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Title:

Potential Demand Side Management Interactions Among Electric Vehicles, Electric Heat Pumps and Photovoltaics

Synopsis: This is a dissertation project that evaluates low carbon technologies in the context of demand-side management (DSM), by means of OpenDSS software.

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Prepared For: School of Electrical and Electronic Engineering
The University of Manchester
Sackville Street, M13 9PL, UK

Prepared By: Hasan GUNDUZ
#9099123

Revised By: Dr Luis (Nando) Ochoa
The University of Manchester
Sackville Street, Manchester M13 9PL, UK

Contacts: Dr Luis (Nando) Ochoa
+44 (0)161 306 4819
luis.ochoa@manchester.ac.uk

Executive Summary

Within the global perspective, in order to build low carbon economy, the deployment of "Go-Green" concepts has been increasing in most of the countries by means of incentives and norms. As a result of increasing low carbon technologies, such as Electric Vehicles (EVs), Photovoltaics (PVs) and Electric Heat Pumps (EHPs) are most likely to bring difficulties and as well as benefits. From this point of view, DNOs and TNOs are already faced with voltage, thermal and capacity issues. To cope with those network problems, implementation of demand side control mechanisms on network has been considered as a solution in recent years.

This project identifies and evaluates behaviour of low carbon technologies on LV network in the context of Demand-side Management (DSM).The simulation is carried out by OpenDSS with Matlab software option. First of all, modelling of load and of micro-generation profiles is taken as a beginning of project. Following that, existing LV network characteristics are applied into the simulation platform by the help of the software with created DSM scenarios. Finally, considering the voltage statuary limits, some implemented DSM scenarios can decrease voltage drop issues on dwellings up to 50%.

INDEX: Demand-side Management, Low Carbon Technologies, Photovoltaics, Electric Vehicles, Electric Heat Pumps

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Abbreviations

ANM	Active Network Management
ASHP	Air Source Heat Pump
COP	Coefficient of Performance
DECC	Department of Energy & Climate Change
DNO	Distribution Network Operator
DR	Demand Response
DSM	Demand Side Management
EHP	Electric Heat Pump
EV	Electric Vehicle
GHGs	Greenhouse Gases
GSHP	Ground Source Heat Pump
LV	Low Voltage
MV	Medium Voltage
PV	Photovoltaic
TNO	Transmission Network Operator

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1 Introduction

1.1 Project Background

The energy industry is going through a revolutionary period. The usage of fossil fuels is losing popularity in developed countries as fossil fuels are non-renewable and environmental pollutants and are running out day by day. Also, many governments are announcing their low carbon energy pathways considering the energy availability, energy security and sustainable development. To illustrate that, government of United Kingdom has a target of 80% greenhouse gases (GHGs) emission reduction in energy sector until 2050 considering 1990 GHG levels [1]. Besides that, electricity demand is increasing quickly. To meet the energy demand, UK government's energy projection shows that, renewable resources will supply more than 30% of electricity generation, 12% of heat generation and 10% of transportation fuels by the end of the 2020 [2]. Thus, one of the main points of UK government on this is that, green technologies can reduce CO_2 emissions if electricity generation is carried out by wind, wave and solar power. These goals demonstrate that decarbonisation technologies, such as domestic solar panels, electric heat pump (EHP) and electric vehicle (EV) will be important components not only in the electricity distribution networks, but also in the sustainability of the earth.

Over the years, traditional electricity generation systems have dominated all energy industry. With growing popularity of renewable energy generation systems, developed countries are trying to reduce their dependency on non-renewable fuels. Although some low carbon technologies are coming with huge uncertainty and questions in deployment, these countries, which have signed Kyoto Protocol for global warming issues, are encouraging their citizens with financial incentives. For example, UK government has committed major incentives for photovoltaics (Feed-in Tariff Scheme) and electrification of heating (Renewable Heat Incentives) [2].

With the integration of low carbon technology placements into electricity distribution and transmission systems, operators are facing problems such as voltage rise-drop, power quality, network capacity and frequency issues [3],[4]. These challenging issues accompanied with electricity network unreliability and inflexibility has created opportunities for research. So as to get rid of aforementioned problems, network reinforcement, active network management (ANM) and last but not least, demand side management (DSM) can be possible solutions. This project is focused on DSM options, which can be implemented by DNOs and end-users.

1.1.1 Project Motivation

Renewable energy resources and energy efficiency are fast becoming key components in energy industry. In this case, the decarbonisation of electricity generation plays a key role to reach legally-binding targets. As stated previously, UK government has been supporting on usage of micro-PVs, EVs and EHPs [2], [5], [6].

In perspective of solar panel's integration, according to UK government statistics, 2.5 GW of solar panel and PVs have been integrated on almost 500.000 homes [7]. In the view of such information, medium voltage (MV) and particularly low voltage (LV) networks can be influenced dramatically. Normally, these DNOs have met electricity demand with traditional methods, which are almost uncontrollable and unmonitored. Until now, distribution network operators (DNOs) have been facing voltage rise, power capacity issues and reverse power flow, which are undesirable.

In addition to this, huge numbers of EHP and EVs have been introduced into the market which adds a strain to the power grid in UK. EHP and EV can be eco-friendly and in general, efficient devices considering their cutting edge technologies where the energy is obtained from renewable resources. Installation of EHPs has increased over the period of 2006-2011, from 2000 to 21000 per year [5]. Also, the proportion of EVs deployment into UK car market has also increased significantly.

To reduce GHG emissions, UK government has given huge importance to the electrification of heating and transport. Although growth of renewables usage is bringing advantages to reach those targets, DNOs are faced with network problems on deployment of EHPs and EVs, like PVs.

Keeping these issues in mind, DSM provides an option for the customers to drop electricity consumption at specific time periods, instead of generating more power. DSM can be one of the possible solutions for DNOs and the LV and MV grids. Not only crucial effects of peak demand, but also financial impacts of electricity price can direct stakeholders to DSM options.

In this work, integration of low carbon technologies with the system will emphasise the concept of DSM. In the second chapter, green technologies and DR possible options and their related concepts will be discussed and evaluated. In the third chapter, explanation how green technologies can be implemented on the current LV network and procedures of creating demand profiles will be examined. Following that chapter, part 4 will demonstrate low carbon devices' influence on the system and implement DSM solutions. Finally, project results will be analysed and project future work will be highlighted. This project will assess to what extent, deployment of low carbon devices could go beyond current usage standards considering their impacts.

1.2 Objectives

- To introduce relevant literature review
- To understand relevant low carbon technology concepts
- To model PV profiles from CREST Tool according to Landgate settlement
- To understand behaviour of Domestic Load Profiles (summer, winter, weekday or weekend)
- To investigate the influence of various penetration levels of PV
- To investigate the impact of various penetrations levels of EV
- To understand the behaviour of LV networks by using low carbon technologies.
- To understand potential Demand-Side Management (DSM) interactions among Electric Vehicles, Electric Heat Pumps and Photovoltaic (PV) in the context of maximizing PV generation and minimizing peak demand.
- To model time-series profiles of EVs and Domestic base load.
- To simulate time-series profile models of EVs, domestic EHPs and small-scale PVs.
- The low voltage grid will be implemented by the help of a visual basic (VBA) software and MATLAB.
- To investigate the impact of various penetrations of EHP
- To suggest optimum DSM solutions within the context of maximizing power generation and decreasing peak demand.
- Learn how to implement techniques into the grid that could be used by relating engineers, project managers and Distribution Network Operators (DNOs).

2 Literature Review

In this section, relevant literature review has been presented with following subtopics:

- Demand side management (DSM)
  - The history and definition of DSM
  - The necessities of DSM for energy system
  - Advantages and Challenges of DSM
  - Types of Demand Response
  - Relevant examples of DSM in the trial fields
  - Relevant case studies
- Photovoltaics (PVs)
  - History and importance of PVs in the energy system
  - Deployment of PVs and its status in the UK
  - Relevant case studies
- Electric Vehicles (EVs)
  - Brief introduction to EVs and underline their significance for energy system
  - Deployment of EVs and their status in the UK
  - Relevant case studies
- Electric Heat Pumps (EHPs)
  - Brief history of EHPs and highlighting their importance
  - Deployment of EHP and their situation in the UK
  - Relevant case studies

2.1 Demand Side Management

Demand side management (DSM), also called as Demand Response (DR) in some cases, is modifying electricity usage of end-users profiles in specific time periods, especially peak or super-peak demand periods. The integration of DSM concepts came up in 1960s and 1970s in Europe and New Zealand [8]. After DR's initial implementation in energy system, significant involvement of DR started in late 1980s in USA [9]. Basically, it occurred as a result of some energy crises, which was due to wrong planning of resources utilization. From that time, USA's government encouraged people with incentives. Hence, DSM concepts provided huge savings[9]. Also due to California Energy Crisis in 2000 - 2001, people and operators faced a lot of blackouts, which was an undesirable situation [10]. It was blamed on a lot of reason like immeasurable increase of electricity consumptions and weak deregulation policies [11]. Following the crisis, specialists understood the importance of DR and how it can be used to avoid such situations. From then on, the popularity of DSM has been rising significantly. Nowadays, along with increasing global warming, energy efficiency projections and smart technologies, DSM's involvement into energy network is improving day by day in most of the countries.

