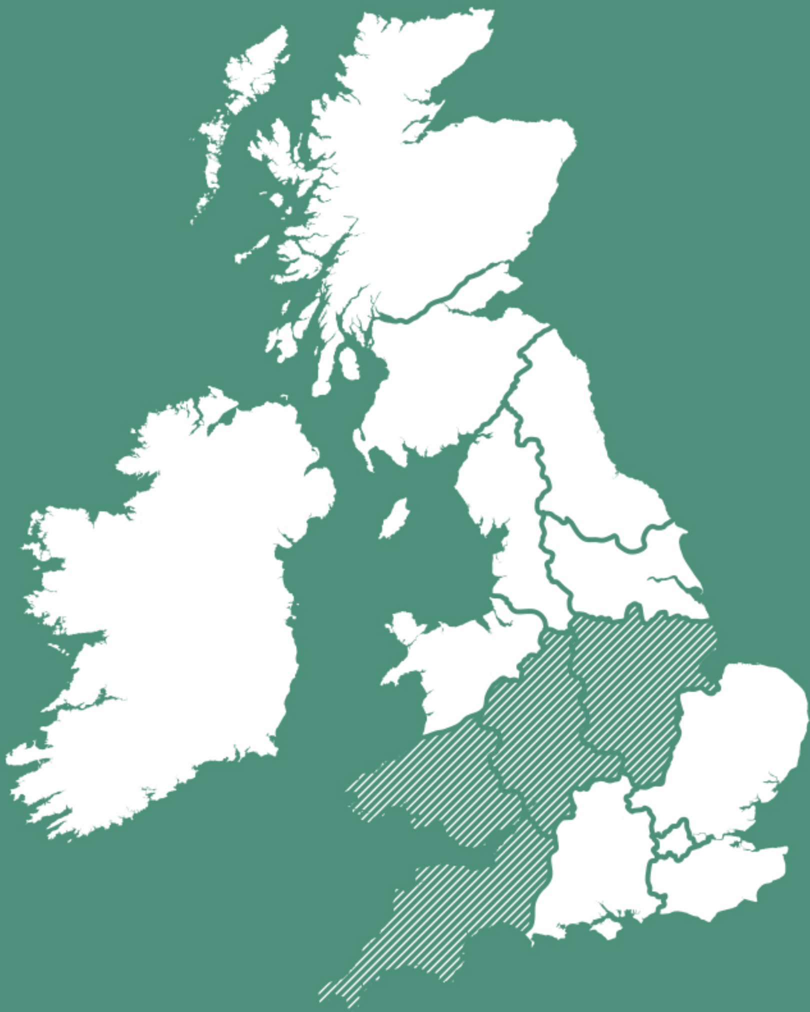
WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

ELECTRIC BOULEVARDS

CLOSEDOWN REPORT



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Contents

Glossary

Term	Definition
IPT	Inductive Power Transfer
WPT	Wireless Power Transfer
LV	Low Voltage
HV	High Voltage
TRL	Transport Research Laboratory

Executive Summary

The UK energy industry faces unprecedented challenges as energy usage patterns change through the use of new technology and the need to be more fuel efficient generally in order to meet GB climate change targets. One such challenge is the increased use of electric buses as a mode of public transport to replace the existing diesel fleets.

There is little anecdotal evidence to point to in order to provide insights into what the impacts of increased electric bus adoption would be on the existing electricity network. Although there is some research in this area we felt it pertinent to do something more robust based on real trials. It also offered technology providers the opportunity to put these ideas into something tangible and gain valuable insight into the impacts of electric buses more widely.

The introduction of Electric Buses could have a major impact on the local electricity distribution network, not only in respect of the potential increase in demand that it could create but also on the network itself in the need to reinforce it on a potentially industrial scale should these vehicles become the norm. The challenge that Electric Boulevards attempted to address was to find out in a real trial the likely impact on DNOs should these buses see wide scale adoption.

Through the use of inductive chargers (enabling on the go charging) and innovative connection arrangements we sought to establish the impact on DNO's of these vehicles on a larger scale- 8 buses covering a 15 mile route around Milton Keynes. The project had three phases over a 2 year period.

This was an extremely successful project incorporating a variety of partners and suppliers. The results were encouraging for both bus operators and DNO's with some compelling evidence that there would be no requirement for significant reinforcement in the event of a more wide-scale deployment of Electric Buses.

1. Project Background

The Electric Boulevards project was designed around the use of Inductive Power Transfer (IPT) chargers meaning that the buses would be charged whilst at a number of bus stops throughout the trial area as well as whilst at the bus depot. This was a large undertaking and required the participation of a number of niche partners, namely Transport Research Laboratory (TRL), Wrightbus, Arriva, Arup and Mitsui.

The project sought to determine the general impact on the network by:

- Facilitating decarbonisation of the transport system by developing a standard connection policy for IPT chargers. Through monitoring of the HV and LV network before and after installation, the level of disturbance was assessed and quantified against existing limits.
- Trialling a number of connection arrangements and comparing traditional reinforcement methods with innovative techniques, allowing the most appropriate solution to be developed.
- Installing a third IPT charger to investigate the ability for deferral of charge during times of network constraint and will demonstrate the role of electrical vehicle to grid interaction.

- Developing the bus depot wired charging methods and investigate the advantages of allowing an intelligent system to manage the charging requirements of multiple vehicles to spread the load evenly rather than having the charging infrastructure run unconstrained.
- Undertaking detailed analysis to further understand what a UK wide electric bus fleet would look like in terms of demand.

The project ran from January 2014 to December 2015 and this report brings together all of the relevant information for stakeholders. We do not go through in detail the findings within this report as they are provided within the Appendices.

2. Scope and objectives

The scope of the project is provided in detail within Section 4, in summary though it covered the installation of technologies across an agreed route to support the mobilisation of a fleet of electric buses within Milton Keynes.

Appropriate monitoring was in place and data captured throughout the trials in order than detailed analysis could be undertaken by TRL. Their reports are included as appendices.

