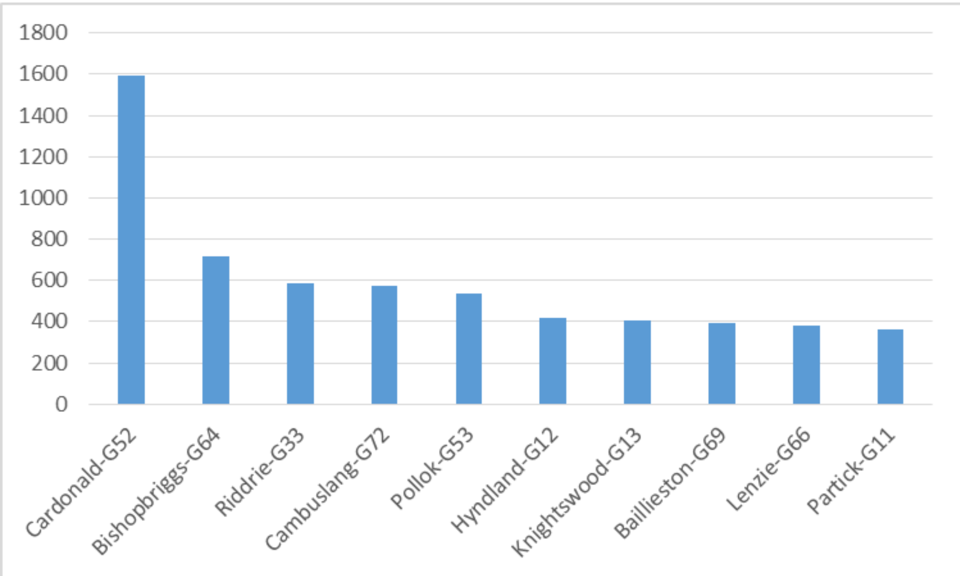

Figure 10: Annual New Car Registrations per Area (Glasgow).

8.5.2 LV Analysis Selection

The filter criteria in Table 4 are used to extract details of the relevant distributions transformers to be selected for baseline EV charger connection analysis. This process identifies the distribution transformers in the areas most likely to see the growth of the desired EV charge point infrastructure types. In future this method could be updated to encapsulate the latest EV uptake figures, as developed by our project partners PTV in Method 1.

Based upon the present access to data, this has been a manual process, SPD destination was not considered in this analysis due to time constraints associated with the data extraction process.

In the following project steps, the further development of these methods will incorporate the automation of the process of substation identification and data collation, with interfaces to either the SPEN GIS, SPEN distribution substation databases or the SPEN NCEWS[13] tool.

At this stage in the project and with the tools and methods available, the analysis has identified the areas listed in Table 5 for consideration. SPD destination was not considered in this analysis due to time constraints associated with the extraction process. In future analysis, the number of sites and the areas covered can be expanded across the full SPM and SPD areas by applying the same search criteria.

Table 5: LV areas selected for analysis.

	Region	Area	# LV Transformers	
			Per Area	Total
On-Street	SPM	Baltic Triangle	28	96
		Bootle	28	
		City Centre	40	
	SPD	Total (various areas)	53	53
Destinations	SPM	City Centre	62	74
		Baltic Triangle	12	
	SPD	-	-	-
En-route	SPM	Burtonwood Service Area	1	4
		Hapsford Services	1	
		Lymm M6 Interchange	1	
		Knutsford Motorway Services	1	
	SPD	Abington Services	1	5
		Clydepark North	1	
		Granda Services	1	
		Harthill Services	1	
		Welcome Break M74	1	

[13] https://www.smarternetworks.org/project/nia_spen0016

8.5.3 HV Area Selection

Due to the number of LV areas selected for study, to create an HV model for all areas would be impractical at this stage of the project. Therefore, a focussed study on the specific area that encapsulates the characteristics of the area that meets the project objectives is undertaken. From the HV area criteria analysis, the areas to investigate are the Bootle and Baltic-Triangle areas in the Liverpool area.

8.6 Baseline Analysis Methodology

The objective of the baseline analysis is to identify the connection works required to host EV charge points on distribution networks based on the input data as defined in Section 8.1 to 8.5. The analysis investigates a number of different EV growth scenarios, studying different forms and scales of EV charge point across the selected representative networks. The analytical methodology to be applied consists of the following steps (see Figure 11) for each scenario of EV charge point growth.

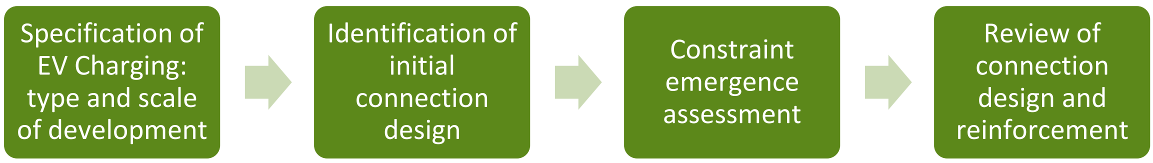

Figure 11: Outline of Analysis Methodology.

The Identification of initial connection design is based upon the design principles described in the following sections. This assigns an initial connection design based upon the rated capacity of EV charge point development sought.

8.6.1 Study Types

The baseline analysis consists of two types of network analysis study:

- **Discrete Connection Analysis**: The impact study of individual EV charge point developments, for example, a single application for connection of on-street, destination or en-route charging infrastructure. This analysis delivers an indication of the reinforcement works required to connect a specific EV charge point development.
- **Aggregated Connection Analysis**: The impact study of a combined series of EV charge point developments across an entire network area. This analysis delivers an indication of the wider HV works that may be triggered as a number of significant EV charge point developments appear on networks in the future.

The assessment of discrete connection analysis follows the process defined in the next section.

8.6.2 Analytical Steps: LV Discrete Connection Analysis

The LV analysis consists of applying the bulk connection application to the network and testing for specific constraints that would escalate the reinforcement to the next design stage:

1. Stage 1: EV charge points to existing LV feeder infrastructure.
    - Assess the feeder voltage drop (in line with limits);

   - Assess overall feeder capacity (in line with equipment rating);
   - Assess Transformer Separation (in-line with SPEN guidance);
2. Stage 2: EV charge points connect to new feeder, new feeder connects radially to closest existing secondary transformer.
   - Assess distribution transformer capacity (in-line with equipment rating);
   - Assess Transformer Separation (in-line with SPEN guidance);
3. Stage 3: EV charge points to new feeder, new feeder connects to next closest existing secondary transformer.
   - Assess proximity distribution transformer capacity;
   - Assess Transformer Separation (in-line with SPEN guidance);
4. Stage 4: Connect EV charge points to new feeder, new feeder interconnected between the two existing transformers.
   - Assess proximity distribution transformer capacity;
   - Assess distribution transformer capacity (in-line with equipment rating);
   - Assess Transformer Separation (in-line with SPEN guidance);
5. Stage 5: Connect to EV charge points to new feeder, connects feeder to a new secondary substation, connect new secondary substation to 11kV Network.
   - At this stage, all applications integrated into the LV network and ready for aggregated HV analysis

The activity load flow of this process is present in Figure 12. For each of the stages in the analysis process there are a number of constrain criteria – further details of their definition and the assessment process are defined in Appendix E.

Charge

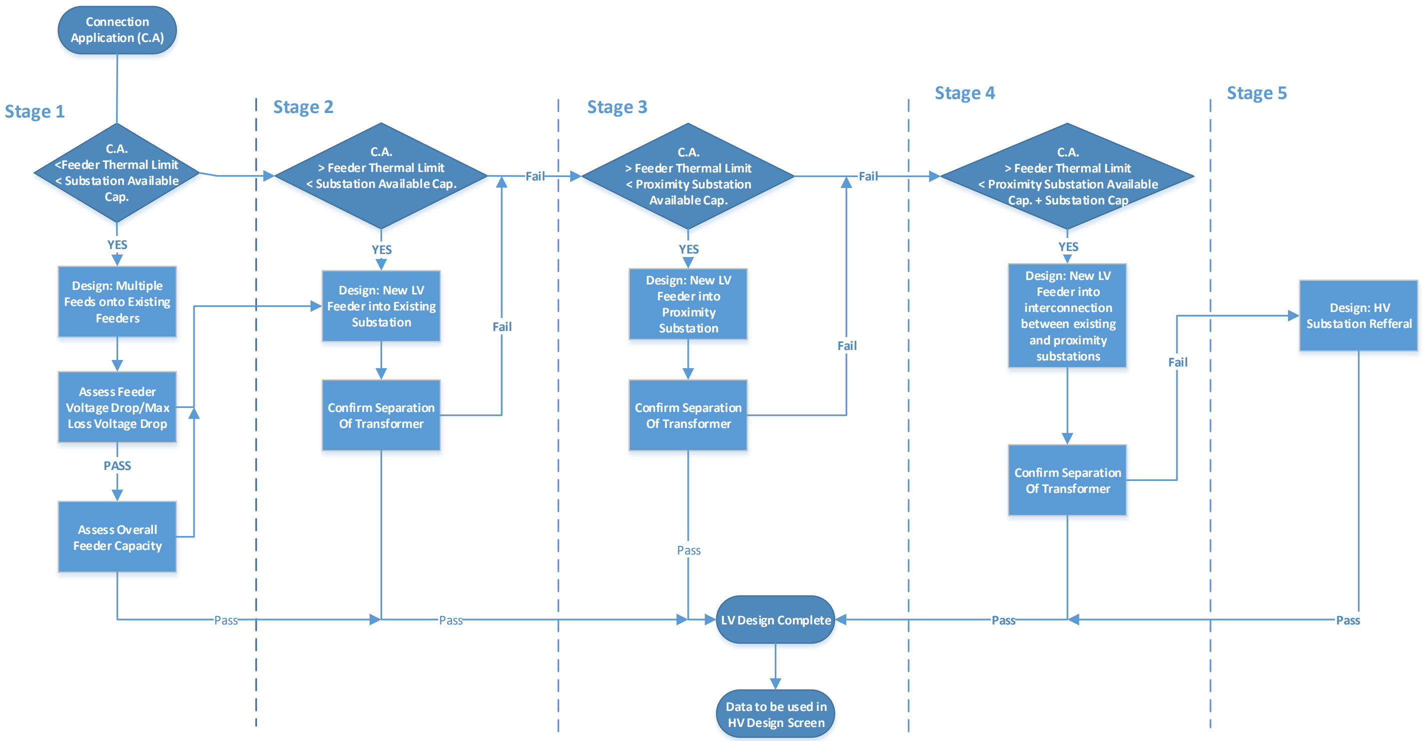

Figure 12: High-Level Design Assessment Process.