To put DR in a different perspective, in locations where there are more generation, DR is controlling customer's demand using an efficient way. From the peak demand point of view, DSM helps to reduce stress on the grid by the help of the peak shifting, shaving and valley filling methods. DSM can also maximize flexibility between demand and supply. These are advantageous for the DNOs and TNOs. On the other hand, from customers' point of view, DR can reduce energy cost and is likely to provide efficient usage of electricity in smart grid concept. Considering both customer and operator sides, "Blackout" can be essential problem. DSM can play a key role to avoid such problems.

There are great deal of DSM concepts exist in electricity systems. DR can be divided into the three categories according to DNOs which are direct-load, local-load and operator-load control mechanisms [12]. Firstly, direct-load control is likely that customers' energy consumption can be kept under control by one or two-way communication systems. These mechanism brings advantages to DNOs for balancing on load and generation. Secondly, local-load control mechanism can provide self-adjustment of peak demand [12]. In this method, customer's awareness on peak time demand reduction plays a key role. In this case, the customers' comfort level is taken into consideration. Thirdly, operator-load control mechanism where DNOs can send electricity price signals to end-users, according to load's rush-hours (Dynamic pricing) [12]. This method relies on communication skills of energy meters and smart appliances' capabilities.

Although there are great deal of benefits for customers and operators, DSM concepts brings some challenges to energy sector. Those difficulties can be as follows:

- ❖ The lack of intelligent communication substructures (one or two-way channels).
- ❖ In perspective of traditional energy industry, customer-side solutions are not preferable, competitive and need more financial incentives. With those incentives, people can be encouraged to adopt DR solutions.
- ❖ Comparing traditional energy system's concepts, DR solutions can maximise the system's complexity. This complexity should be solved with deployment of smart infrastructures.
- ❖ The shortage of comprehension of DSM concepts' advantages in the energy industry.

As pointed out previously, there is great deal of DSM concepts implemented in the energy industry. In order to implement DR solutions, basically, understanding of customer's behaviour on loads is likely to play a significant role [13].

Starting from the point of customer's behaviour role, households have been analysed from variety of DSM studies. One of them is integrating of heat pumps, EVs, PVs, base domestic appliances (refrigerators, washing machines, etc.) and some storage systems into network [14]. In this literature [14], the concept of changing electricity price according to local voltage level is not an equitable approach. The main approach should consider changing end of the feeder users' load flexibility capacities. Low carbon technologies' deployment can be as much as possible theoretically using DSM concept but these green devices can be harmful to network without any smart control mechanisms.

Based on load analysis, in [15], domestic appliances are categorized into 4 groups and it is investigated that group of washing machines can be implemented into demand response concepts. There was an assumption that grid operators can manage washing machine demand with control mechanism at the peak demand times. By means of that method, it was found out that peak demand shaving method can minimize load intensity up to 32% [15]. In some cases, peak demand reduction reached 14% (maximum ratio in this work) [15].

According to [12], it is stated that one of the DSM solutions implemented in UK is called Economy 7 tariffs which is based on domestic heat consumption of end-users. The aim of this tariff program is changing peak demand consumption by the help of the night time heating method. It is related to regulation of on-peak time energy consumption by DNOs.

Another positive example for DR solution in recent years is the financial incentive programs in UK, which might actually be one of the best options. In that DSM program, customers who have large energy consumption are offered incentives to change their electricity utilization behaviour. This programme are managed by operators and 117.000 end-users have endorsed it [16].

In spite of the fact that DSM techniques are likely to have some benefits to all stake holders, in the most of cases, it is mostly in research-development stage (communication plane). When deployment of smart technologies is increased or government pushes its objectives are to move a low-carbon economy, the significance of DSM is more likely to increase.

In this sub-part, DSM techniques are analysed and possible concepts for residential buildings are discussed as much as possible. DR's advantages and challenges are highlighted in the context of traditional energy market borders.

2.2 Photovoltaics (PVs)

Solar power as is known a renewable energy resource. Although utilization of solar power started as early as 1900s for research-development, commercial utilization of photovoltaics (PVs) began 1960s with the development of semi-conductors[17]. In case of UK, deployments of PVs started in 1990s with very little steps, nevertheless, real improvement on deployment of PVs reached late 2009 [18].Nowadays, particularly in developed countries, integration of PV panels has increased significantly. Because of carbon emissions policies and targets, financial encouragement of small-scale PV panels are taken into energy program's consideration (Feed-in Tariff). For example, installed capacity of PVs in UK has reached at 2.4 GW with those incentives, according to 2013 data [7]. With UK's ambitious CO_2 targets, capacity of domestic PVs have to be targeted at 10 GW until 2020 [7]. This amount of PV deployment can bring possible network problems (voltage rise, thermal issues, etc.).

In perspective of DNOs, LV networks are already facing reverse power flows, which is generally undesirable status for traditional power networks. Those flows brings voltage and capacity issues in the system, but impact of these issues are not completely understood. But, as stated previously, voltage rise is certainly problem for distribution network operations considering solar power generations. Therefore, there has been considerably high quantity of literature carrying out on PVs. Nevertheless, there is small amount of trial studies in the context of low voltage networks. Some of them are assessed as follows:

In this literature [19], performed with "Monte Carlo" method that PV integration on grid was implemented with UK's location data and its typical load features which investigated that penetration level of PVs on that specific network (with heavy loads) could reach 40% considering without any voltage issues. This shows us that higher penetration levels can be dangerous for network if there is no reinforcement or voltage control mechanisms.

In literature [20], it describes potential DSM technique with PV systems where it evaluated 1000 end-users' electricity generation and consumption in an economical DR concept. It provided to customers significant amount of savings by means of time of use technique. However, this study lacked on any discussion based on voltage and network issues. DSM profits were shown, but this technique was applied in Istanbul's location. According to solar light potential of location, benefits of DR can be changed. Another case study presented a broader perspective on PV generation with DSM technique [21] where in this article, overloading of network, voltage rise-drop issues were analysed in the context of PV generation. In order to examine effects of PV generations, DSM and storage options were implemented. It was investigated that in high penetration levels of PV, battery systems could be implemented. However, low penetration levels of PV with DR solutions could give better performance than storage options. Considering that study's location (Sweden), DSM is likely to be another option for maximizing PV generation. But, as previously mentioned that DSM depends on customer's behaviour and which location where it is implemented.

In this sub-section, DSM interactions with PVs is assessed briefly and relevant case studies are presented.

2.3 Electric Vehicles (EVs)

As a general knowledge, Electric vehicles (EVs) are driven by electric motors and contains battery systems. Despite the fact that EVs were invented at the end of the 19th century, EVS became popular only after the oil crisis in 1960s and 1970s [22],[23]. Along with increasing global warming and countries climate change targets, deployment of low carbon vehicles has been increasing. For instance, it is expected that EVs will play key roles on low-carbon transportation in UK looking at their ambitious go-green targets. According to [1], 60% of mileage on transport will be met by EVs till 2050. So as to reach the targets, UK government is planning to rise EVs utilizations in transport sector. As stated previously, one of the essential aims of EV's deployment was to reduce the environmental problems caused due to extensive use of fossil fuels for transport purpose. Electric vehicles with exception of hybrid electric vehicles do not emit greenhouse gases (nearly Zero carbon emissions). The use of electric vehicles can be acceptable if electricity generation is coming from renewable energy.

The UK government introduced consumer incentive program in 2011 to encourage people to use EVs [6]. As per the plan, consumers can get subsidies up to £5000 considering EV's performance, reliability and safety features [6]. It shows us that future deployments of EVs will rise to considerably high levels in the UK.

Along with the financial incentives, stake-holders will be supported for trial projects by the government. While development of EVs is increasing significantly in energy sector, penetration level of EVs on networks is expected to be a problem for operators, especially DNOs. For this reason, EVs characteristic behaviours on medium and low voltage networks should be understood before EVs high penetration levels. EVs power demand, charging criteria and customers' behaviours will have to be considered and will be of utmost importance now. Considering these features, EV's case studies are analysed in next part.

2.3.1 Electric Vehicle Case Studies

In the literature of EVs, there are great deals of case studies on analysing EVs status on low and medium voltage levels. It is noteworthy of that in [24], the work focused on low voltage network operation mainly considering customers charging habits, average electricity consumption of end-users and vehicle characteristics. When doing EV trail analysing, two electric cars was examined in low voltage network suburban area for one year on a quarterly basis [24]. In total, eight customers' behaviour was examined. It was examined that energy consumption of selected EVs was around 8-9 kW per day, considering 3.3kW – 6.6 kW of their charging ratio [24] with the peak aggregated demand time observed approximately at 11pm. This field trial describes growth of maximum demand dramatically, which cause huge voltage issues. If high penetration levels of EVs are taken into consideration, DNOs and customers will probably face with voltage issues.

From this point of view, there was also one case study carried out on presence of EV's impacts on network. In this work [25], author tried to investigate feasibility of EV smart charging with DSM concept. The case study mostly focused on direct load control mechanism. There were two different charging scenarios implemented for EVs in [25], one was demand shifting and the other one was considered as a smart control, which was EV owners were divided into some EV charging groups. Both methods succeeded in peak time demand reduction. Also, with EV charging curtailment method, overconsumption of electricity decreased slightly for a portion of peak demand, compared to base scenario.

Those case studies show that deployment of EVs will be problematic in perspective of network operations in the near future. As a result of this, engagement with DSM on network is likely to be a solution model.