The objectives of the project and their achievement status are provided below and a more detailed commentary on them is provided later in this report within Section 6.

As mentioned throughout this report all of our stated criteria and objectives were met on this project and we are very pleased with the outcomes and in particular being able to develop a template for the industry based on these results.

Criteria/Objective	Overall Status
Objective 1: Infrastructure will be installed to provide connection to three IPT chargers in the Milton Keynes area using a number of different arrangements.	✓
Objective 2: HV and LV monitoring will be installed before and after IPT charger commissioning in order to retrieve background harmonic levels.	✓

3. Success criteria

The Electric Boulevards project had a series of success criteria. Given the complexity of the project and the need to undertake changes within the local community it was essential that the measures of success were such that the project could fully test the technologies and determine what impacts these buses have on the network in order to provide a level of confidence for WPD and our stakeholders.

The success criteria were as follows and it is pleasing that we were able to meet all of them:

Success Criteria	Overall Status
Success Criteria 1: Install HV and LV monitoring devices on the adjacent network	✓
Success Criteria 2: Conduct preliminary lab testing of the IPT charger	✓
Success Criteria 3: Connect IPT chargers to the network using innovative techniques	✓
Success Criteria 4: Demonstrate charge deferral based upon network constraints	✓
Success Criteria 5: Develop an IPT charger connection policy	✓

4. Details of the work carried out

DNOs did not understand the power requirement for connecting the various devices required to run a fleet of electric buses and in addition to this there may be diversity, peak current, flicker properties and harmonic contribution to take into account as well.

The aim of the overall project was to increase DNO understanding of the impact of inductive charging of electric buses on the distribution network. This was done through the monitoring and recording of data from electric buses operating on a route in Milton Keynes.

The project aimed to facilitate connections of inductive power transfer devices by connecting a number to the distribution network through innovative ways and monitoring their effect on the adjacent electrical system.

This project sought to facilitate the decarbonisation of the public transport system by determining the infrastructure requirements for inductive power transfer (IPT) chargers and trial new techniques of connecting these devices to the distribution system. Stored battery energy on the buses was supplemented by opportunistic wireless charging around the route and the application of charge deferral to alleviate network constraints.

The location and route chosen was Milton Keynes and the Route 7 between Wolverton and Bletchley. This is shown below in Figure 1.

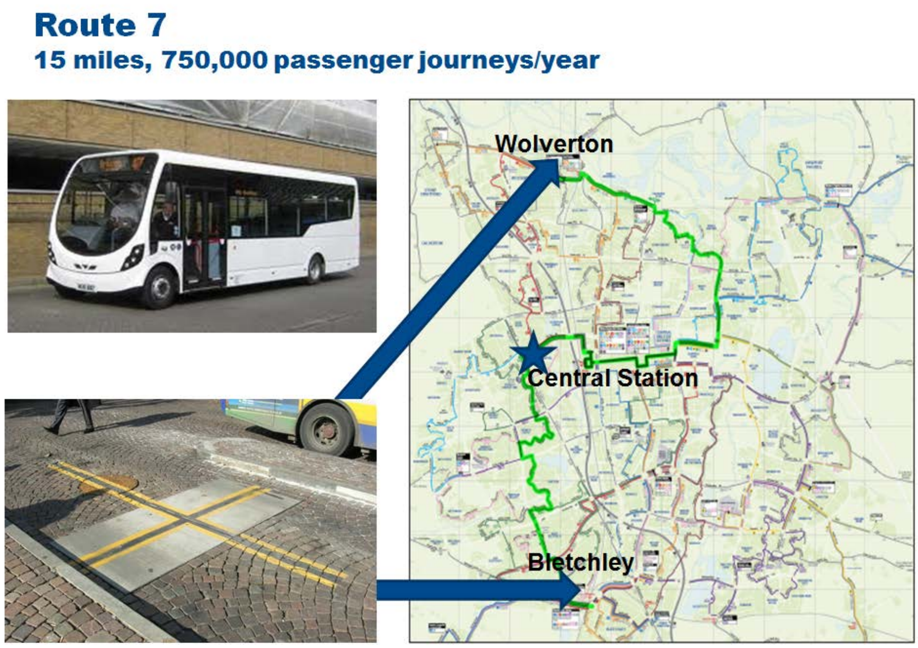

Fig 1: Route of electric bus trial (From pre-installation proposal)

The trial consisted of 8 vehicles through a principally urban route through Milton Keynes. Cable fed charging was provided overnight and inductive bus stop charging throughout the route.

A capacity of 120kVA was required to deliver sufficient charge to the bus within the short window of time it was waiting at a bus-stop. A linear load of this size should be able to be supplied by the low voltage system in most cases without thermal ratings being exceeded, however the non-linear equipment used in the IPT system was thought likely to cause high levels of harmonic voltage distortion. Engineering Recommendation G5/4 sets the planning levels for harmonic voltage distortion to be used in the process for the connection of non-linear equipment and LV equipment creating disturbance levels outside of this would need to be connected at HV, increasing the cost and acting as barrier to uptake.

Electric vehicle infrastructure is currently designed to run unconstrained so can be used at any time and could add to demand peaks, triggering reinforcement. Demonstrating the ability of the existing networks “off-peak capacity” to be used to charge electric vehicles through various techniques could potentially alleviate this issue.

WPD investigated and compared innovative techniques for connecting the IPT chargers to the grid without conventional HV reinforcement. Harmonic disturbance on the adjacent network was monitored and controlled where possible. Opportunities for deferment of electric bus charging at times of network stress were investigated and how active management could enable the uptake of this type of infrastructure.

Traditional load on the LV network tends to drop off during the evening and overnight, which would free up capacity to deliver charge to electric vehicles without triggering upstream reinforcement. The delivery of this charge would need to be managed in order for the network to remain within thermal and voltage limits. Using technology, the level of charge can be managed and prioritised according to the anticipated charging window of the vehicle, which will allow more vehicles to be charged simultaneously at the same location.