8.6.3 Analytical Steps: HV Aggregated Connection Analysis

For each HV network being studied, the area was mathematically modelled to provide an acceptable approximation of power flows on the HV network. This has been achieved by:

- mathematically representing the network in the form of the power balance equations;
- Inserting secondary substation loads, including the EV charge point load, from the LV baseline analysis
- approximating the electrical properties, such as r/x values, of the model from GIS database resources, and
- Solving the load flow via a full non-linear Newton Raphson method.

With the network model approximated, the HV methodology can be applied. The HV methodology presents a static envelope of tests to determine where thermal and voltage exceedances occur on the network.

The final full HV Analysis approach is presented as a flow chart in Figure 13.

The inner-loop of the analysis can provide a snap shot of each branch loading and voltage, this can be sorted to show which assets are overloaded or the relative level of loading compared to their rating or limit. The outer-loop provides the same snap shot but for all contingencies.

Overall the analysis highlights the worst case loading and potential conditions for each asset on the network and for each contingency. This can determine where reinforcement is required due to potential overload, or areas of weakness due to relatively high loading.

Charge

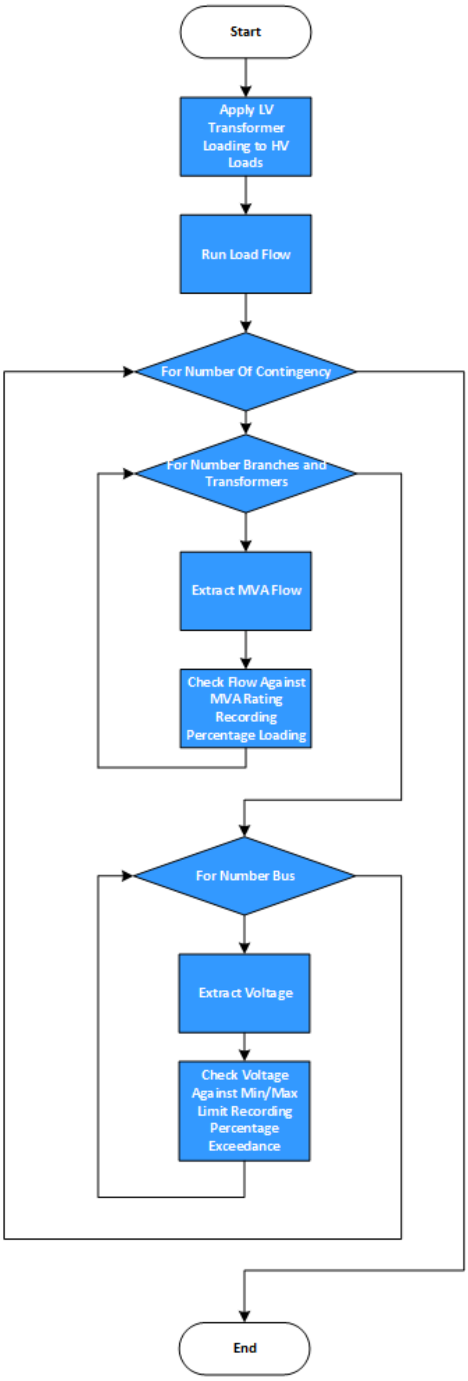

Figure 13: HV Analysis Flow Chart.

8.7 Baseline Analysis Results and Conclusions

This report has investigated the projected growth of EV charger penetration on selected network areas and use cases, and the network reinforcements that would be applied in order to alleviate constraints according to standard network design assumptions.

A pragmatic estimate of the expected connection applications, on a per-feeder and per-transformer basis, was developed in accordance with the National Grid Future Energy Scenarios projections for EV uptake, and making necessary assumptions concerning the EV growth and charge points in both urban and rural areas.

The analysis was developed to include real network data extracted from SPEN databases, including historical transformer loadings and feeder cable data taken from the GIS database. Realistic modelling of each distribution transformer under study was therefore achieved, ensuring a high degree of confidence in the impact assessment results.

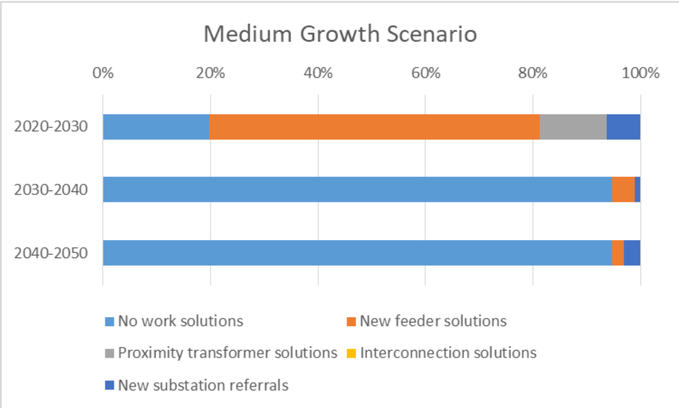

Figure 14: SPM On-Street Medium Growth Scenario Results.

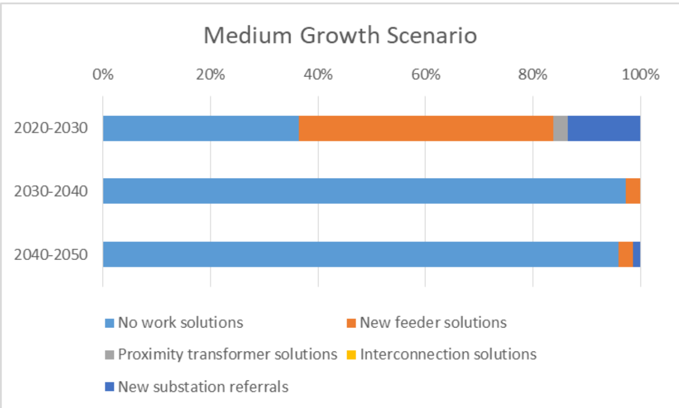

Figure 15: SPM Destination Medium Growth Scenario Results.

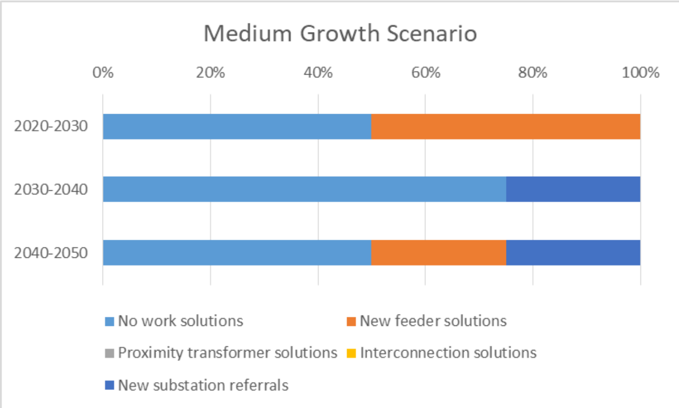

Figure 16: SPM En-Route Medium Growth Scenario Results.

Highlights from the LV baseline analysis include:

- The uptake levels of EV charge points in urban areas (up to 1.5% of potential customers with unrestricted access to a charge point) results in an overall electrical demand growth of more than 50% compared with 2018 baseline levels. This shows that a relatively small uptake in EVs will have a significant impact on the electrical capacity required of LV distribution systems in the coming years.
- The analysis explicitly studies the load growth from increasing EV charge point penetration, and does not include other forms of electrical demand growth (e.g. heat pumps, rail electrification, etc.). Therefore reinforcements/upgrades outlined in this analysis are likely to be required sooner than indicated here due to separate growth in the baseline demand profile of the network through the decades.
- A high proportion of the reinforcement comes in the form of new feeder solutions performed in 2020-2030 (See Figure 14**,** many of which provide ample capacity for subsequent EV growth in the following decades. This is likely to be the main solution employed in densely populated areas such as cities.
- A high degree of correlation between SPM and SPD On-Street and SPM Destination use cases, in terms of the expected types and proportions of reinforcement solutions.
    - Similar patterns of reinforcement requirements in reaction to projected EV growth are expected in other built-up areas throughout GB
    - En-route use cases, which tend to be in rural areas, differ dramatically from the urban scenarios due to a lack of neighbouring local capacity and therefore there are fewer opportunities for transfer and interconnection solutions.
    - Examples of destination use cases where the destinations are located in rural areas are expected to exhibit similar reinforcement behaviour to the en-route, rather than to destinations located in built-up, urban areas.
- As the magnitude of the EV charge point connection applications increases, the severity of reinforcement requirements increase. Escalating through the low, medium and high penetration scenarios clearly shows that reinforcement solutions are needed in a faster timeframe as penetration increases.