2.4 Electric Heat Pumps (EHPs)

The popularity of electric heat pumps (EHPs) has been increasing nowadays. EHPs are heating-cooling devices that use ambient heat of environment and injects that heat to dwellings [5]. Two kinds of EHPs dominates electric heating sector, they are air and ground source heat pumps (ASHP and GSHP respectively). This is not new technology in general; it has been a part of thermal sector for a long time. In order to reach the climate change targets, electrification of heating has become an essential objective for governments. When global targets taking into account, some governments have financial incentive schedules on electrification of heating. In context of EHPs, their running performance is important point. EHPs performance is defined by co-efficient performance factor (COP). COP, seasonal performance, can identify as ratio of EHP's electricity consumption to its generated heat quantity in a same time scale. Considering that UK government has been given warranty on renewable heat incentive (RHI) to people if they have EHPs that has 2.9 or above 2.9 COP value [26]. According to this UK's framework, renewable electric heating is likely to take place in future dwelling plans, already it has started in some regions. According to [27], EHPs can sort out some environmental issues, but it will bring overloading, last but not least infrastructure cost. In particular, distribution systems will face undesirable voltage and flicker issues. In order to cope with those issues, DSM can be a solution. From this point of view, there are some EHP's case studies, following paragraphs examines that studies.

To illustrate network issues resulting from EHPs, the [28] was selected which investigated the effect of large penetration levels of EHPs on voltage, thermal limit and overloading problems. In particular, after implementing 100% penetration level of EHPs, the peak demand of system measured 2.6 times more than the base scenario of the network [28]. So to have a higher quantity EHP deployment on the network there needs to be a smarter solution (DSM) or network reinforcement.

In this [29], DSM solutions on EHPs impacts on network, was considered when thermal energy storage is used and on peak demand period, the devices are turned off for around 3 hours. With this method, peak loading and stress on the line decreased while considering customers comfort level. Not only peak demand, but also total electricity cost declined dramatically. In this case, comfort level was taken into consideration in the study. Scenarios presented positive feedback on EHP's interactions on DSM. However, customer behaviours can change in perspective of comfort level.

In case study [30] dealt with peak demand shifting and price signal scenarios, which are examined in the context of EHP's utilization in residential areas. These scenarios were implemented with smart meter control mechanism. With uncontrolled mechanism of EHPs, traditional network system faced voltage issues as well as huge infrastructure cost. Nonetheless, peak demand shaving and price signal on EHP's deployment methods could decrease overconsumption stress on network. In this sub-section, relevant case studies are presented and as much as possible analysed. Generally, network reinforcement and DR solutions are highlighted as network problem solver. Network reinforcement is not expected from DNOs and customers because of huge investment cost. DR solutions can be a better option for both consumers and energy providers.

3 Methodology

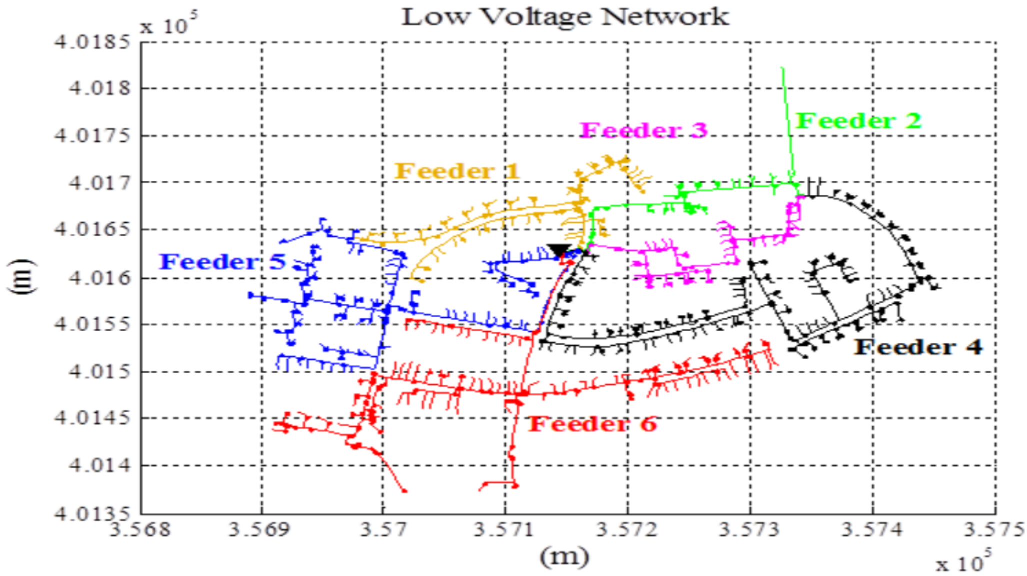
This section focuses on description of the project procedures. Relevant scenarios, load-generation profile modelling methods, and assessment tools are presented.

3.1 Network Assessment and Simulation Tools

The case study's network and simulation tools' characteristics are detailed as follows:

3.1.1 Landgate Network

In this project, only one low voltage network is evaluated. It is called The Landgate Network, which is a typical urban distribution grid. The network is located in North West region of UK. There are six feeders connected to the busbar of the primary substation. The topology of Landgate Network is shown as follows:



LANDGATE	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6
1Φ Customers	49	21	30	100	68	83
Total Length (km)	1.22	0.67	0.78	2.32	1.83	2.48

Figure 1. The Topology of the Landgate Network

It consists of 6 feeders that have 49, 21, 30, 100, 68 and 83 connected customers respectively (From 1 to 6 feeders), in total 351 customers. It is assumed that these feeders are joined in one delta-wye connected transformer, which has a rating of 800 MVA. Also, the substation has 11kV/0.416kV ratio. The frequency of system is constant

(50 Hz) and 3-phases. Furthermore, PVs, EVs and EHPs connection to grid with unity factor and 1-phase. In order to examine network's voltage behaviour, the standard voltage characteristic limits are used (230 +10% -6%).

3.1.2 OpenDSS with Matlab

OpenDSS software, which is called Open Distribution System Simulator invented by EPRI [31], is used for the distribution network simulations. The OpenDSS has a wide range of features on utilization of distribution system. This simulator is open-source software where developers can download it and set up distribution network in it.

To show DSM interactions on low carbon technologies, OpenDSS is practical to develop new relevant approaches. Time-series concepts can be applied on networks easily. Thus, daily or yearly power flow solution scenarios can be implemented. The dissertation project focuses on daily solution mode.

Furthermore, one of the essential characteristics of OpenDSS is that different kind of software platforms can be managed by using OpenDSS's COM server DLL feature. This characteristic provides more flexibility, easy coding ability and easy visualising of distribution networks.

For this project, all simulations are investigated by OpenDSS with Matlab. The basic simulation steps are shown in following figure.

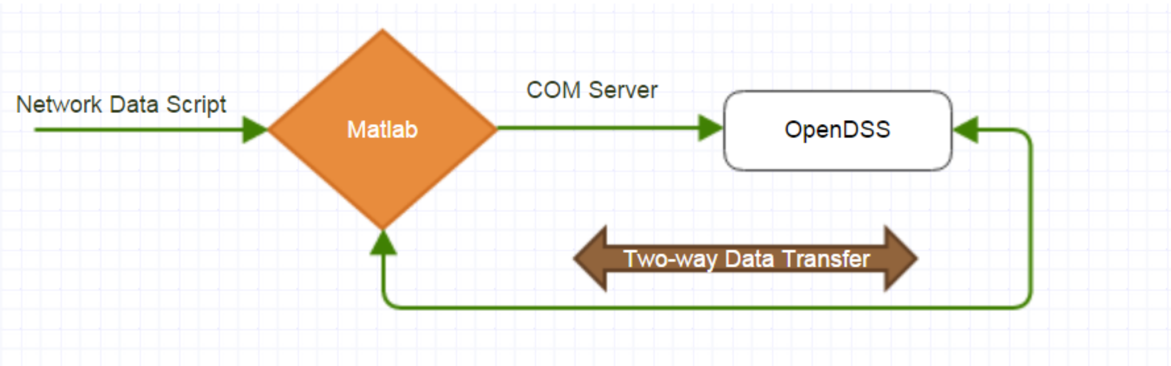


Figure 2. Flow chart of the Project Simulation

First of all, the script of the network data is created in Matlab considering OpenDSS features. Following that case scenarios can be applied by running OpenDSS with Matlab. The main numerical functions are made on OpenDSS and computed on Matlab to generate results for the simulation. Finally, diagrams of exported or imported data can be visualized by Matlab or Excel software.

3.1.3 CREST Tool

CREST tool is a domestic load model developed by the school of Electrical and Electronic Engineering of the University of Loughborough [32]. This tool is designed according to statistical data of UK in order to evaluate residential electricity consumption. In general, customer behaviour on electricity consumption and domestic appliances utilization estimates are taken into consideration with seasonal and day changes (winter or summer, weekday or weekend and months). All the domestic appliances' electricity consumptions data can be created considering minute by minute resolution.