WPD worked with the project consortium to complete both pre and post installation testing of the electrical disturbance of the devices, as well as evaluating the results and investigating various methods of mitigation.

The project had three distinct phases, all waterfall in approach. This was essential as each phase required key outputs & deliverables to be in place from the proceeding phase before commencement of the next phase/work package. The outline lifecycle is shown below in Figure 2 with phasing and dates.

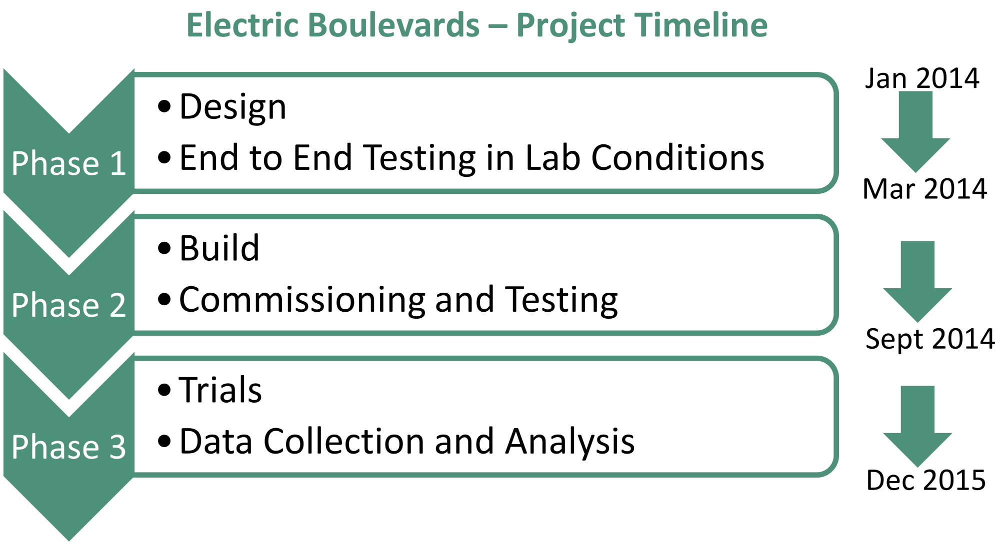

Fig 2: Project Timeline

4.1 Phase 1

Phase 1 of the project involved testing of the IPT charging equipment at the bus manufacturer's facility before being installed on the live distribution network. This involved the following activities:

- Confirmation of round-trip efficiencies compared to manufacturer's figures.
- Indicative charging times for a typical daily cycle.
- End-to-end testing of the system.
- Initial analysis of harmonic output and effects of misalignment.

The results of these tests were such that we could proceed to the next phase. The next phase focused solely on the installation of the equipment in Milton Keynes.

4.2 Phase 2

Phase 2 of the project involved installation and commissioning of the IPT charging equipment at three sites in the Milton Keynes (Wolverton, Milton Keynes Central and Bletchley) area using a variety of innovative connection techniques. These were as follows:

- Connection of the IPT charging equipment on a sole-user LV feed.

- Connection of the IPT charging equipment via a small form factor HV transformer.
- Connection of the IPT charging equipment via a standard HV transformer.
- Installation of advanced HV and LV monitoring at all locations.

The comparison of the different connection methodologies enabled a variety of template approaches to be developed, offering a number of solutions to planners and these can facilitate the connection of the IPT devices without further individual analysis.

4.3 Phase 3

Phase 3 of the project involved understanding the energy duty cycle of the system following the initial results from standard operation. The tests undertaken included:

- Comparison of overnight wired charging versus opportunistic inductive charging
- Evaluating the effects that different route profiles and timetable duties have on energy requirements
- Comparison of overnight wired charging versus opportunistic inductive charging
- Understanding the potential effects that widespread uptake of electric buses might have on the UK electrical network

As part of the delivery Transport Research Laboratory (TRL) were asked to complete 6 reports as follows:

- Evaluation of ITS data for prediction of power demand (Task 1)
- Modelling of power and energy demand from vehicles and chargers (Task 2)
- Analysis of results after 1 month of operation and refinement of models (Task 4)
- Analysis of results after 1 year of operation and refinement of models (Task 5)
- Analysis and Reporting of Outputs (Task 6)
- Modelling of uptake and future power demands (Task 7)

These reports are contained as an Appendix and the findings are summarised within this report. The work was structured so that data would come on line and TRL would do an initial analysis (Task 4) and then do a final analysis (Task 5). The other reports support the work including Task 7 which models the implications of a wider roll out of these buses and the supporting devices on demand.

During the final phase the final results were also collated and analysed and the final reports from TRL were produced and approved by WPD. These reports are provided as a number of appendices.

5. The outcomes of the Project

The detailed commentary of the outcomes of the project is explained below with reference to the relevant Appendix. We also detail some conclusions as well that we feel can be taken forward from the project.

The project showed that although operation of electric buses in Milton Keynes required high power charging from the IPT chargers of 120kW (134kVa at the distribution network connection point), it was feasible to implement this type of charging infrastructure without substantial disturbances for the DNO if bespoke filtering was facilitated to minimise voltage and current disruptions. However, the project also identified a number of potential challenges that should be taken into consideration if larger scale deployment of such WPT or similar conductive charging infrastructure is to be undertaken in the UK. These are summarised below .

There were a number of key outcomes from the project as follows:

- HV reinforcement is not always needed and our templates provide DNOs with a tool to help with planning for this.
- IPTs can be connected to the LV network in certain circumstances (e.g. where the network impedance permits connection).
- By connecting to the LV, the cost of full IPT adoption of electric buses would be reduced by in excess of £43.9m.
- The impact on end customers whilst the electrification of the bus network is undertaken could be substantial as the works required are not insignificant.
- The PM7000 units used for power quality analysis recorded detailed information for analysis to be carried out.
- We already have the correct processes to assess disturbance.