- The need for new substation solutions is proportionally smaller in built-up areas (cities and destination) when compared with rural (en-route) due to increased availability of neighbouring assets such as the ability to transfer feeders to proximity transformers. In contrast, en-route scenarios must escalate to new substations even in low EV growth scenarios.
- Due to the small number of substations studied (as a proportion of GB), and the modelling limitation of proximity transformer selection, there were no instances in the analysis of an interconnection solution. A more detailed interconnection analysis would likely highlight opportunities for such solutions in the On-Street and Destination test areas.
- Due to the nature of the proportional allocation of EV chargers to car parking spaces, and the relatively low baseline demand, the en-route scenarios experience demand growth as high as 119% over the current baseline by 2050, however there generally exists enough capacity on the distribution transformers to accommodate the growth, or a new substation solution can be applied. It should be noted that 22kW AC chargers have been assumed for en-route charging and that higher capacity chargers are envisaged.
- The scenarios provide a sliding scale of severity, which, if linked with the future energy scenarios, could provide the DNO with an indication of the timeframes in which reinforcements will need to move at to ensure steady state compliance is met for possible future EV growth.

The results produced in the baseline analysis will inform the development of “smart solutions” that are expected to offset the need for network reinforcement in reaction to expected EV growth. The results of both the baseline and smart solution analysis will allow a cost-benefit analysis to be undertaken in order to capture the financial benefits of applying smart solutions to offset the network reinforcement project in the baseline analysis. The methodology, assumptions and LV impact study outcomes presented in this report also scope the next stage of the analysis that explores the impacts on the HV network.

8.7.1 HV Results Conclusions

The HV analysis has shown a consistent growth across scenarios results in impact to existing network capacity margins.

- For the most part the existing margin can handle the approximated growth and modelling in these studies. As shown in Figure 18 and Figure 20 there is sufficient headroom in the modelled transformers to withstand forecasted growth.
- Reducing the requirement of reinforcement to 90% to accommodate this approximation show that some of the network will need to be reinforced consistently over the scenario and time periods within.
- When comparing Bootle and Baltic, Bootle has far more interconnections at 6.6kV than Baltic triangle, resulting in less stress across the existing capacity in comparison (See Figure 17 and Figure 19). Where a relatively smaller asset area such as Baltic triangle has a similar amount of kVA demand growth, its existing margin is reduced considerably.
- If approximation on growth are therefore found to be 10% higher than what ultimately appears, then primary transformer assets could be at risk.

Full results are provided in Appendix E, but key figures are shown below relating to the HV analysis conclusions.

Charge

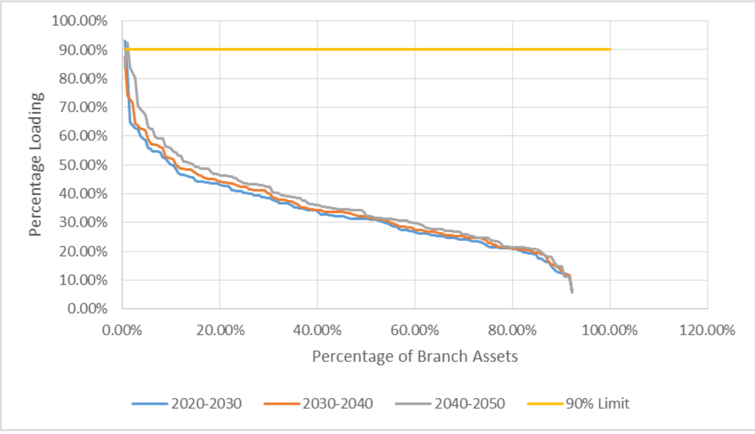

Figure 17: Medium Growth Scenario Worst Case Contingency Loading of Branch Assets (Bootle).

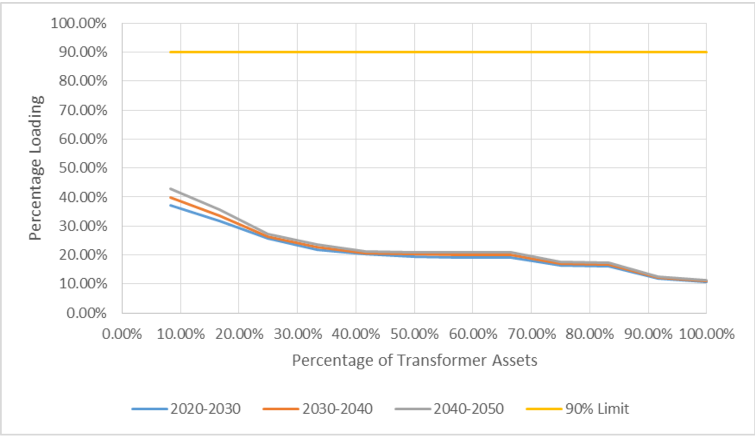

Figure 18: Medium Growth Scenario Worst Case Contingency Loading of Transformer Assets (Bootle).

Charge

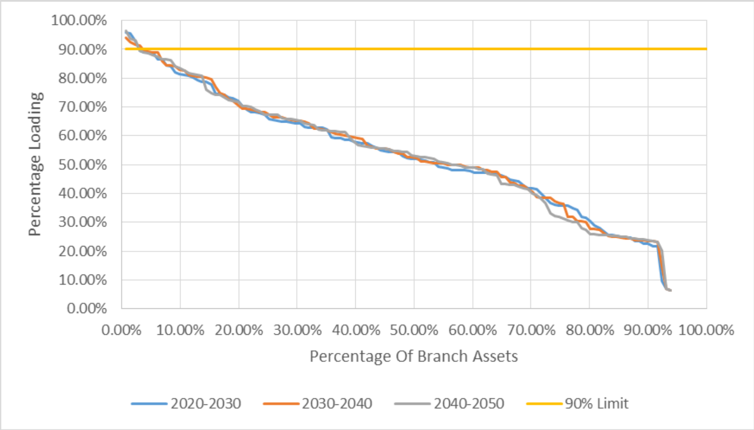

Figure 19: Medium Growth Scenario Worst Case Contingency Loading of Branch Assets (Baltic Triangle).

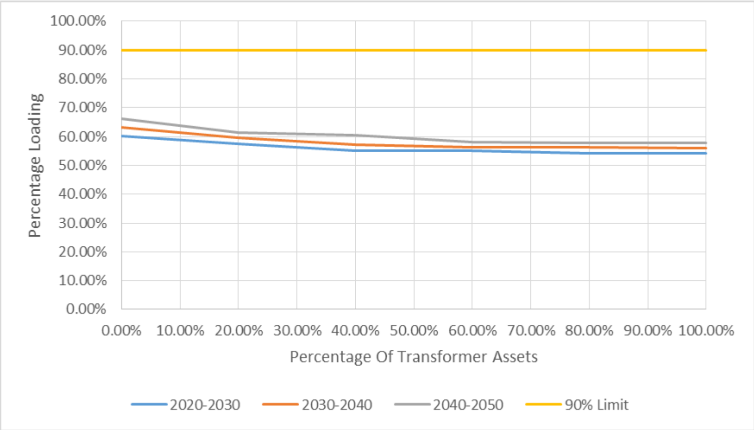

Figure 20: Medium Growth Scenario Worst Case Contingency Loading of Transformers Assets (Baltic Triangle).

9 SMART EV CHARGE POINT INTEGRATION SOLUTIONS ANALYSIS

This section presents the methodology and results for analysis of smart solutions to EV charge point network capacity issues. The results for different smart solution types quantify how much benefit (in terms of capacity) can be obtained from deploying smart solutions. This contributes to the overall assessment of the impact of EV growth on different parts of the SPEN networks and how that might project to the wider GB networks.

The study of Smart Solutions builds upon the baseline analysis outcomes to explore the capability of Smart Charging Solutions to avoid reinforcement and facilitate connection of EV charge point infrastructure with DER coordination and constraint of EV charge point during peak demand periods. The analysis assesses the impact of deploying each EV charge point Smart Solution to:

- understand how often smart charging methods are required to mitigate network constraints caused by EV charger connection and growth; and
- understand the implications for smart charging methods on availability of EV chargers.

Through the Smart Solutions analysis, the frequency and severity of constraints is understood, allowing an assessment of feasibility for each Smart Solution as an alternative to reinforcement.

The Smart Solution analysis follows a distinct methodology for different forms of solution, in keeping with the diversity of approaches, but sharing a consistent initial stage of study. This first analytical step performs time-series studies, modelling half-hourly variations in background demand levels, to derive an annual illustration of network constraint during periods of high demand. All subsequent EV charge point smart solutions analysis uses the outputs from the time-series analysis to derive understanding of how often smart intervention operation is required, and how many charge points are interrupted in each event. The Smart Solution studies consist of two separate cases:

LV analysis, which utilises the same methodology as the baseline analysis to identify asset loading levels and cases where network capacity limits are exceeded. The requirement for Smart Solution interventions to mitigate constraint on the LV system is then derived.

HV analysis, which utilises the same methodology as baseline analysis (HV) to identify loading levels on the HV system (11kV and 6.6kV), taking account of FCO contingency conditions. This utilises the outputs from LV Smart Solutions analysis to reflect the management of constraints as identified on the LV system.