In this project, to model domestic base load and generation of time-series profiles, CREST tool is mainly used. The tool is presented as follows:

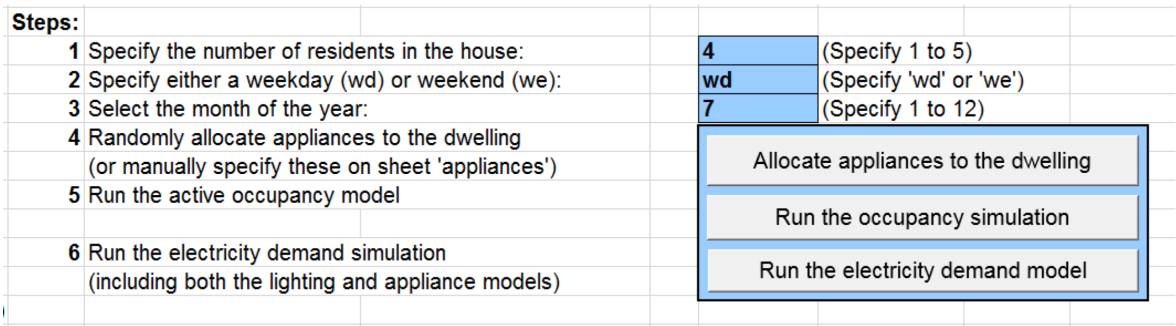


Figure 3. The a part of the CREST Tool

3.2 Domestic Load Profiles Modelling

Residential demand is going to be created by using the CREST tool as previously stated. In order to have a more relevant modelling on domestic load profiles, household population is a key element. Since the number of people in dwellings affects energy consumption, peak demand ratio could change and increase to a high level and for any season. Therefore, statistical household size of UK data is taken into consideration in this project [33]. Hence one of the important CREST tool's characteristics, active occupancy concept, is added in the modelling plan. Active occupancy model means the number of active end-users who consume electricity in dwellings.

The Landgate network connects 351 end-users in total, by describing more accurate average domestic load demand profiles, 1000 different load profiles are created with one-minute resolution for each month considering weekdays and weekends.

The ratio of UK's household sizes is presented in Figure 4 as follows:

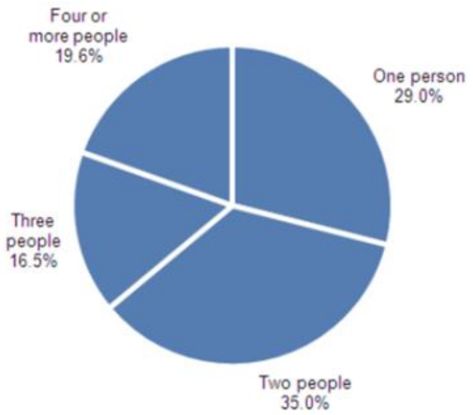


Figure 4. Household Distribution Diagram of UK (2012)

Considering above pie chart, average load profiles are described in following line graphs:

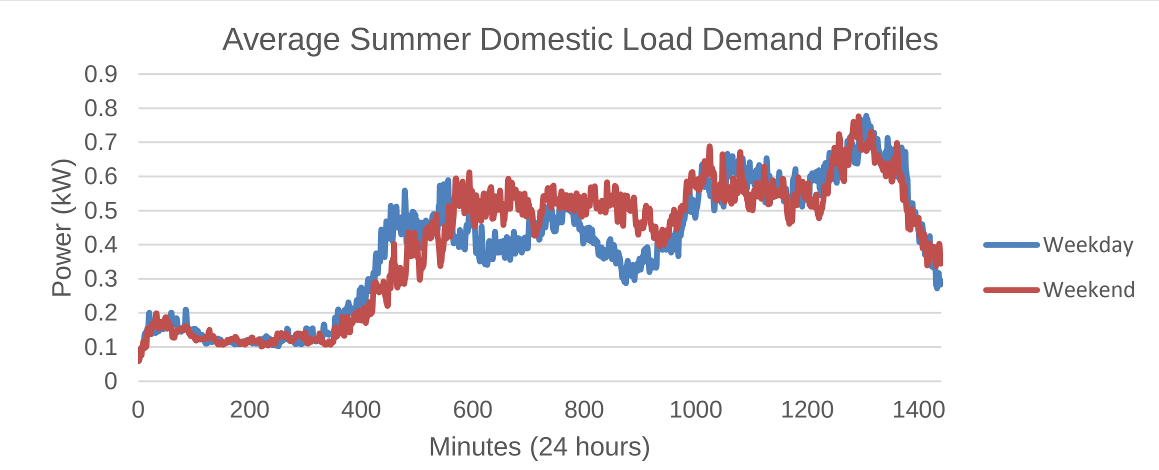


Figure 5. Diagram of Average Summer Domestic Load Profiles (July)

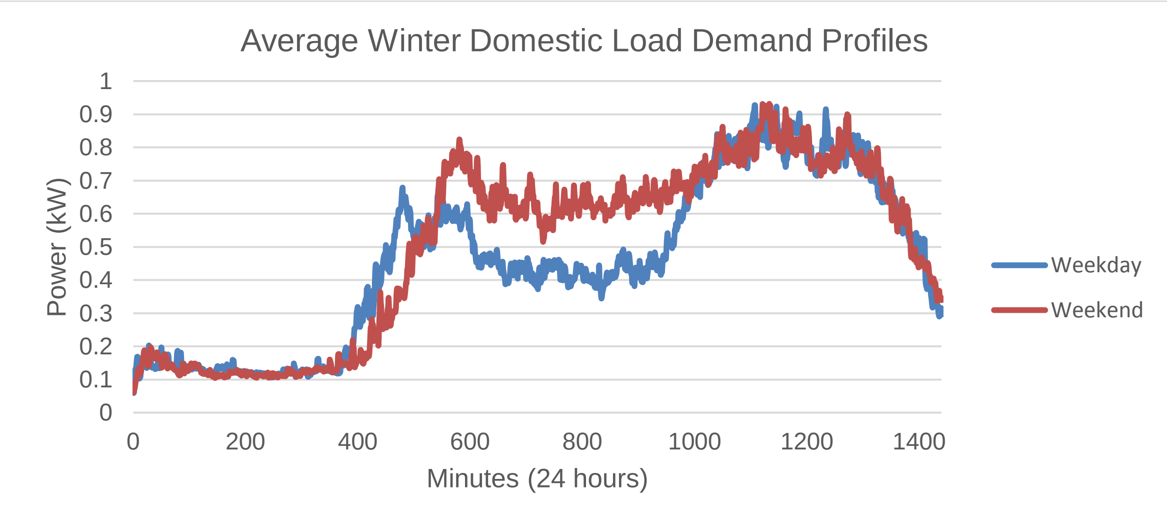


Figure 6. Diagram of Average Winter Domestic Load Profiles (January)

It can be clearly seen from both Figure 5 and Figure 6, that electricity consumption on weekends is more than weekday's electricity consumption. Also, electricity consumption in summer (July) is less than winter (January) which is based on how people spend their time (indoor and outdoor time).

- Peak demand times of electricity utilization starts at 17.00 and ends around 23.00.
- In summer, peak demand reaches to 0.9 kW (Figure 5).
- In winter, peak demand reaches to 0.8 kW (Figure 6).
- All domestic load profiles are created without electric space heating.

3.3 Power Generation Profile Modelling

In order to model more accurate PV generation profiles, location of the Landgate Network is firstly take into account as the angle of incident of sunlight is mainly based on location. Data of the network location is as follows:

- **Network Location and Solar Panel features:** The latitude and the longitude of network location are 53.29° and -2.38° respectively. The capacity of solar panels is assumed 3.5 kW (35 m^2) and the solar panel efficiency is considered as 10%.
- When generating PV profiles, the clearness of weather is also considered in the CREST tool. According to these assumptions, 1000 PV profiles are created for each month. Average one day PV generation profiles are described per months as follows:

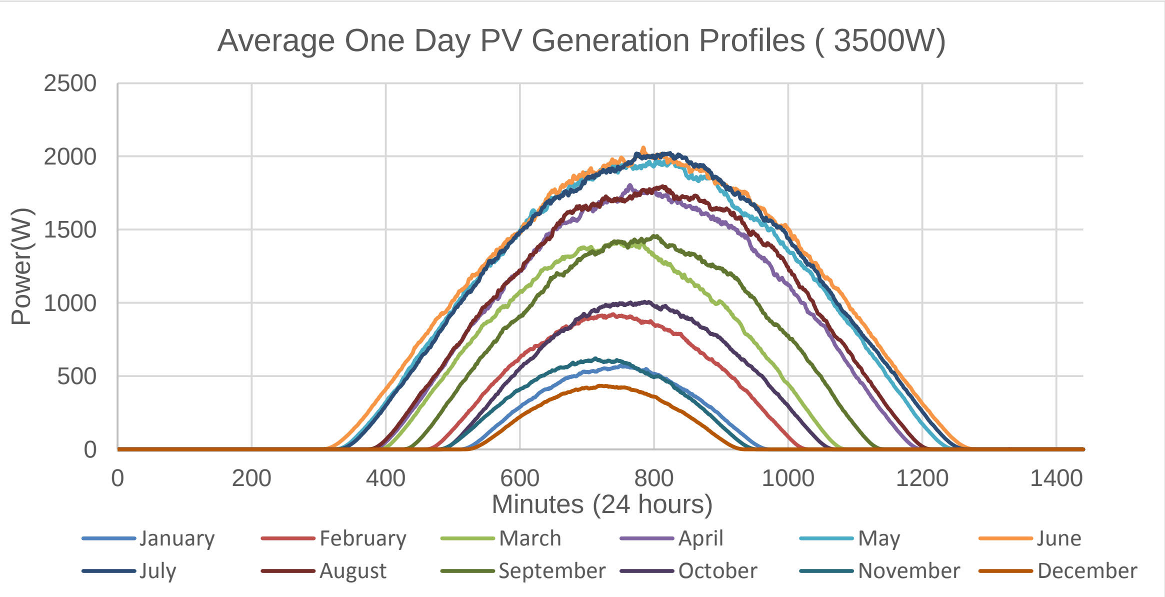


Figure 7. Diagram of Average One Day PV Generation Profiles (Months)

As can be seen in figure 7, the highest PV generation take place in July, and the lowest PV generation is in December. Basically, average daily PV generations for peak time are approximately 500W (winter) and 2000W (summer). Figure 7, also shows that peak time for PV generation for every month change dramatically because of the location's seasonal characteristics. All PV generation profiles are modelled by the help the CREST tool with Excel Visual Basic (VBA).