5.1 Apparent Power Demand

Although the average apparent power required by the WPT chargers was 134kVA, much higher power demand was also observed with a maximum continues power demand of 155kVA and instantaneous spikes of up to 178kVA. In isolation, these may not present much of an issue but if a large number of chargers are connected to the same transformer and demonstrate similar behaviour then this could have an adverse effect on transformer lifetime. Furthermore, if significant increases in WPT electric buses and chargers are anticipated, then their installation and utilisation should be planned carefully. Large bus stations could host up to 20 charging bays, resulting in power demand of 2.7MVA.

The mean, minimum and maximum apparent power values were also studied to one-second detail for certain anomalies. The anomalies were determined by analysing any data values that do not fit in with the general pattern. These anomalies were generally detected in the graphs and by filtering the data set for minimum or maximum values.

More information is provided on this within Task 6: Analysis and Reporting of Outputs.

5.2 Power Factor

Power factor of the IPT chargers used in Milton Keynes was found to be above 0.95 when the chargers were supplying power to vehicles. However, during idling and cooling system operation, the power factor was below 0.7. If a large number of chargers are connected to the same DNO connection and operate at low power factor at the same time, this could lead to higher than allowable disturbances. This is particularly likely to have a greater effect on low utilised chargers that experience low power factor for a greater proportion of the time. More information is provided on this within Task 6: Analysis and Reporting of Outputs.

5.3 Energy Consumption

The WPT chargers were found to have a constant background power draw of between 3kVA and 15kVA. This would result in energy consumption by these units even when buses are not being charged comparable to a regular EV plug-in charger charging an EV but at a much lower power level. For bill payers this would result in higher energy consumption and costs for operating such chargers than may have been anticipated based on bus energy consumption. More information is provided on this within Task 6: Analysis and Reporting of Outputs.

5.4 Voltage Harmonics

The predicted voltage harmonic Vhp (5.15%) and 5th harmonics (4.69%) were found to be higher than the requirement stated in ENAG5/4 of 5% and 4.69% respectively, exceeding the requirements for low voltage connections. The first 50 harmonic current values were used to calculate the voltage harmonics based on ENA G5/4 requirements document, as can be seen in Figure 3 below. The predicted voltage harmonic (Vhp) when modelled with a LV fault level of 10MVA is 3.85%; this is below the 5% requirement.

Therefore, DNO's must undertake further assessments depending on existing background harmonics and decide whether to allow the system to connect to the network or request the necessary modifications to be made to the equipment in order to take the harmonics below the required limits.

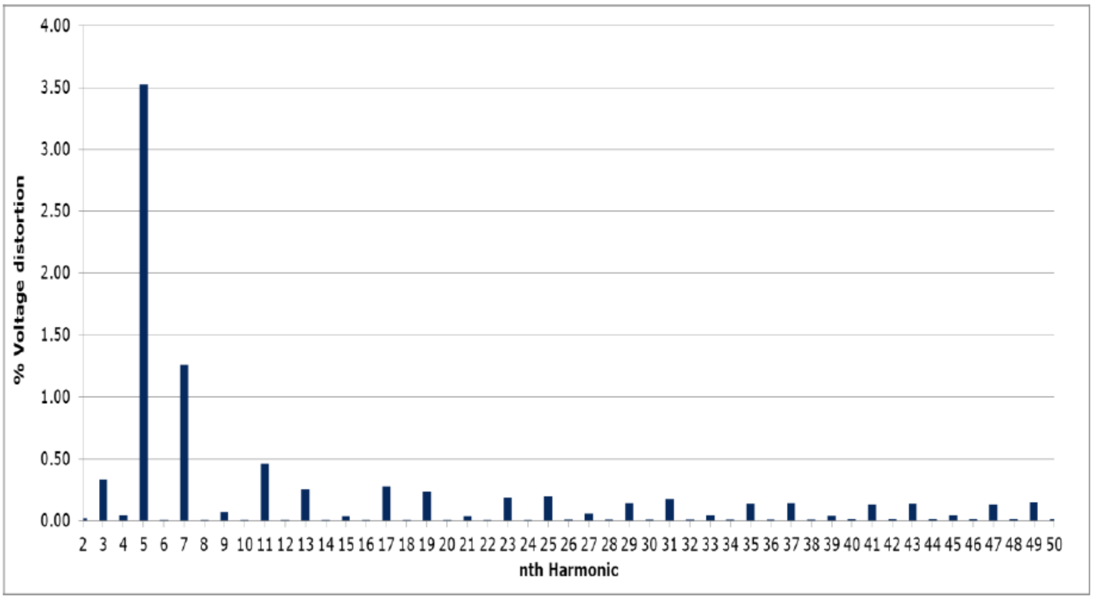

Fig 3: First 50 voltage harmonics

More information on harmonics is provided within Report 6: Analysis and Reporting of Outputs.

5.5 Current

The three phases of the input current and the neutral current were analysed separately. An example of the most frequent mean and maximum values are shown for Bletchley in Figure 3a. The maximum values recorded are due to fluctuations in the current flow, mainly at the points when a charging cycle started or ended. This is the case shown in Figure 3b for the phase A current at Bletchley.

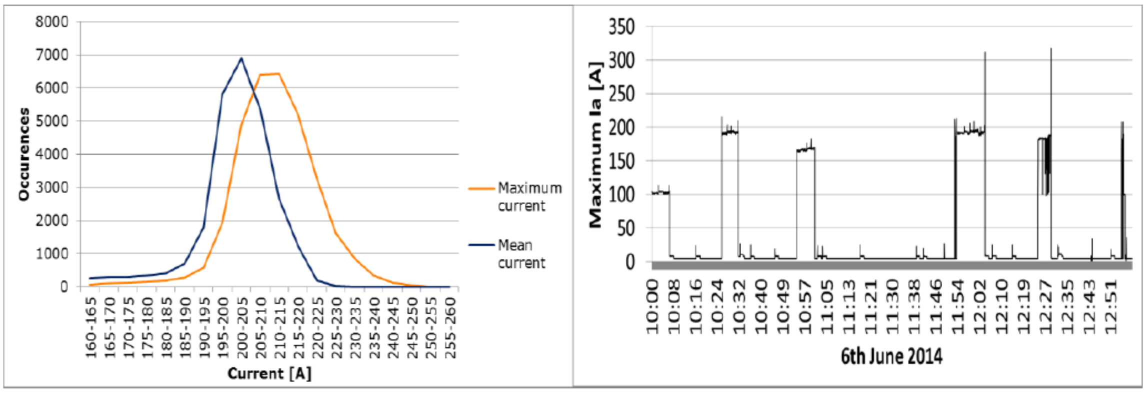

Figure 3a: Bletchley, (a) mean and maximum current occurrences and (b) three hours of the current pattern of phase A