Of all Smart Solutions for EV charge point previously defined, the Flexibility Market Smart Charging solution is the only example to be omitted during the Smart Solutions analysis. This particular approach is similar to the Real-Time Capacity Smart Charging, with the exception of market prices identifying the specific EV chargers to be interrupted, and so can be modelled in a similar manner. The overall frequency and severity of EV charge point constraint interventions, is therefore assumed to be the same between Real-Time Capacity Smart Charging and Flexibility Market Smart Charging. Market based approaches are at a very early stage in their development and the results of the analysis presented in this report will provide valuable input to that development. A summary of the analysis methodology, as applied to each of the different smart EV charge point solutions, is illustrated in Figure 21, and full details of the approach are provided in Appendix F.

Charge

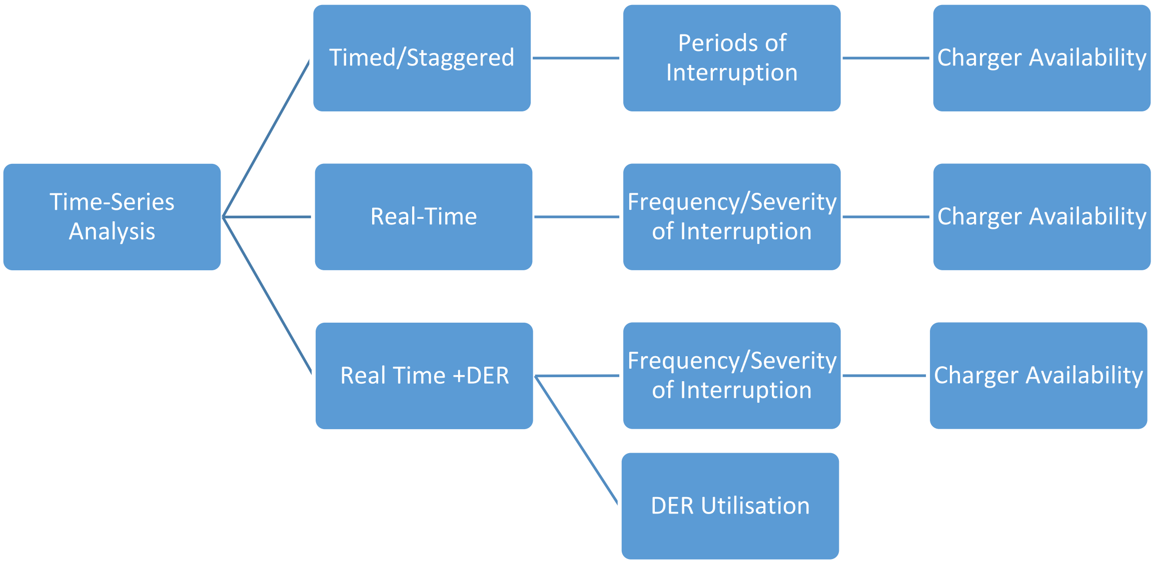

Figure 21: Summary Illustration of Smart EV charge point Solutions Analysis Methodology.

Charge

9.1 Smart Solution Results and Conclusions

Full results are provided in Appendix F, but a selection of key figures are provided below in relation to the headline findings.

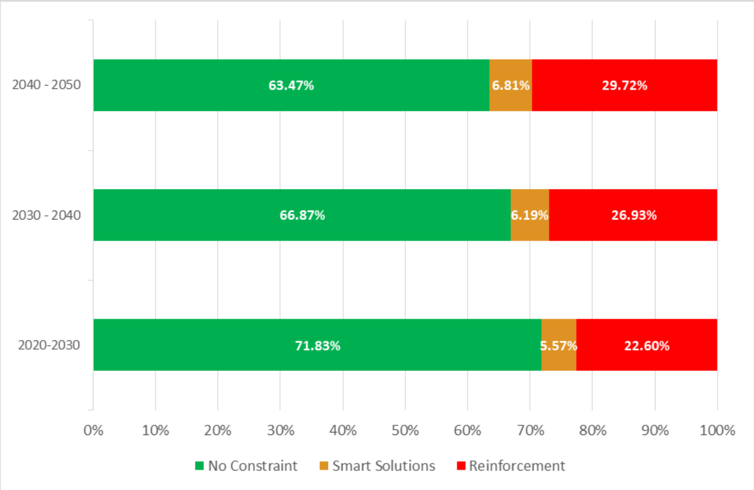

Figure 22: Proportion of Cases Suitable for Timed/Staggered EV charge point – On-street charging.

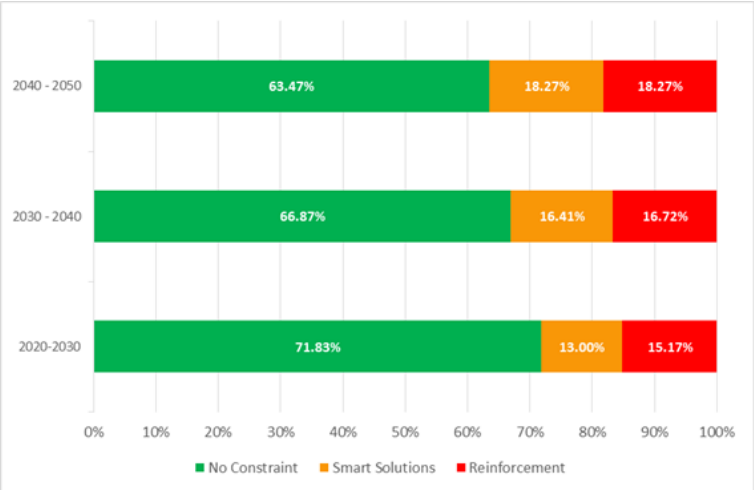

Figure 23: Proportion of Cases Suitable for Real-Time EV charge point – On-street charging.

Charge

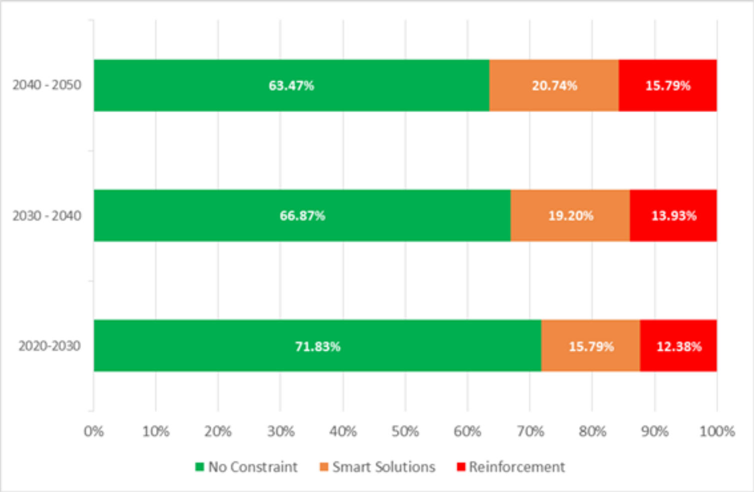

Figure 24 Proportion of Cases Suitable for Real-Time and DER EV charge point – On-street charging

Through modelling the application of innovate control techniques to EV charge point infrastructure, the Smart Solution studies have explored the value of such techniques in the deferment of EV-driven reinforcement and cost-effective connection of charge points. Importantly, the studies have highlighted the growing benefits of different solution types, reflecting the additional capacity that can be released as solutions grow in complexity.

A summary of findings from the Smart Solutions studies are as follows:

- **The significant step in feasibility between 'active' and 'passive' smart solutions**. The real-time smart solutions, which provide real-time control of EVs based upon real-time measurements of network loading, can be applied to over twice as many sites as the 'passive' approaches that apply fixed limits in the planning timeframe using offline observations of historical loading conditions. In the on-street study case for the 2020-2030 period, this is reflected in the Real-Time solution being applicable to 13% of studied feeders, in comparison to the Timed/Staggered solution being applicable on 5.5% of feeders.
- **The deployment of DER at charge points provides marginal gains in capacity release.** The Real-Time + DER solution has deferred reinforcement at additional study locations, offsetting EV charger interruption through use of on-site energy storage devices. The value of this solution is better suited to marginally-constrained cases where the deployment of energy storage can provide a greater percentage reduction in charge point interruption.
- **Into the future, a greater proportion of sites see uptake of smart solution as a feasible alternative to reinforcement.** The studies have shown that as previously-unconstrained cases enter constraint conditions, with relatively low levels of constraint, smart solutions become a feasible alternative to reinforcement. This sees the overall proportion of sites deploying smart solutions increase towards 2050.
- **Real-Time Smart Solutions can avoid reinforcement in over 50% of all cases that observe constraint conditions**. In all cases that study the Real-Time case and equivalent with DER coordination, the number of sites that are feasible for Smart Solutions roll-out is higher than the sites with greater than 10% interruption that require reinforcement.

10 EV CHARGE POINT NETWORK INTEGRATION COST BENEFIT ANALYSIS

This section sets out the method and results for Cost Benefit Analysis (CBA) of conventional and smart solutions to facilitate EV charging for on-street, destination and en-route charging use cases.

10.1 CBA Approach

The CBA follows the standard Ofgem format for determining the best network investment options.

A baseline CBA model has been created, which uses the results of the baseline analysis, to understand the proportion of the studied network that requires upgrades, and apply the required upgrades across the time period 2020 – 2050 in 10 year intervals. The baseline CBA model calculates the total reinforcement costs required based on the subset of network studied. The results are then scaled appropriately to calculate the reinforcement costs for the whole SPM license area.

Once the baseline is confirmed, the results of the smart solution analysis are used to identify the percentage of studied locations where a ‘smart solution’ could be applied. The costs of smart solution implementation are included in the CBA model, and compared with the baseline option to understand the costs and savings from deploying smart solutions on the network. This overall CBA process is illustrated in Figure 25.