However, those average profiles are not going to be used for the project simulations. It is assumed that the project simulations uses same PV generation profiles for winter and summer because customers are considered very close to each other. Those PV generation profiles are shown in the below graph.

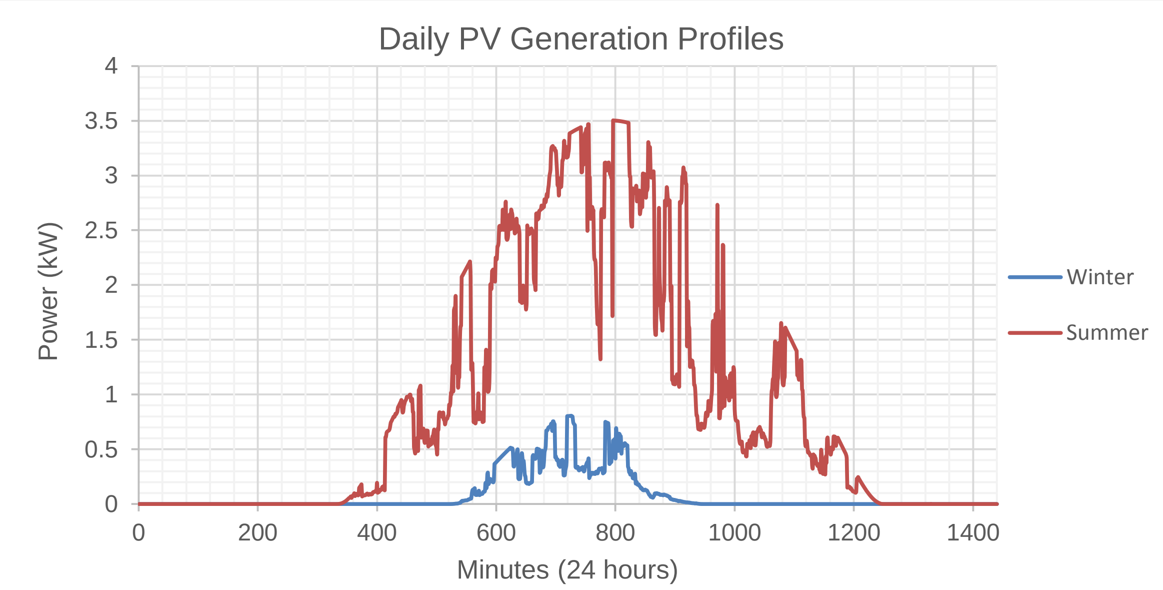


Figure 8. Daily PV Generation Profiles for winter and summer

- In summer, PV generation time is between 6.30 am and 8 pm.
- In winter, PV generation time is between 10 am and 2.30 pm.
- The up and down spikes in PV generation profiles are caused by the clearness of weather.
- Peak time electricity generations are 3.5 and 0.8 kW for summer and winter respectively.

3.4 Electric Vehicle Demand Profile Modelling

In this section, EV's load demand profiles are examined. EV charging characteristics in UK are evaluated and EV profiles are modelled, and finally DSM scenarios are presented. There are some considerations on EV load profile modelling. These are:

- EVs charging start time, EVs charging level

- ❖ Average electricity consumption of EVs and type of EVs

It is likely that those factors are increasing modelling accuracy of EV load profiles. Also, average journey time and charging efficiency can be taken into account. In this work, Dublin EV trail is taken as an example study [24]. The probability of EV charging times on the field is used by this study. By means of Dublin EV field trail, UK's EV charging time's probability diagram is modelled manually. Peak time of demand was considered 2 hours early in UK, compared to Ireland. The peak time of demand is around at 21.30 for UK's circumstances. UK's EV charging time's probability is illustrated as follows:

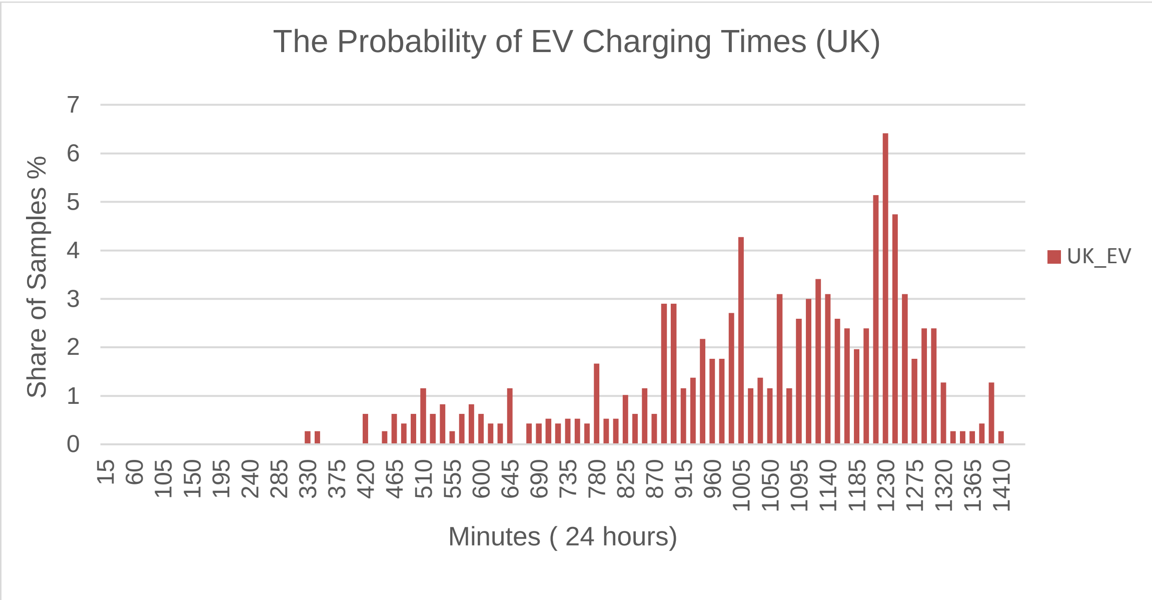


Figure 9. Diagram of the probability of EV charging times (UK)

Figure 9 represents base case scenarios of EV charging probability. Some of the assumptions for this scenario are as follows:

- ❖ All EVs are of the same type
- ❖ Battery capacity of EVs is 24 kWh
- ❖ Slow charging rate of EVs is 3 kW and EVs can be fully charged within 8 hours.
- ❖ EVs have 100% charging efficiency

From this point of view, 351 different EV load profiles are created by the help of the probability values and matlab-coding, considering one minute resolution. Following that, average electricity consumption of 351 EVs is also investigated and presented in Figure 10. The graph shows that peak time of demand starts approximately at 18.00 and ends at 23.30. The maximum electricity demand reaches around 1.2kW at between 21.30 and

22.30. In this section, the modelling procedure of base EV profiles are presented for UK (EV_UK).

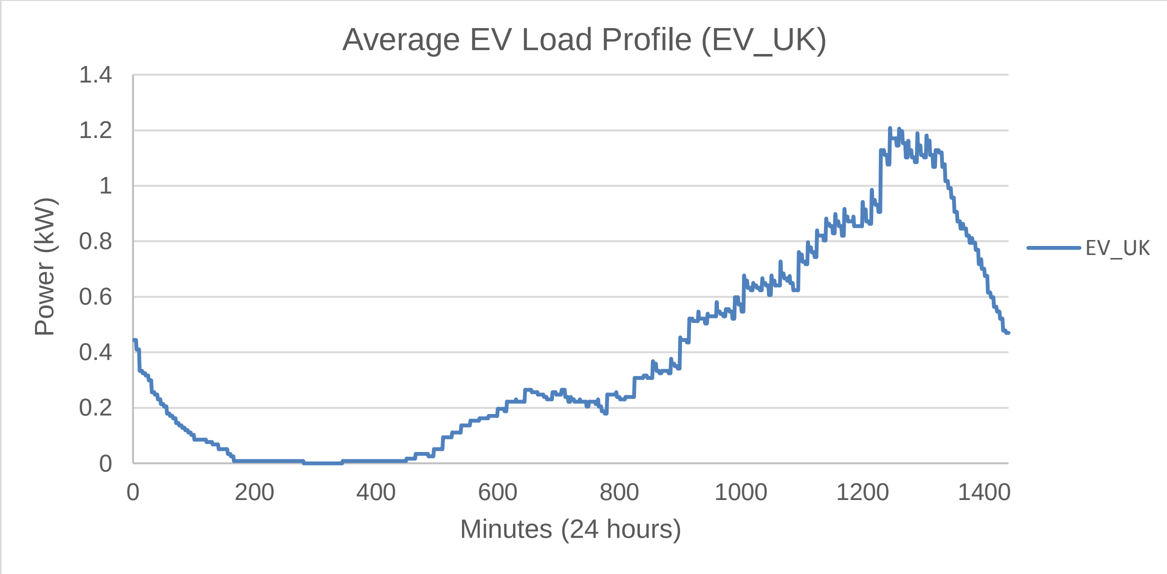


Figure 10. Diagram of Average EV Load Profile (Base Case EV's status)

3.4.1 DSM Scenario 1 (Midnight_EV)

The aim of this scenario is to change people's EV charging habits after midnight period, but not all customers are considered. In the base case EV charging scenario, there is a low electricity consumption of EVs from 24.00 until 8.00. On the basis of that time range, the probability of EV charging times is shifted 4 hours to midnight region. Re-created EV's charging probability is described in figure 11. After that, 351 different EV load profile is created by means of matlab-coding.