5.6 Data Collection Throughout the Trial

The data from the monitoring units was collected over the course of the year. During that period TRL produced two reports Tasks 4 and 5 - detailing the results after one month and one year. The results of the data collection then fed into the models for informing Task 7. In that task we were seeking to understand the wider effects of electric buses and therefore would suggest that those with an interest in the detail read this report.

In summary, it is clear that whilst there is an impact on total demand across the UK it is not sufficient we believe to impact on the overall integrity of the system whereby widescale reinforcement would be needed.

5.7 Conclusions

Our conclusions from this study are shown in Table 1 below. We feel that there is some potential for follow on work in the future, but the production of a template for planning purposes, coupled with the detailed analysis is sufficient information for now:

Conclusion	Next Steps
The trials proved that the use of the IPT chargers can be integrated readily into the existing network.	The outputs of the trials will form a template that will be integrated into our planning tools. This template will be provided to other DNOs for their use.
The WPT chargers were found to have a constant background power draw of between 3kVA and 15kVA. This would result in energy consumption by these units even when buses are not being charged, comparable to a regular EV plug-in charger charging an EV but at much lower power level. For bill payers this would result in higher energy consumption and costs for operating such chargers than may have been anticipated based on bus energy consumption	It must be assumed that the chargers import a certain minimum demand off the network, over and above the additional energy required to power the electric buses over their daily route mileage.

Overall the trials proved that whilst there is the potential for the wider network to be impacted by Electric Buses, it appears that there is no immediate concern about widespread reinforcement. There are some additional matters for consideration but we do not believe them to be barriers to wide scale roll out.	The template produced will enable local analysis to be done to the required level and ensure that connections can be provided in an appropriate form to allow the take up of electric buses.

Table 1: Conclusions and Next Steps

6. Performance compared to the original Project aims, objectives and success criteria

Below we detail each of the measurement criteria and objectives for Electric Boulevards and provide commentary against each. This has been a very successful project providing insight and data that has been invaluable in creating a template for future IPT connections. This template can be used across the industry for the requirement of connecting IPT charging devices to network and as such represents a good result for the industry.

Whilst the results and findings cannot be implemented now it does provide a template for all DNO's as and when the take up of Electric Buses comes to fruition. It is encouraging to WPD that the impact on the network is broadly manageable and does not appear to indicate a large programme of work to reinforce the network across the board.

Criteria/Objective	Commentary	Overall Status
Objective 1: Infrastructure will be installed to provide connection to three IPT chargers in the Milton Keynes area using a number of different arrangements.	Three IPT chargers were successfully installed in the Milton Keynes area at Bletchley Bus Depot, Church Street Wolverton and Elder Gate, Central Milton Keynes. Each charger was connected via a different arrangement: LV connection to an existing network, Small form factor Padmount HV transformer and Conventional HV substation respectively.	✓
Objective 2: HV and LV monitoring will be installed before and after IPT charger commissioning in order to retrieve background harmonic levels.	Monitoring was installed on the distribution network in key locations to record the pre- and post-operation disturbances.	✓
Success Criteria 1: Install HV and LV monitoring devices on the adjacent network	Comprehensive monitoring was installed prior to the installations and continued for over 12 months of operation and this enabled the corresponding change in network usage to be analysed.	✓
Success Criteria 2: Conduct preliminary lab testing of the IPT charger	The third IPT charger was tested at WrightBus facilities in Ballymena for integration purposes prior to being deployed at the Central Milton Keynes location.	✓
Success Criteria 3: Connect IPT chargers to the network using innovative techniques	A number of different connection methods were trialled and analysed for their varying effects on the network. These connection methods had different physical size and space requirements to cater for a wide	✓

	variety of installations.	
Success Criteria 4: Demonstrate charge deferral based upon network constraints	The different IPT charger locations demonstrated that each individual charger has a load characteristic based upon the number of bus routes and frequency of journeys passing through the location. This data enabled the requirements for connection to be refined and reduce the potential reinforcement requirements for the installations.	✓
Success Criteria 5: Develop an IPT charger connection policy	This project successfully proved that existing LV networks can accommodate the 120kVA IPT chargers as long as the network impedance is sufficiently low. Methodologies for analysing the connection have been developed so that the installations can be replicated throughout the UK.	✓

7. Required modifications to the planned approach during the course of the project

The approach throughout the project was waterfall with each phase, as detailed within Section 3 delivering key elements before transitioning to the next phase.

During the course of the project there was a revision to one of the success criteria to exclude:

"6. Ability to constrain and prioritise charging of multiple EVs based on total load and individual requirements."

This criterion was removed due to the potential impact on the electric bus operation if the physical implementation of the smart charging system was to fail. Due to the charging requirements of the bus operation being an order of magnitude greater than the capacity of the existing connection, the reinforcement of the wired charging connection was fully funded by the customer in line with WPDs charging methodology. This meant that there was no reinforcement deferral in this instance and the extra risk placed on the customer using the smart charging scheme would have not been balanced by any direct benefit.

A cost reduction of £20k was realised by removing the smart charging requirements and no other changes were made to the approach throughout the duration of the project.

8. Significant variance in expected costs and benefits

Below we detail the original budgeted costs for the project and actuals. Costs were reduced due to having to remove one of the objectives as detailed within Section 6.