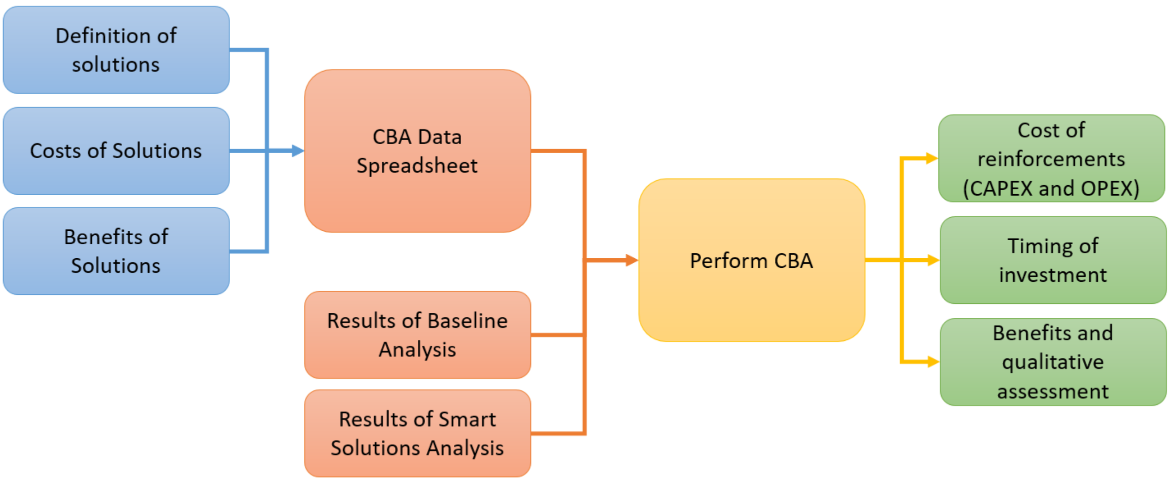

Figure 25: CBA Approach Overview.

10.2 Ofgem CBA Tool

The Ofgem CBA spreadsheet tool is selected and used for this EV charge point study based on its clear alignment with DNO business cases. The prices and indexes in the CBA template are based on 2012-13 figures (i.e. the same template used for ED1 business case planning).

Outcomes from the network modelling work presented in Section 8 and Section 9 identify the number of feeders that need to be upgraded within a given timeframe e.g. substations requiring additional capacity by 2030. From these results, the cost of the associated network reinforcements can be calculated during that given year, for both conventional and smart solution options.

The CBA will present investment costs only at this stage with further work during the trial to measure other costs and benefits to be analysed at a later date in the project. Full details of the CBA inputs and assumptions are provided in Appendix G.

10.3 Cost Benefit Analysis Results

The results below present the costs associated with conventional and smart solutions for each of the scenarios studied in the network modelling, focusing on presenting results for the medium growth scenario.

10.3.1 Conventional Reinforcements

Costs for conventional reinforcements scaled up for the whole of the SPM license area are shown in Figure 26. There are no OPEX costs associated with recommended reinforcements in the studies carried out, as all reinforcements were LV cable upgrades. The HV substations studied had sufficient capacity and did not need replaced. The largest expenditure occurs in the first decade following the initial increase of demand on the network.

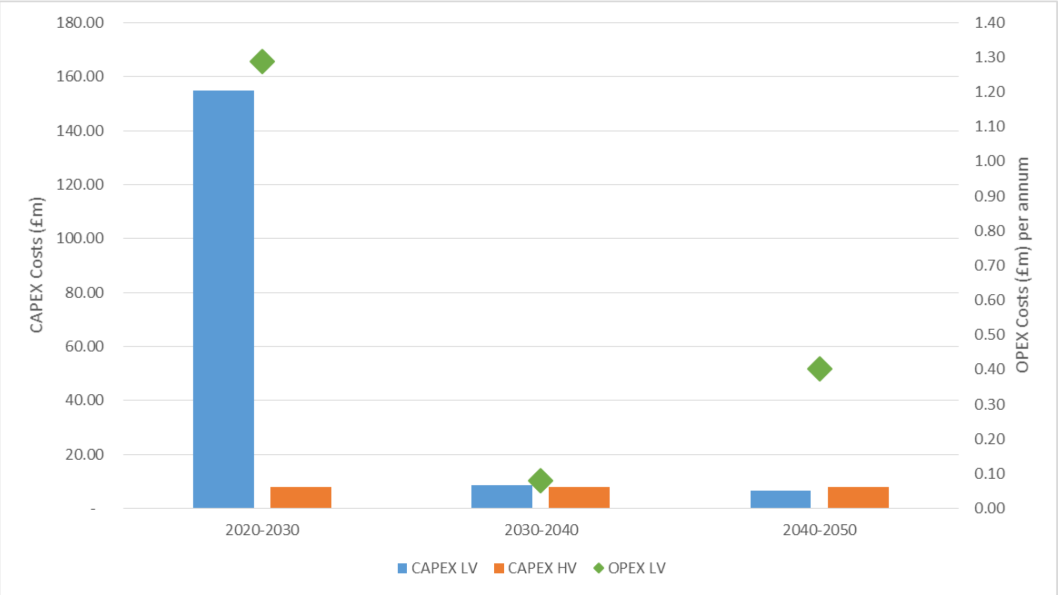

Figure 26: Graph showing split of costs between LV and HV reinforcements (conventional solutions) in the SPM license area.

10.3.2 Smart Solutions

Charge

Figure 27 - Figure 29 present a comparison of costs between deploying conventional reinforcements, the costs of smart solutions alone based on the proportion of network they can be applied to, and the combination cost of replacing a proportion of feeders with smart solutions. All results presented are for the Medium Growth scenario, scaled for the whole SPM license area.

For the Timed and Staggered solution, it is assumed that there are no costs associated with this solution for the DNO as explained in Appendix G.2. This may not be the case in reality but the use of existing processes and resources to establish the timed and staggered configuration of charging with Charge Point Operators is assumed to be low.

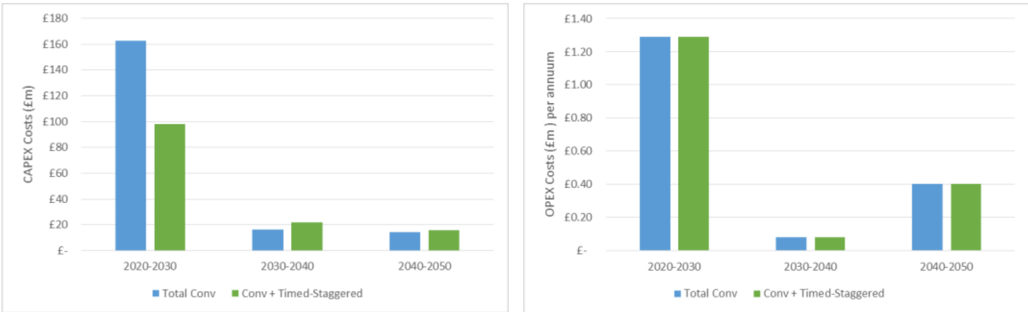

Figure 27: Reinforcement costs comparison for all conventional solutions vs blended conventional with Timed + Staggered smart solutions – SPM license area.

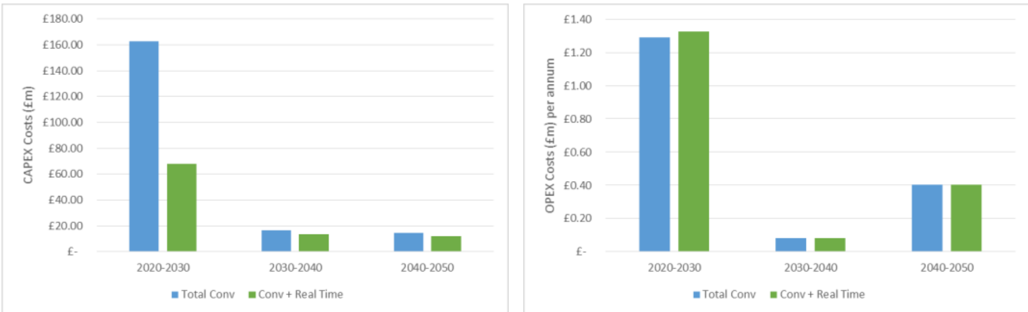

Figure 28: Reinforcement costs comparison for all conventional solutions vs blended conventional with Real Time smart solutions – SPM license area.

Charge

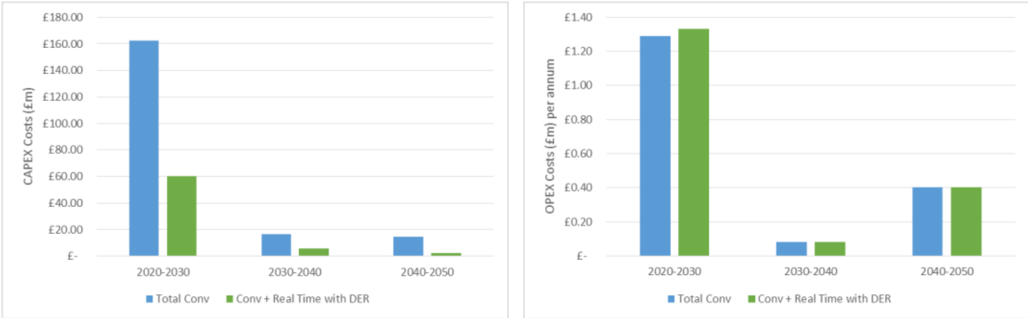

Figure 29: Reinforcement costs comparison for all conventional solutions vs blended conventional with Real Time+DER smart solutions – SPM license area.