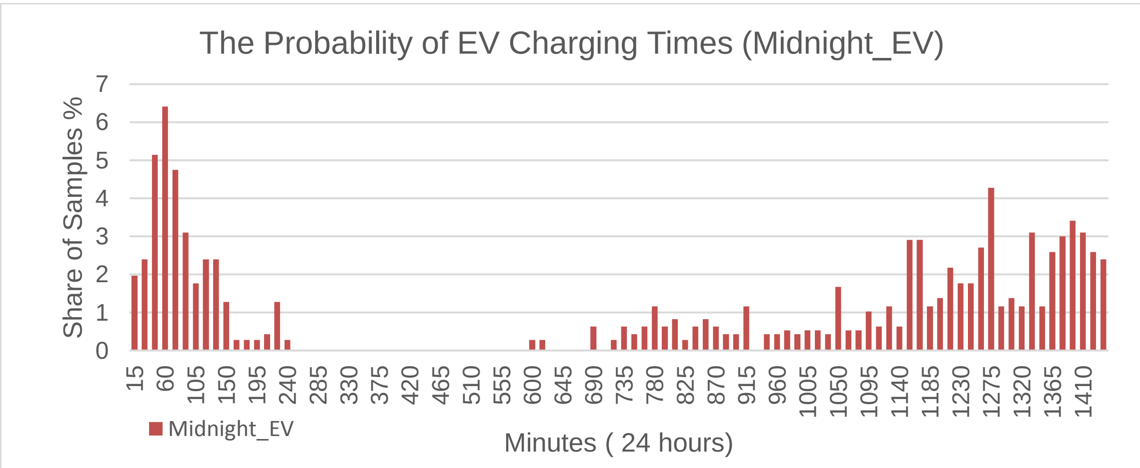


Figure 11. Diagram of the probability of EV charging times for Midnight_EV

After created 351 new customers EV profiles, average EV load profile for Midnight_EV

Scenario is investigated and it is shown in following line graph.

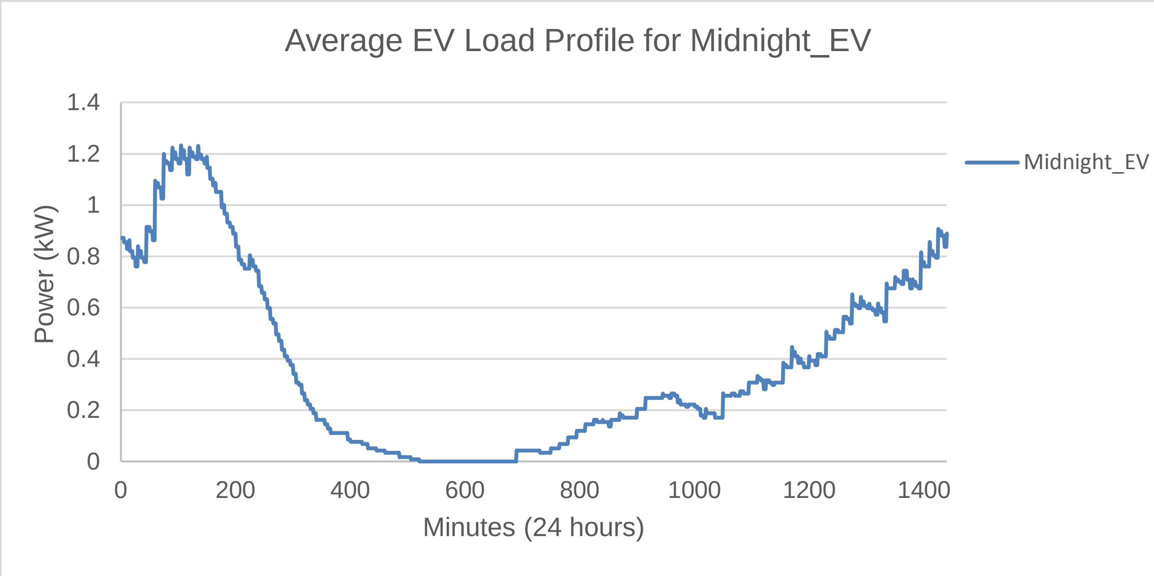


Figure 12. Diagram of Average EV Load Profile for Midnight_EV (DSM scenario 1)

Compared to base case (EV_UK), the peak time of demand has changed to after midnight period with same amount of power consumption. One of the essential necessities of this scenario is to diminish peak demand when implementing aggregated demand into the network.

3.4.2 DSM Scenario 2 (Afternoon_EV)

The aim of this scenario is to change customers' EV charging habits during afternoon, but not all customers are considered. The probability of EV's charging times are changed by creating new DSM scenario approach.

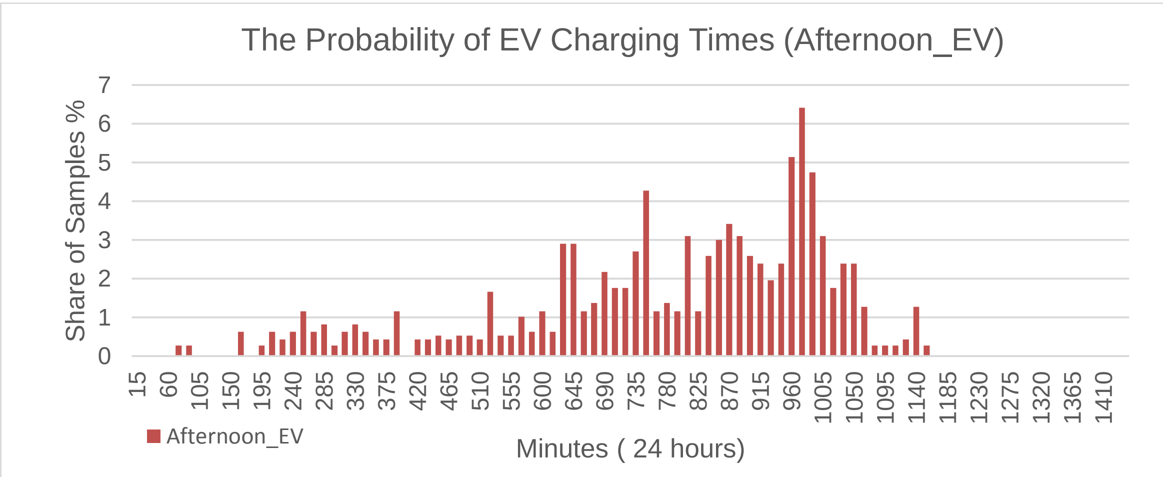


Figure 13. Diagram of the probability of EV charging times for Afternoon_EV

The scenario is considered as afternoon demand shifting to increase PV generation's involvement on the DSM concept. Based on this, the probability of EV charging times is shifted 4 hours to afternoon time period (in front of the base case). Re-created EV's charging probability is described in figure 13. Afterwards, 351 different EV load profile is created by the help of the matlab-coding.

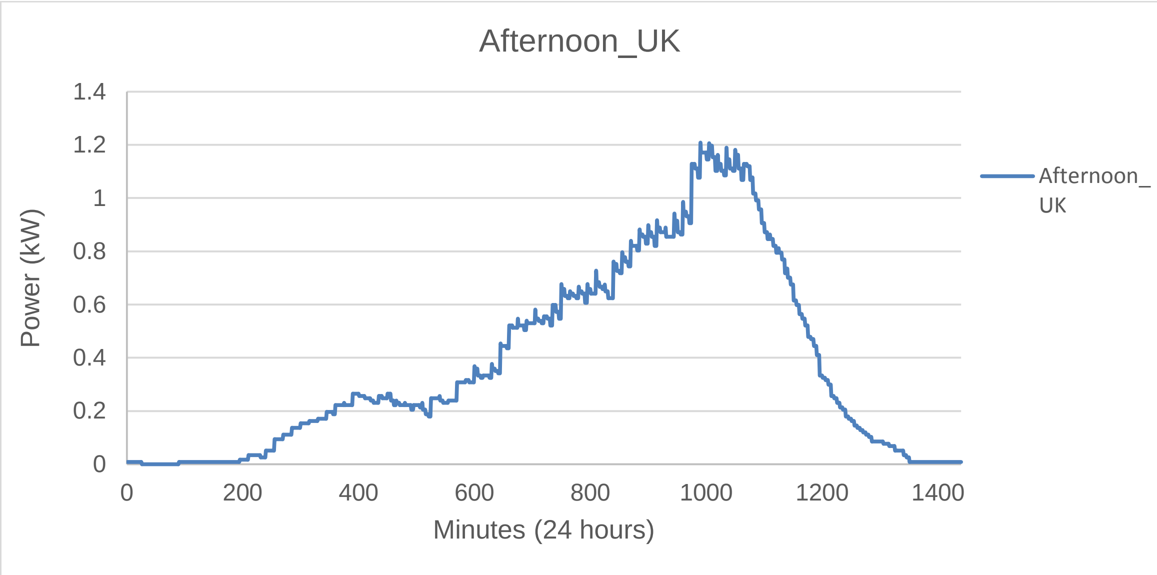


Figure 14. Diagram of Average EV Load Profile for Afternoon_EV (DSM scenario 2)

Compared to base case (EV_UK), the peak time of demand is changed to afternoon period with same amount of power consumption. One of the basic understandings of this scenario is to decrease the peak demand and to raise utilization of PV generation from the solar panels.