Category	Budget (£)	Actual (£)	Variance (%)
Project Management	70,000	38,839	-44.5
Equipment	215,000	207,371	-3.5
Installation	205,000	231,512	12.9
Analysis	115,000	115,000	0.0
Total	**605,000**	**580,192.22**	**-4.1**

Table 3: Project Budget and Actual figures

Significant costs savings were realised by using internal staff for the overarching management of the project, rather than using external project management resources. The represented a large variance in spending, resulting in an underspend of over £30k.

The costs associated with the installation of the inductive chargers was also much more expensive than anticipated, due to a large amount of unknown variables with excavating such a large pit within the highway. Whilst the distribution related installation costs were more predictable, the contingency related to the civil installation costs needs to be larger to factor in drainage diversion, additional reinstatement provisions and any knock-on impacts on equipment, time and resources due to project overruns.

8.1 Updated Business Case

The original business case for this project was relatively simple because the project was seeking to provide information on something that WPD knew little or nothing about. We believed that we could approach the assessment of the impact of Electric buses in two ways:

- Undertake a project to investigate the impacts of electric buses or;
- Take the view that all costs associated with the uptake would be passed through for connection and reinforcement on an as requested basis (the “do nothing” approach).

We did not feel that there was another option and so the risk we saw with the do nothing approach was that the cost of reinforcement could undermine the business case for the take up of these vehicles, but until such analysis had been undertaken the lack of information may undermine the potential benefits to the economy and the achievement of emissions reductions.

For a relatively short, focussed piece of work the results had the potential to be extremely powerful and ultimately provide a template for all DNOs where and when the take up of these vehicles started to become more meaningful.

In determining that it would be better to do something positive it was decided to undertake the Electric Boulevards project with the intention of undertaking some research around the impact on the network of increased uptake in terms of total load impact- as if there are specific costs associated with reinforcement it would then be a relatively simple exercise to determine the total cost impact to DNOs across the UK from a set of agreed industry scenario’s. From this it is a further evaluation of what the impact would then be on the bus operators.

As mentioned previously WPD contracted with the Transport Research Laboratory to undertake the various studies associated with Electric Boulevards. These deliverables were as follows:

- Evaluation of ITS data for prediction of power demand (Task 1).
- Modelling of power and energy demand from vehicles and chargers (Task 2).
- Analysis of results after 1 month of operation and refinement of models (Task 4).
- Analysis of results after 1 year of operation and refinement of models (Task 5).
- Analysis and Reporting of Outputs (Task 6).
- Modelling of uptake and future power demands (Task 7).

These reports provide the foundation for this closedown report.

9. Lessons learnt for future Projects

Electric Boulevards has provided WPD with a range of lessons learnt and information, many of which form part of the "solution". Below we summarise the main project learning points that pertain to business as usual or running innovation projects as well as the detailed technical learning and dissemination aspects of the project:

9.1 Project Learning

Learning Point	Progress
A clear statement of work is crucial, especially when undertaking the wide range of analysis that this project required.	This has been fed back into our purchasing team to ensure that on future projects there is as much clarity up front as possible.
Dialogue is critical when the project covers as many aspects as this one did. Ensuring all parties are aligned throughout is key to success.	A project kick off a quick run through with the partners together is a useful way to ensure who is doing what, enabling relationships to be built based on a common understanding.
Partners with clear objectives from the project helps with maintaining focus on deliverables.	This is being fed back into our Innovation project assessment process and lessons learnt.

Table 4: Key WPD Project learning

Whilst some of these may be simplistic, we felt that it was important to reflect on the project as a whole and where we could have done better or where by chance something worked particularly well.

9.2 Technical Learning

In addition the key technical learnings from the project are;

Learning Point	Commentary
The 120kVA chargers can be accommodated on the existing LV network if the impedance is sufficiently low.	This forms part of the planning template that we have developed as part of the project.

Padmount substations and conventional HV substations provide other options for multiple installations or where the LV network is constrained.	This forms part of the planning template that we have developed as part of the project.
If rolled out across the UK, over 6,500 bus chargers would be required and if connected to the existing LV using this project learning, could save customers in excess of £43.9m.	This forms part of the planning template that we have developed as part of the project.
The power demand from IPT chargers largely occurs between 7am and 12am. This indicates that the electrical distribution network is expected to supply power on demand between 07:00 and 00:00 hours. The power demand for plugin charger rises from around 19:00, peaks between 00:00 and 01:00, and starts to drop until it reaches zero, by around 05:00.	This forms part of the planning template that we have developed as part of the project.
The results showed that after 20:00 the total power demand increases rather than decreasing, as the number of operational buses begins to reduce and some buses start charging from the plugin chargers at the bus garage. This somewhat counter-intuitive as the assumption may be that as the number of buses using the IPT chargers reduces, the overall demand also reduces. However, the results show that although the number of IPT charge events reduces after 17:00 hours; charge time for each IPT charge event increases. Therefore, the power demand from the IPT chargers after 17:00 hours remains at the same level as during the day. The additional demand from the overnight plug-in chargers is then added to the existing WPT demand, which results in higher power demand from the distribution network overall.	This forms part of the planning template that we have developed as part of the project.

Table 7: Key Project Learning

These learning points have been extremely valuable to WPD, the premise of the project was establishing what, if any, the impact would be of a substantial take up of electric buses. These findings have enabled us firstly to determine that major reinforcement is not always necessary which is very positive news, but also that we now have a usable template for all DNO's to help with the planning of these charging devices on the network.

Challenges still exist of course, we do believe that there is the potential for widespread disruption to the highways whilst the works required are carried out and we feel that this needs to be carefully considered.

9.3 Dissemination

Electric Boulevards held a number of events & engagements during the project as detailed below. Given the nature of the project, we undertook a considerable amount of dissemination about this project because we felt that it's premise and outputs would be of keen interest to a variety of stakeholders.