It is clear from these results that the application of smart solutions and the blending of smart and conventional solutions has a very positive effect on CAPEX but with an increase in OPEX (of two orders of magnitude difference however).

10.4 Cost Benefit Analysis Conclusions

The baseline analysis and conventional solution selection (as configured) identifies that the 90% of investment is required in the first ten year study period (2020-2030). Based on current plans, this would fall into the remainder of the current plus the next two price control periods (ED2 and ED3).

The Charge CBA estimates an expenditure of £154m for LV reinforcement in the SPM license area across the next 10 years, which compares to RIIO-ED1 submitted values of £27.7m in SPM across the eight year price control period. This is a five-fold increase in the required LV reinforcement expenditure for SPM.

When these results are scaled to cover the whole of GB, the capital cost of conventional reinforcement on LV networks totals just under £3 billion over the next 30 years for a demand growth of 50% (Medium Scenario) at LV on EV integration (scaled up from the assumed growth applied to SPM and SPD studies).

The most recent NG ESO Future Energy Scenarios[14] report identifies an annual residential demand of 108.9 TWh/year. This translates to an average hourly residential demand of 12 GW. If we consider the 50% growth to that level of domestic demand (so an additional 6 GW), and the estimated reinforcement cost of £3 billion, this equates to £500,000/MW for secondary network reinforcements across GB. This value will vary across license areas, network types, and use cases but the analysis performed here provides a high level of view of the impact that significant demand driven reinforcements may have on the network.

When Smart Solutions are introduced as an option, there are significant savings in the order of a 60 % reduction in total costs during the first 10 year period. There are noticeable CAPEX and OPEX savings when the alternative EV integration network investment strategies are placed side by side. The costs do not account for inconvenience and effort costs associated with a move to the smart

[14] http://fes.nationalgrid.com/fes-document/ - Figure 4.24

solutions approach, but they also do not place a value on the benefit of connecting customers to the network in a shorter timescale.

Secondary network reinforcement

Secondary Network Reinforcement Expenditure (£m)						
		£m p.a.			Total	
		DPCR5	RIIO-ED1	% change	DPCR5	RIIO-ED1
SPD	11kV	2.9	3.7	31%	14.3	29.9
	LV	1.6	1.7	7%	8.1	13.9
	Total	4.5	5.5	22%	22.4	43.8
SPM	11kV	1.6	2.5	64%	7.8	20.4
	LV	0.8	0.9	12%	4.1	7.3
	Total	2.4	3.5	46%	11.8	27.7
SPEN	Total	6.8	8.9	31%	34.2	71.5

Figure 30: Extract for RIIO ED1 business plan indicating spend across price control period on Secondary Network Reinforcement.

There is clearly a substantial level of effort required to integrate this type of solution in to business as usual, however this move will not be driven solely by a desire to manage EV charge point, but a desire to enable the business with a greater level of control and visibility over assets connected at the distribution level.

A positive NPV for the SPM license area is shown for all three categories of smart solution, and these are presented in Table 6. The results for both Real Time and Real Time with DER smart solutions are similar due to the similarity in costs of implementing these approaches. While the Real Time with DER smart solution includes monitoring and control of DER assets, the incremental cost of this to the DNO is minimal.

Table 6: NPV for Smart Solutions when compared with baseline.

£m	NPVs based on payback periods			
	16 years	24 years	32 years	45 years
Conventional Reinforcements	-	-	-	-
Timed and Staggered	£41.96	£48.53	£53.36	£57.04
Real Time	£58.91	£72.55	£82.41	£91.73
Real Time with DER	£58.88	£72.68	£82.72	£92.23

11 SELECTED LOCATIONS FOR EV SMART CHARGING TRIALS

11.1 Trial Selection Criteria

To determine the areas of interest from this study to be recommended for Charge trial locations, two specific criteria are proposed that must be met within the medium EV charge point connections growth scenario for 2020-2030:

- The LV analysis returns at least one feeder, or HV substation upgrade to carry the predicted demand growth from the EV charge point connection application. This shows that the area will require some capacity uplift work; if the predicted demand growth or is experienced in the area for the first 10 year period;
- The HV branches that share a common connection with the distribution transformer are loaded greater than 60% but below 100%. This shows that the HV network area may overload in the future under continued EV charge point connection growth, and takes into consideration inaccuracies in modelling and loading data approximations, the is highlighted in greater detail.

The impact of EV growth is more significant in the Baltic triangle area, as highlighted in the HV analysis conclusions, suggesting it may benefit from deployment of smart solutions sooner than other areas studied. The mix of on-street and destination distribution transformers in the area will inform other partners as to the behaviour of different charging types. Therefore, based on the results of the network analysis, the Baltic Triangle is recommended for a trial location.

11.2 Trial locations identified through analysis

For the distribution transformer in the Baltic triangle area, the following areas meet the two criteria.

Table 7: Candidate EV Smart Charging Trial locations meeting LV and HV analysis selection criteria.

	Area Name	Area Type
1	CHANDLERS_WHARF_BLOCK_A_6 1	On-Street
2	105_DUKE_STREET_6 1	On-Street
3	CORNHILL_6 1	On-Street
4	BLUNDELL_STREET_6 1	On-Street
5	NORTH_HILL_STREET_6 1	Destination
6	GRENVILLE_ST_SOUTH_COMMUNITY_COLLEGE_6 1	On-Street
7	SUFFOLK_STREET_6 1	Destination
8	CHANDLERS_WHARF_6 1	On-Street
9	HENRY_STREET_NO_2_6 1	On-Street
12	LETITIA_STREET_6 1	Destination
13	KENT_ST_BLOCK_D_6 1	On-Street
14	THE_CINNAMON_BUILDING_6 1	Destination

11.3 Stakeholder Engagement

Stakeholder engagement has been on-going throughout the early stages of the project, beginning in April 2019, with follow up discussions with local authorities and further engagement through stakeholder events. Early stakeholder engagement has demonstrated that while Local Authorities are keen to deliver EV charging solutions, they lack enough funding to be able to progress with schemes and trials on a timescale that aligns with Charge.

Currently, work is on-going with other developers and third-party charge point operators to understand if these parties can collaborate to identify targeted trial locations in the areas studied for Phase 2 trials.

In addition to the analysis work performed in Method 2, SPEN has engaged with key EV charge infrastructure customers and stakeholders in the SPM region to understand the needs, potential and appetite for participation in the Charge trials.

The studies have identified parts of the SPM, Liverpool Baltic Triangle network area as strong candidates for **Phase 2 EV smart charging trial locations**.

Ultimately the decision on trial locations will be dependent on stakeholders and their ability and desire to fund elements of smart solutions and trial them. If alternative locations are proposed by stakeholders the methodology developed in this initial phase of Method 2 will enable the suitability of those new sites for smart EV charging solutions to be assessed.

11.4 Recommendations for trials

Ultimately the decision on trial locations will be dependent on stakeholders and their ability and desire to fund elements of smart solutions and trial them. If alternative locations are proposed by stakeholders the methodology developed in this initial phase of Method 2 will enable the suitability of those new sites for smart EV charging solutions to be assessed.

At this stage in the Charge project, the smart EV integration solutions have to be selected for the trial areas and the trial has still to be designed. These recommendations are only for the location of the trials based on detailed analysis and stakeholder engagement. Final trial location selection and approval will also consider the specific commercial value (i.e. the value to the stakeholders as well as SPEN and all of its customers) of the trial as well as the innovation learning value.

12 CONCLUSIONS & NEXT STEPS

This report has presented a summary of the EV charge point connections network analysis programme led by Smarter Grid Solutions during the first phase (Jan-Sep 2019) of Charge Method 2: 'Tactical Solutions to support EV connections'.

The objectives met by this SDRC milestone are as committed in the project direction[15]:

- **Complete assessments of candidate networks in SPM and other licence areas**: analysis of hundreds of substation areas in the SPM and SPD license areas for both LV and HV networks for a range of EV and charger growth scenarios and types and for different conventional and smart EV charger connection solutions. The SPM network analysis provides the evidence-based foundation required for selection of the Charge trial areas. SPD was selected as the additional network area as required in the project as the underlying design, topology and characteristics are distinct from the unique SPM network attributes.
- **Updated Cost Benefit Analysis** (building from the project application stage CBA) using network study results, detailing the impact of EV growth on the network, assessing the costs and benefits of conventional and smart reinforcement solutions: completed the CBA for all studied networks, EV scenarios, charge modes and identified solution types, presenting the economic impacts of all and drawing general conclusions applicable to SPEN, UK DNOs and the EV charge network integration and smart EV charge point sectors more generally.
- **Stage Gate report which will determine the scope for trial deployment, and likely pilot trial locations**: Trial locations identified through search, screening criteria and analysis are presented and these will now form the candidate list for SPEN and other Charge project partners to discuss with project and network user stakeholders to select the best areas for the Charge trials.

Headline Conclusions

The headline outcomes of the network and EV charging analysis in this first phase of Charge are:

- **A significant amount of network reinforcement would be required in both SPM and SPD LV networks to deal with a modest EV uptake.**
- **More than 50% of the identified reinforcement cases can be feasibly addressed with the Charge smart EV charging solutions.**
- **The required LV network reinforcement investment compresses into the 2020-2030 period as the additional loading from EV charging creates a significant early investment requirement.**
- **Smart Solutions create significant CAPEX savings in the period 2020-2030, with a 55% reduction from £160m for conventional reinforcement to £70m for a reinforcement plus smart charging solutions investment strategy in the SPM license area.**
- **Indicative projections to the whole of GB reveal an estimated £3 billion of savings to upgrade LV networks to cope with the EV charging demand over the next 30 years.**

[15] https://www.ofgem.gov.uk/publications-and-updates/electricity-nic-submission-sp-energy-networks-charge

It should be noted that the targeted benefits of the application of smart EV charging solutions are in faster and cheaper connections to charge point developers and also in reduced load related reinforcement costs borne by all customers.