3.5 Electric Heat Pumps Demand Profile Modelling

In this section, it is likely to be explain how to design EHP's demand profiles and DSM scenario are presented.

3.5.1 EHP Profiles

In order to model EHP profiles, heat demand profiles of dwellings play key role. There is an essential connection between heat demand dwellings and electricity consumption of EHPs. This connection is called co-efficient performance (COP) factor of EHP, theoretically, it is based on Carnot Cycle theorem. In terms of heat exchange, COP is basically based on temperature difference between indoor and outdoor. Following equation shows the relation between injected heat and electricity.

$$COP_{factor} = \left(\frac{Q_{Injected}}{W_{Input\_Electricity}} \right) = \left(\frac{T_{High}}{T_{High} - T_{Low}} \right)$$ Eq. 1

As a basis, in order to model accurate heat demand profiles, there are great deals of considerations. Some of them are shown as follows:

- ❖ Type of house (detached, semi-detached, etc.)
- ❖ Location of dwellings
- ❖ Heat losses of dwellings
- ❖ House specifications (Insulations, what sort of wall, etc.)
- ❖ Number of occupants (Also need to consider people behaviours)

These key elements describe us the creation of heat demand profile is very challenging considering in limited time period and lack ability of coding. As a result of those challenges, heat demand profiles of dwellings are generated from these works[34], [35] (Help from the PhD student Lingxi Zhang) For getting more accurate results on applying DSM solutions to network, those profiles are taken into consideration. As can be seen below, Figure 15 describes an EHP's heat and electricity consumptions profile in winter.

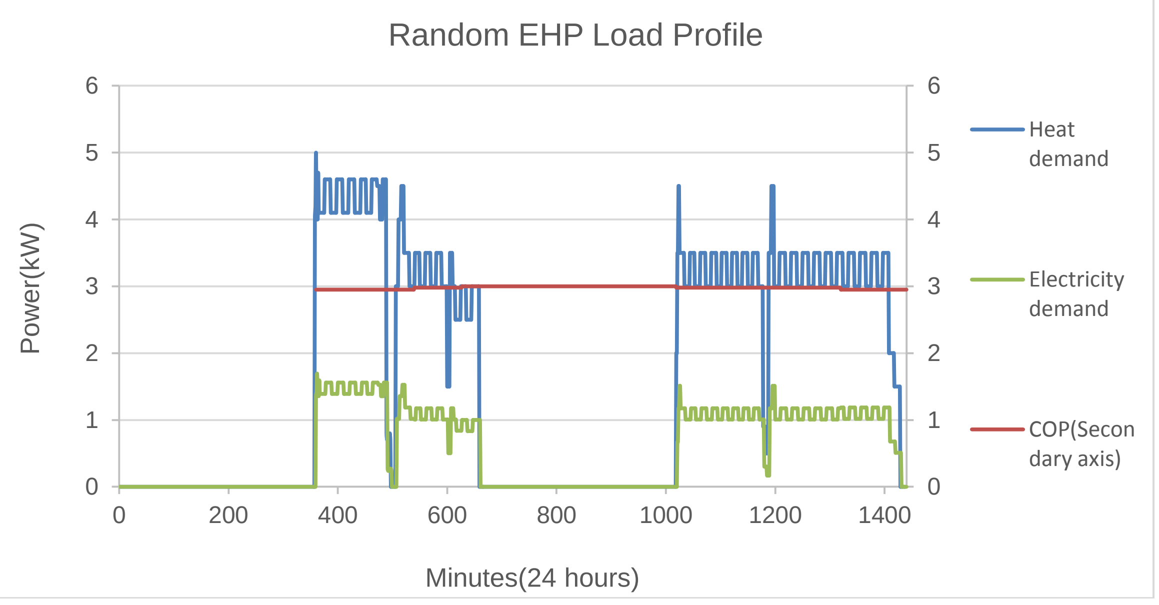


Figure 15. Diagram of Random EHP Load Profile

When modelling EHP load profiles, there are also some assumptions taken into account for. These are:

- ❖ Only semi-detached houses are selected, because of this type of house are very common in UK.

- ❖ Air source heat pumps (ASHPs) is chosen due to it is also widespread in UK and does not need much space for settlement (not like GSHPs).
- ❖ House location is considered in northwest of the UK.
- ❖ COP factor of EHPs is likely to be change between 1.97 (0°C) and 3.65 (20°C).
- ❖ Assumed that COP changes linearly (according to outside temperature)
- ❖ COP factor values are created according to outside ambient temperature changes (assumed more linear shape)
- ❖ EHP profiles are modelled considering the Carnot cycle theorem and by the help of excel.

3.5.2 EHP profile with DSM Scenario

In order to implement possible DSM solution with EHPs, it is assumed that people can decrease their heating habits. This DSM scenario is examined ambient temperature of dwellings. The scenario is assumed 18°C and 21°C of indoor ambient temperatures that people comfort level is in standard circumstances.

- ❖ Firstly, EHP load profiles is generated for 21°C (one-minute resolution) and secondly all profiles are applied into the Landgate Network (By means of heat demand profiles and excel).
- ❖ According to EHP's penetration levels on the network, DSM scenario's result data is generated by matlab.
- ❖ It can be clearly seen in figure 16, there are two peak times of demand.

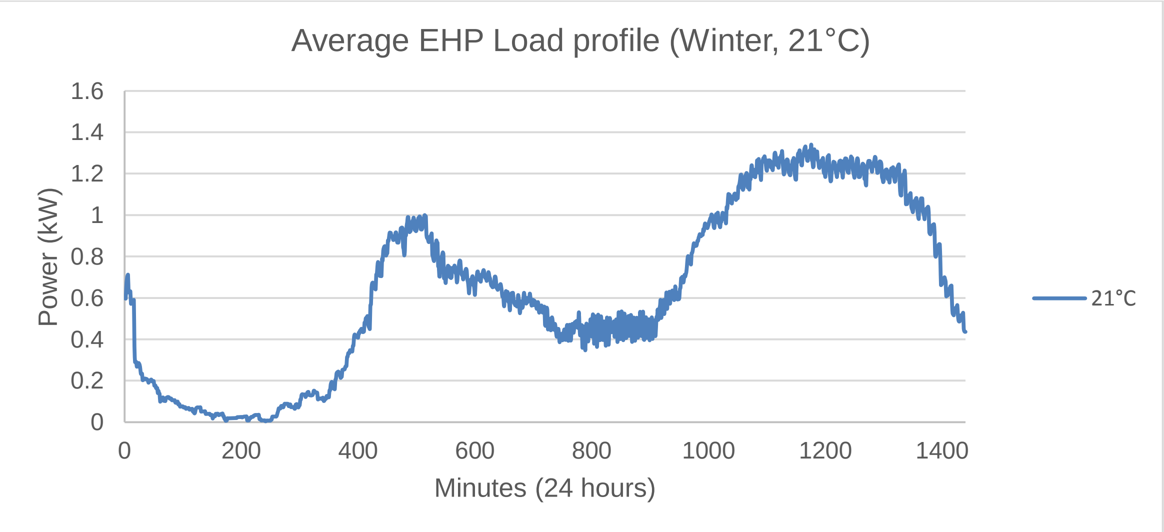


Figure 16. Diagram of an EHP Load profile of dwelling (winter, 21°C)

- ❖ Morning peak times are around between 6.30 am and 8.30 am for both temperatures.

- Evening peak times starts 5.30 pm and ends 10.00 pm for both temperatures.
- In both temperature circumstances, peak demand of EHPs reaches around 1.2 kW in the night. On the other hand, morning peaks of EHPs rise up to 1 kW for both temperatures.

Furthermore, average EHP load profile of 351 dwellings' diagram is provided in below figure 17.