- Presentation at MK Energy Group – 08.05.2013
- Presentation at EVE Meeting, Geneva – June 2013
- Presentation at LCNF 2013 – 14.11.2013
- Article in Thinking Cities– November 2013
- Article in Thinking Highways – April 2014
- Presentation at IET Transport Sector: Electric Vehicles and their Appetite for Power – 19.06.2014
- Presentation at LCNI 2014 – 21.10.2014
- Article in IET Magazine – Wireless Power Transfer for Electric Vehicles – May 2015
- Presentation at MASP Project Consortium – 14.05.2015
- Presentation at Thinking Cities – 03.06.2015
- Article in Energy Engineering – September 2015
- Presentation at LCNI 2015 – 27.11.2015

9.4 Key Project Learning Documents

There are a number of presentations that have been used to present our findings throughout the duration of the project. These are as follows:

WPD Ben Godfrey - Electric Boulevards.p

Ben Godfrey - Electric Boulevards 1!

Ben Godfrey - the Electric Vehicles and t

In addition we produced a corporate leaflet to be used at Stakeholder events and industry events to socialise the project and its objectives.

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10. Planned implementation

During the planning, installation, operation and analysis of the inductive electric bus chargers, it became clear that there would likely be three situations where the connection of the equipment would be likely. These three situations are reflected in the three template approaches below:

Single IPT charger on existing LV:

- Existing HV network must have available capacity
- Existing transformer must be thermally capable to deliver 134kVA per charger
- Transformer must be 800kVA or above to provide a sufficiently low LV impedance
- LV cable must be a clean feed 300CNE of less than 30 metres

- QAS cost range £1,711 to £2,405

Single IPT charger on HV:

- Existing HV network must have available capacity
- Single IPT charger can be accommodated via a 200kVA ANSI Padmount
- No further demand customers to be connected to Padmount LV network
- No interconnection possible with existing LV network
- QAS cost range £8,478 to £19,860

Multiple IPT chargers on HV:

- Existing HV network must have available capacity
- 800kVA transformer or above to be used
- LV cable must be a clean feed 300CNE of less than 30 metres
- QAS cost range £19,204 to £31,725

The assessment of available HV network capacity can also be varied from conventional planning processes using the project learning:

Wired Charging at Depot:

- No diversity to be used as all charging units expected to operate concurrently
- Maximum feeder load to be analysed between 10pm to 7am only

Wireless Charging on Street:

- No diversity to be used as all charging units expected to operate concurrently
- Maximum feeder load to be analysed between 6am to 12am only

11. Facilitate Replication

The system deployed in Milton Keynes comprised of four main components:

- The Electric Bus (including on-board battery storage).
- The IPT charger (Primary and secondary coils).
- The LV electricity distribution network.
- The HV electricity distribution network.

In order to understand the impact of the IPT charger on the distribution network and to be able to identify the reasons behind any disturbances on the network, the behaviour of all four components was recorded and analysed. The intention of the project was also to look beyond possible issues and investigate what opportunities there were for improving the quality of the network that may arise from implementing inductive charging systems. This is especially important should the take up of these buses increase.

The diagram below, Figure 4, illustrates the main components of the system and the flows of data and electricity between each component.

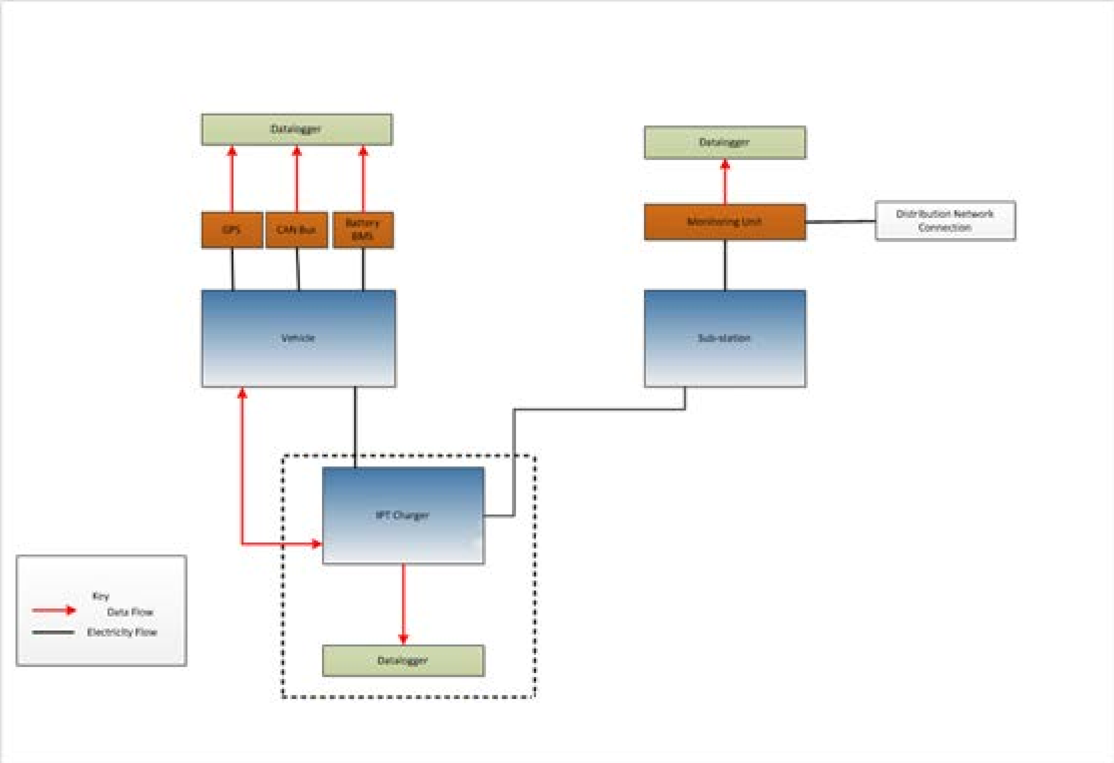

Fig 4: Main components of the Electric Boulevards solution

11.1 Monitoring the Network

Of the four main system components listed above, the LV distribution network system was thought to face the greatest challenge during the implementation of the Inductive charging, due to the existing electrical system design of the sub-stations and low voltage feeders, and the dependence of other electricity users on this equipment. Therefore, the objective was to minimise any adverse impacts on the hardware and any unwanted disturbances on the network that could impact the service provided to other customers connected to the same low voltage infrastructure in the area.