12.1 Conclusions and Insights

Through scoping, methodology development, analytical tools implementation, data capture and analysis, the Charge project has gained significant insights into the technical and economic implications of network integration of future EV charge infrastructure.

12.1.1 Scenarios for EV charger connection in on-street, en-route and destination applications

- Three connection and DNO smart charging solutions for three different EV charging applications (or use cases) have been modelled and analysed:
    - **On-street EV charging**: for domestic electricity customers without dedicated off-street parking such as in terrace, apartment and tenement dwellings.
    - **Destination EV charging**: for charging at typical public destinations such as retail, entertainment, leisure and tourism sites.
    - **En-route EV charging**: for charging while in transit between home, work and destinations including highway service areas and urban refuelling stations.
- In order to assess the performance of conventional connections compared to smart charging solutions, a pragmatic estimate of the expected EV charger connection applications, on a per-feeder and per-transformer basis, was developed.
- These future estimates align with the National Grid Future Energy Scenarios projections for EV uptake and makes necessary assumptions concerning the difference in uptake levels in the rural and urban settings in the SPEN networks.
- The scenarios do not yet align with the ongoing work in Charge Method 1 but it will be possible to integrate those transport planning scenarios of EV and EV charger growth into this network analysis as the Charge project progresses. The scenarios used in the analysis to date provide a sliding scale of severity of network capacity issues, which, if linked with the Future Energy Scenarios, could provide the DNO with an indication of the timeframes in which reinforcements will be required to support EV growth and then track EV growth scenarios to monitor network reinforcement.

12.1.2 Utilisation of Corporate Data

- The analysis utilised real network data extracted from corporate systems, including historical transformer loadings and feeder cable data taken from SPEN's GIS database.
- This enabled each of the sampled distribution networks to be realistically modelled, providing a high degree of confidence in the impact assessment results.
- This approach ensured attention was focussed on the assumptions about how and where EV chargers will connect, operate and the impact they have on the network.
- The methodology utilising corporate data is replicable for additional sections of network, other licence areas and for other low carbon technologies in LV and HV networks. Such an

extension of the analysis would use the data extraction and preparation methods created in Charge but also leverage new data tools and capabilities in SPEN.

12.1.3 Analysis Methods and Tools

- A sophisticated set of tools and methods for technical and commercial analysis of EV charger integration into distribution networks has been configured, adapted, developed and applied for the Charge project, using best practice in high volume smart grid analytical techniques.
- These tools and methods have been applied to a large number of LV and HV network areas for Charge. This creates a strong foundation for the next phases of Charge but also presents additional analytical and planning opportunities within Charge but also beyond Charge as required of innovation projects.
- The analysis methodology created and used sets of robust assumptions, applying time series customer and asset loading profiles and assessed the technical and economic application and merits of multiple conventional network reinforcement and smart EV charge point solutions. Accessing LV and HV network data to build the network models for the analysis programme has been a challenge but aided by the parallel SPEN initiatives for enhancing data sets and models. With all of these factors in play, the analysis programme has been a significant undertaking which has now produced three significant network modelling platform and baseline outcomes:
    - A tried and tested analysis approach using existing and new tools, methods and data sets that can now be used for other large scale analysis campaigns (e.g. wider EV or other low carbon technology) in support of customer and network business objectives (e.g. investment planning), and
    - A baseline analysis was undertaken to create a reference case of EV load growth, headroom issue identification and conventional reinforcement requirements. Smart EV charging solutions are analysed with the same network conditions but with reinforcement offset by one or more of the smart charging solutions.
    - Analytical results that shed light on the impact of EV charge points on the SPEN networks and the roles of conventional network reinforcement and smart EV charge point solutions.
- The analysis in this report considered two charger ratings and these are used in the scenarios and allocated to the different EV charging use cases according to the best information available at present:
    - Fast single-phase chargers: 7kW AC
    - Fast three-phase chargers: 22kW AC

12.1.4 LV baseline Analysis

- The uptake levels of EV charge points in urban areas (the scenarios based on Future Energy Scenarios assumptions model up to 1.5% of potential customers with dedicated and unmanaged access to an EV charging) results in an overall electrical demand growth of more than 50% compared with 2018 baseline levels. This shows that a relatively small uptake in EVs will have a significant impact on the electrical capacity required of LV distribution systems in the coming years.
- **The required LV network reinforcement investment compresses into the 2020-2030 period.** A high proportion of the reinforcement comes in the form of new feeder solutions

required in the first time period of the study (2020-2030). The characteristics of LV network reinforcement, while costly and inconvenient, create network capacity for further EV growth in later decades. Many of these conventional reinforcement investments provide ample capacity for subsequent EV growth in the following decades of the study. Network reinforcement in the form of new LV feeders is likely to be the main solution employed in densely populated areas (e.g. cities) with relatively few requirements for additional secondary transformers (see result further below). This result might appear to be at odds with other EV integration studies that have identified the latent capacity of LV networks to host EV charge point in the early years of EV growth but this Charge analysis result points specifically to the need for upgraded and new LV feeders rather than transformer capacity that may have been the focus for other studies. The characteristic of LV network reinforcement, while costly and inconvenient and required in the next decade, creating network capacity for further EV growth in later decades requires thought. It might be that an effective LV networks EV integration strategy is to build more assets to create capacity to address the immediate headroom squeeze and create room for growth in future decades. Smart solutions may buy time before reinforcement is required but whether they can defer reinforcement to the extent that material value is created is a matter for further analysis and investment strategy.

- **EV penetration rate increases the network reinforcement need**: As the magnitude of the EV charge point connection applications increases (in response to EV growth), the reinforcement requirements increase accordingly. Traversing through the low, medium and high EV charger penetration scenarios clearly creates the requirement for more reinforcement solutions and earlier in the studied period. This is not a surprising result but taken with the other baseline analysis outcomes it creates a clear picture of the heightened need for EV charger related network reinforcement.
- **Load growth in LV networks from non-EV developments will increase the LV network reinforcement requirement further**: The analysis explicitly studies only load growth from increasing EV charge point penetration, and does not include other forms of electrical demand growth (e.g. heat pumps, rail electrification, etc.). Therefore reinforcements/upgrades outlined in this analysis are likely to be required sooner than indicated here due to separate growth in the baseline demand profile of the network through the decades.
- **SPM and SPM On-Street, and SPM Destination EV charge point cases create similar network headroom issues and investment needs**. There is a high degree of correlation between the SPM and SPD On-Street and SPM Destination EV charge point study cases in terms of the expected types and proportions of reinforcement solutions. This points to a general area-by-area requirement for network reinforcement in response to EV charger growth with specific local factors to be considered.
    - Given that the network topologies and existing loading levels are likely quite different in different areas of SPM and SPD and between SPM and SPD it is significant that, at an aggregate level, similar patterns of reinforcement are required in response to projected EV growth in SPM and SPD. Comparisons of SPM and SPD with other DNO license areas in the UK will be an interesting factor in DNO investment planning and overall CAPEX and OPEX budget setting and recovery for EV integration across the UK.
- Proportional allocation of EV chargers to car parking spaces and the relatively low baseline demand where **en-route charging** is assumed to occur results in **demand growth as high as 119%** over the current baseline by 2050 (and up to 170% growth where a greater proportion of 50kW rapid chargers are modelled). However, there is **frequently sufficient capacity on existing HV/LV transformers** to accommodate this relatively modest level of growth. If more significant fast and rapid (22kW and 50kW) charger connections to a LV network occur (e.g. at a dedicated new EV en-route charging site) then a new HV/LV substation solution would typically be required and so a reinforcement solution would result.

Charge

Only the integrated DER management would then be a logical smart charging solution addition to reinforcement since the immediate connection capacity issues would be resolved.

- Due to the relatively small sample of substations studied (as a proportion of GB), and the modelling limitation of proximity transformer selection, there were **no instances in the analysis where the interconnection solution is selected**. A more detailed interconnection analysis may highlight opportunities for such solutions in the on-street and destination test areas. This might indicate an areas for further or wider analysis to test the triggers for the interconnection solution or its applicability in other networks to ensure that conventional solutions are full tested.

The methodology, assumptions and LV baseline study outcomes were a key input to the analysis of impacts of EV charge point on the HV network. The highlights of the HV baseline analysis are:

- The HV network analysis has assessed the growth of LV connected EV charge point across the EV growth scenarios and across decadal periods. There is a clear **impact to existing HV network capacity margins with some HV upgrades required**. However, for the most part the **existing HV asset capacity headroom can cope with the forecast EV charge point load growth** approximated in these studies. This includes consideration of voltage regulation and fault level contribution (which is assumed to be low as a result of the EV on-board charge electronics and the impedance between LV connected charge points and the HV network.
- Reducing the threshold for reinforcement to asset loading of 90%, to accommodate the load approximation, showed that some of the network will need to be reinforced consistently over the scenario and time periods studied.
- When comparing Bootle and Baltic Triangle network areas in SPM, Bootle has many more interconnections at 6.6kV than Baltic Triangle, resulting in **less stress across the existing Bootle network capacity in comparison to Baltic Triangle**.

These **baseline analysis results** inform the development of “smart solutions” that are expected to offset the need for network reinforcement in reaction to expected EV growth. The results of both the baseline and smart solution analysis will allow a cost-benefit analysis to be undertaken in order to capture the financial benefits of applying smart solutions to offset the network reinforcement project in the baseline analysis.

Through modelling the application of innovate control techniques to EV charge point infrastructure, the **Smart Solution studies** have explored the value of such techniques in the deferment of EV-driven reinforcement and cost-effective connection of charge points. Importantly, the studies have highlighted the growing benefits of different solution types, reflecting the additional capacity that can be released as solutions grow in complexity.

A summary of findings from the Smart Solutions studies are as follows:

- **Real-time EV charging controlled smart solutions can avoid reinforcement in more than 50% of all cases that observe constraint conditions**. In all cases that study the real-time smart charging solution (and the equivalent combined with DER coordination), the number of sites that are feasible for smart solutions deployment is higher than the number of sites where greater than 10% charge time interruption would be required and so where it is judged that network reinforcement would be the best solution to EV charge point connection. The issue of charge interruption and shifting with the smart solutions required further analysis and thought.
- **There is a significant increase in applicability of ‘active’ over ‘passive’ smart solutions**. The real-time smart solutions, which provide real-time control of EVs based on real-time measurements of network loading, can be applied usefully to over twice as many sites as the ‘passive’ approaches (i.e. Timed and Staggered charging) that apply fixed limits in the

planning timeframe using offline observations of historical loading conditions. In the on-street study case for the 2020-2030 period, this is reflected in the real-time solution being applicable to around 13% of studied feeders, in comparison to the Timed and Staggered smart solution being fund applicable to only 5.5% of feeders. This outcome is evident across the On-street and Destination use cases with the en-route use cases having particular characteristics that narrow the scope of smart charging solutions as discussed above.

- **The deployment of DER with the smart charging solutions provides additional gains in network capacity headroom or reinforcement deferral.** The real-time control plus DER smart charging solution defers reinforcement at additional study locations by offsetting EV charger interruption through use of on-site energy storage devices. A further 2-5% of reinforcement cases are addressed through the addition of DER in addition to the 12-18% of reinforcement cases dealt with by real-time controlled smart charging for the on-street and destination charging cases between 2020 and 2050. This DER integrated solutions might be better suited to marginally-constrained cases where the deployment of energy storage can provide a greater percentage reduction in charge point interruption or else where the customer has other DER value streams or objectives anyway.
- **Into the future, a greater proportion of sites see uptake of smart solutions as a feasible alternative to reinforcement.** The studies have shown that as previously-unconstrained cases enter constraint conditions, with relatively low levels of constraint, smart solutions become a feasible alternative to reinforcement. This sees the overall proportion of sites deploying smart solutions increase towards 2050. This is a strong indication that the deployment of smart solutions will be required to address new capacity issues on an ongoing basis, even where reinforcement supersedes some smart solution deployments for reinforcement deferral.

By using the outcomes from the network analysis, scaling the results to provide a license wide view, the CBA analysis has provided indicative cost comparisons between the use of conventional network reinforcements to upgrade the network in response to demand growth, and the use of smart solutions to manage demand at peak times and use the flexibility in the network to enable connections in a timely manner.

A summary of the CBA findings are as follows:

- **When Smart Solutions are introduced as an option, there are significant CAPEX savings in the first 10 year period (2020-2030)**. The installation of smart solutions provides ‘breathing space’ for DNO investment needed to support LV network demand growth from EV charge point connections and EV charging. With the analysis outcome showing a significant reinforcement need in the 2020-2030 decade, the early capital investment reduction or deferral benefits of smart charging are very clear.
- **A hybrid investment strategy of conventional reinforcement and smart solutions provides the lowest combined CAPEX and OPEX outcome for EV connections and the associated demand growth.** For example there was a clear reduction from £160m for conventional reinforcement for EV charge point connections to £70m (so a circa 55% reduction) for the hybrid reinforcement and smart charging solutions in the SPM license area in the decade 2020 to 2030.
- **The baseline analysis and conventional solution selection (as configured) identifies that the majority of investment in the LV network is required in the first ten year period (2020-2030).** There is currently sufficient capacity in the 33kV network to withstand the initial increases in LV demand but as with most of the network studies, this will vary across license areas, and network types.
- **The GB-wide costs to upgrade LV networks to cope with the EV charging demand increase is estimated at £3 billion over the next 30 years.** Based on the analysis of the

selected network areas in SPM and SPD, an indicative projection of the cost reduction benefits for integrating EV charging in across the GB distribution networks shows a significant target for DNO investment and regulatory arrangements. This estimate is indicative of the scale of work that is required to upgrade the LV network but also the potential scale of benefits from EV smart charging.

- **Further work is required to understand the cost of charge session shifting inconvenience to customers**. While there are some quantitative analysis that can be undertaken ahead of the trials, true understanding and learning on the topic of customer inconvenience from EV charge shifting or curtailment will become evident during the next phase of the project, and will be one of the key areas to report on as part of the trial outcomes. This should be expected to be an important topic given the experiences of flexible DG connections in recent years and the difference between self-managed charging, supplier managed charging, CPO managed charging and DNO smart charging (as studied in the Charge project).

The studies have identified parts of the SPM, Liverpool Baltic Triangle network area as strong candidates for **Phase 2 EV smart charging trial locations**.

12.2 Potential Further EV Charging and Network Analysis

The analysis tools and methods will be utilised to support the final trial decisions and to provide a more detailed baseline of expected trial outcomes.

The platform of methods, tools, data, network models and configurations for analysis of EV charge point integration to distribution networks created for the Charge project present the opportunity for further detailed analysis of this important area.

The potential further analysis requirements within Charge and beyond the project have been identified and are summarise below:

- **Analysis of additional scenarios and EV charge point assumptions**: This analysis has created a very valuable foundation of understanding of the impacts of EV charge points on the SPEN distribution networks. In a fast moving area such as EV growth and smart charging solutions it is expected that analysis will be required for additional scenarios for EV growth, testing of the assumptions of how this translates into EV charge point requirements (e.g. locations, ratings, types), specific approaches to smart charging, what level of flexibility in EV charge point will arise from third party action (e.g. energy retail supplier incentives and tariffs, Charge Point Operator action) and other emerging questions. The EV charge point integration analysis tools created in Charge can be readily adapted to build on the assumptions made in each of these areas so far and test a wide spectrum of additional issues. Specifically, the outputs of the Method 1 EV charging scenarios will be integrated into further analysis to provide a more focused assessment of the impact of EV charging on the SPM network than the uniform allocation of Future Energy Scenarios charge points penetration.

- **Network investment planning in ED1 and ED2**: Assessment and exploration of roles, preferences, volumes, costs and benefits of conventional and smart solutions for EV network integration will underpin network investment planning for EV integration. Analysis for investment planning should include the additional commercial implications of network capacity dependency on EV charge point flexible connection methods and flexibility services. Several of the possible analysis enhancements noted above (e.g. additional scenarios, extending the coverage of the models to whole or more representative portions of the SPM, SPD and other DNO areas) along with building on the EV charge point integration CBA will be necessary to feed these Charge outcomes into network investment planning for the remainder of ED1 and in preparation for ED2. Study of the 'intra-decadal' (e.g. annual granularity) growth of EV charging and requirement for reinforcement and smart solutions would add additional detail and value to the investment planning analysis, especially in the 2020-2030 decade.

- **Analysis of additional distribution network areas**: Additional studies may be required to analyse network areas for the Charge trials that are selected for other reasons (e.g. stakeholder interest, development areas), for network areas beyond the Charge trial target locations and potentially for other DNO networks. This would enable the tools and methods used in Charge to be applied consistently and for comparison with other areas. The studies of non-SPM network areas required in Charge were focused on the SPD network area as this created distinctiveness to the special features of the SPM network.
- **Detailed assessment of smart charging operations**: When the smart charging solutions are developed further from the existing concepts (e.g. once the design of the Charge trials begins) then analysis of their expected operation and performance can be undertaken in a more detailed manner using the same analytical tools and methods utilised in the analysis presented in this report. This analysis will provide useful information for comparison with the actual smart charging operation in trial as well as providing insight into the implications of smart charging for potential trial participants.
- **Understanding the cost of undelivered energy to charge points:** Further analysis could usefully be undertaken as part of the trials to understand the inconvenience cost to consumers of being unable to receive the full capacity charge during their length of stay or charging session at a charge point. Such information can then be fed back into the CBA to further understand the implications of interruption. In addition, the cost of EV charge flexibility to customers will play a vital role in the adoption of DNO led EV smart charging.

12.3 Next steps for Method 2 in the Charge Project

The outcomes of the analysis will support the decision on pilot and trial scope, locations and design. The next steps that lead on from this first phase of activity in Charge Method 2 are:

- **Additional analysis** of network reinforcement and smart charging application to selected trial areas and wider SPM and SPD network areas to enhance the understanding of the applicability, benefits, costs and customer implications of the conventional and smart charging network integration solutions. This will include analysis of the EV and charging scenarios produced in Method 1.
- The **scope of the trials** will be specified and this should be sufficiently broad to maximise the learning captured on applicability and value to customers from the range of smart EV charging solutions. The trials will provide a much deeper understanding of the assumptions made in the network analysis and CBA as well as the technological, integration and customer impacts of the smart solutions.
- The **trial locations** identified in the analysis will now be considered by SPEN, the Charge partners and project stakeholders and decisions made to finalise the trial locations and begin smart charging solution design.
- The **trial design** will be informed by completed analysis and some new analysis to configure the smart solutions, including charge time window and staggering parameters, baseline of expected curtailment or shifting of charging under real time control.

Smart solution design will follow a structured process of requirements, specification and design with focus on the most applicable and value adding smart charging solutions for the specific trial locations and participating customers as well as for a more generic solution that is replicable to many other SPEN network areas.