In terms of managing and mitigating the impacts on the network, there were two main issues that need to be addressed:

- Peak power demand.
- Harmonic disturbances on the network influencing power quality.

The approach adopted was to capture sufficient information about the state of the distribution network within the area, the state of charge (SOC) of the on-board battery in the vehicle and the stationary battery to understand what would be the best way to charge the vehicle in order to minimise any adverse impacts on the network. This was a considerable undertaking for a small project and as such having a small discrete team working through the objectives, focussing on the end result proved invaluable.

Additional demand and use of new power electronics systems, such as the inductive charger, could cause disturbance on the network. In order to understand the state of the network during charging, data was monitored and recorded using a power quality analyser (Outram PM7000).

The following measurements (Table 5) were planned to be recorded at low and high voltage points in order to model the impact of the charging infrastructure on distribution network. These are in-line with the measurements taken by SSE in their LCNF funded project Demonstrating the Benefits of Monitoring LV Networks with embedded PV Panels and EV Charging Point (Evans, 2013). It should be noted that whilst we have detailed the data capture requirements for the project, it is not necessarily true that this is a business as usual requirement, but we felt that for purposes of this report it was useful background information.

Required Data	Size (byte)
Voltage (V)	2
Current (A)	2
Apparent power (VA)	2
Real Power (W)	2
Reactive Power (VAr)	2
Power Factor	2
Harmonic Distortion	2
Individual Harmonics (first 100)	Up to 200 bytes
Line Frequency (Hz)	2
Phase difference between phases	2
Time stamp	2
ID	2

Table 5: Planned measurements

Similarly requirements for data capture were needed for the stationary battery storage as follows:

Required Data	Size (byte)
Battery operating status (operational/ fault/ disconnect	1
Battery state (fast /slow charge / discharge)	1
Battery SOC (% (out of total available capacity – i.e. taking into account State of Health)	1
Ambient temperature (°C)	1
Battery pack temp (°C, (Average temp over all modules)	1
Battery Max Energy (kWh)	2
Battery state of health (%, available capacity / total max capacity)- only required daily	1
Battery pack Voltage (Volts)	2
Battery pack current (Amps)	2
Battery Max charge current (Amps)	2
Battery Max discharge current (Amps)	2
Module Voltage (average, max and min) – per module, (Volts)	6
Module Current, charge and discharge (average, max and min) – per module, (Amps)	12
Average module temp – per module (°C)	1
Max module temp – for each module (°C)	1
Battery pack internal resistance - sum of modules (milliohm)	2
Battery module internal resistance -sum of cells in module (milliohm)	2
Battery ID (Unique number)	1
Timestamp (Time and date – ideally GPS synchronised but not essential)	1

Table 6: Data collected at Stationary Battery Storage site

Data was collected over an 18 month period, which covered a duration pre-installation network activity, data collected during the introduction of the buses and a further period of monitoring during which all the buses were operational.

The data was collected from the WPD metering cubicles connected to the IPT charger as shown in Figure 5 for the Bletchley installation.

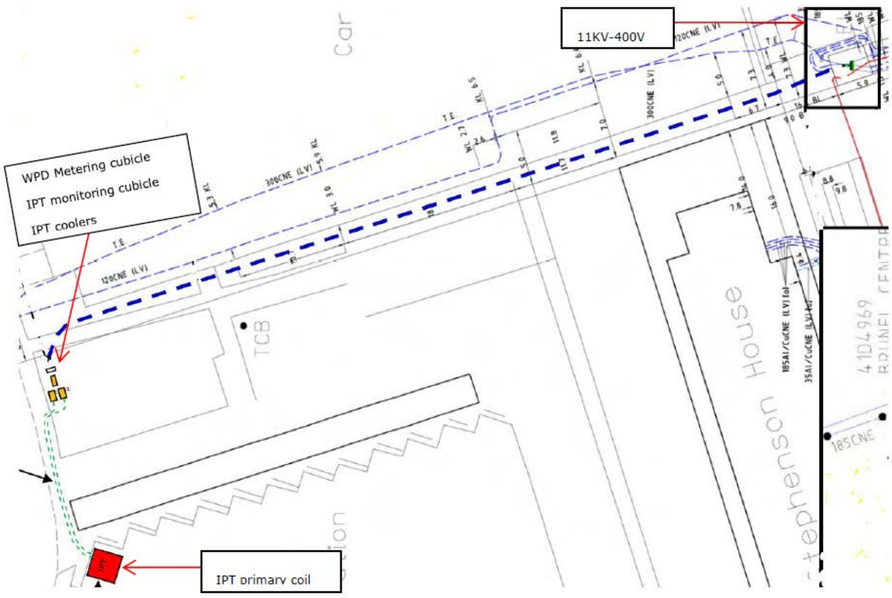

Fig 5: Bletchley Installation Diagram

11.2 IPT Charger

The pictures below show the installation of the IPT charger within Milton Keynes. It can be seen that the equipment is of considerable scale and this has been highlighted in the key learning. The potential for significant highway disruption if the buses become the norm is considerable and this should we feel be borne in mind by stakeholders involved.

Fig 6 : Bletchley Installation Progress

Fig7: Bletchley Station Final IPT installation

12. Points of Contact

Further details on replicating the project can be made available from the following points of contact:

Future Networks Team
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Appendices

Below are the detailed reports from TRL that form the basis of this closedown report and the projects conclusions:

Task 1 Evaluation of ITS data for predictio

Task 2 Modelling of power and energy de

Task 4 Analysis of results after 1 mth of

Task 5 Analysis of results after 1 year o

Task 6 Analysis and Reporting of Outputs

Task 7 Modelling of uptake and future po