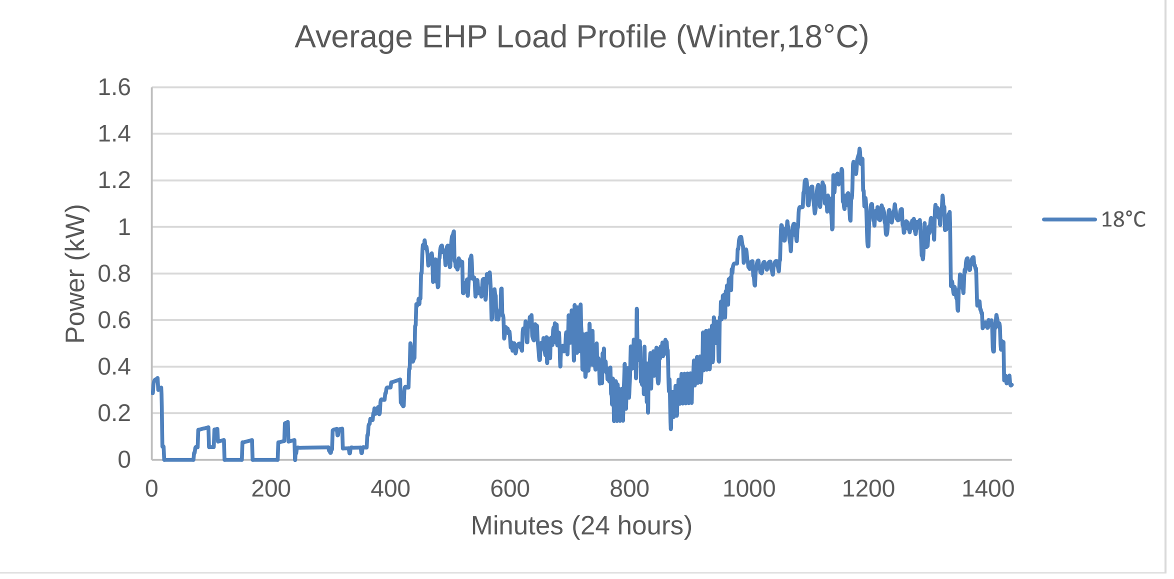


Figure 17. Diagram of an EHP Load profile of dwelling (winter, 18°C)

In this part, the procedure of modelling EHP load profiles are presented as much as possible. By means of those 351 load profiles of EHPs, DSM's interactions with EHP is assessed in simulation part of the dissertation project.

4 Results and Analysis

In this section, simulation results are summarized and presented.

4.1 Domestic Load profiles' interactions with PVs

In this part, the created domestic load demand profiles and electricity generation (PV) profiles were integrated into the Landgate LV network. In this case, 60%, 70%, 80%, 90% and 100% penetration of PVs were examined for two specific days in summer (a weekday and a weekend) into the network. These specific days were selected since electricity generation level in winter is low and hence only summer days are evaluated. To show network behaviour, feeder4 was chosen. Below Figures shows 3 phase-voltage changes of end of the feeder4 considering 60% and 100% PV penetration levels with domestic loads.

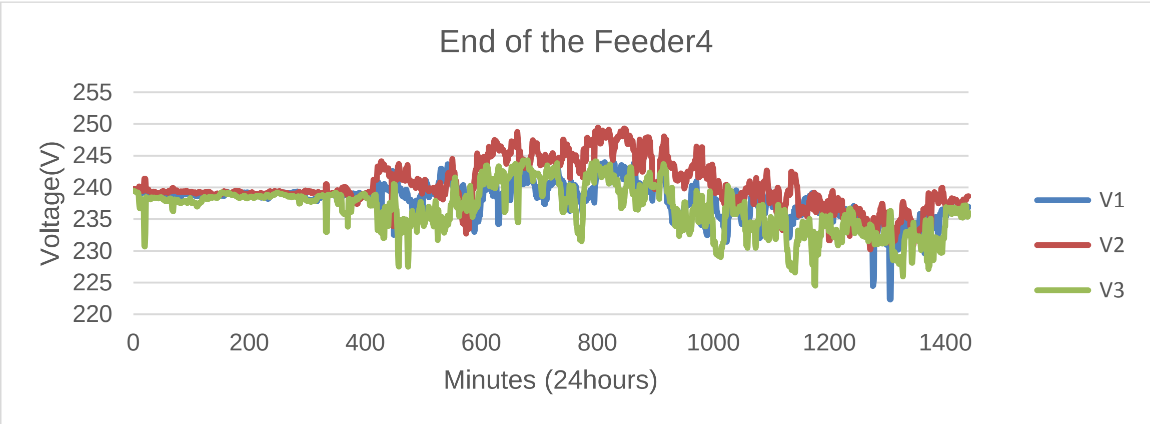


Figure 18. 60% Penetration level of PV's effects on the network

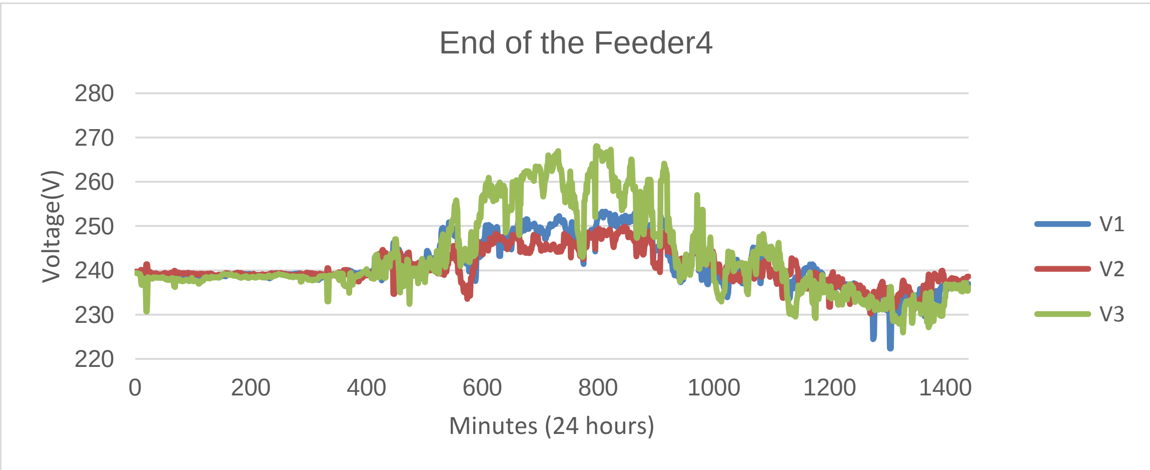


Figure 19. 100% Penetration level of PV's effects on network

In order to show PV's influence on the network, Feeder4, which has 100 customers and the most affected were selected. Accepted voltage statuary limits were LV network standards for UK (230V +10%, -6%) were used. According to simulation data, up to 60% of PV penetrations was an almost acceptable level for summer weekdays. As can be seen from the figures 18 and 19, 100% of PV penetration caused the voltage to rise up to (almost 270V) 17% of base voltage value.

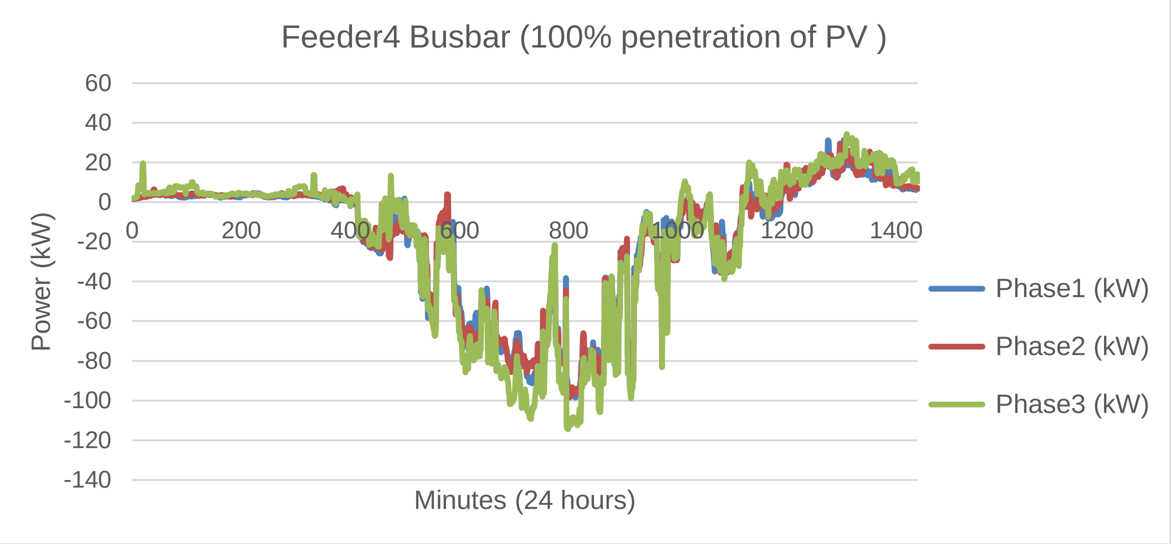


Figure 20. Net Aggregated Power Generation and Consumption for Feeder4 (100%)

It can be seen on above graph that generated power on feeder4, the on-peak time is around 4 times greater than consumed power on the load peak times. This data shows that power generated from PVs can supply up to 4 feeders equivalent to feeder4, if the electricity generation can be shifted to peak demand period. The Table below shows the overall energy results.

Table 1. Overall Energy Results for Landgate (Considering PVs and base loads)

		Summer	**Weekday**		
Energy Meter	Busbar				
Penetration of PVs	**60%**	**70%**	**80%**	**90%**	**100%**
Net kWh	-1498	-2257	-2986	-3713	-4542
kvarh	1163	1258	1371	1506	1686
Generator kWh	4446	5230	5994	6763	7647
		Summer	**Weekend**		
Energy Meter	Busbar				
Penetration of PVs	**60%**	**70%**	**80%**	**90%**	**100%**
Net kWh	-1899	-2656	-3385	-4111	-4937
kvarh	1030	1128	1246	1385	1568
Generator kWh	4446	5230	5994	6763	7647

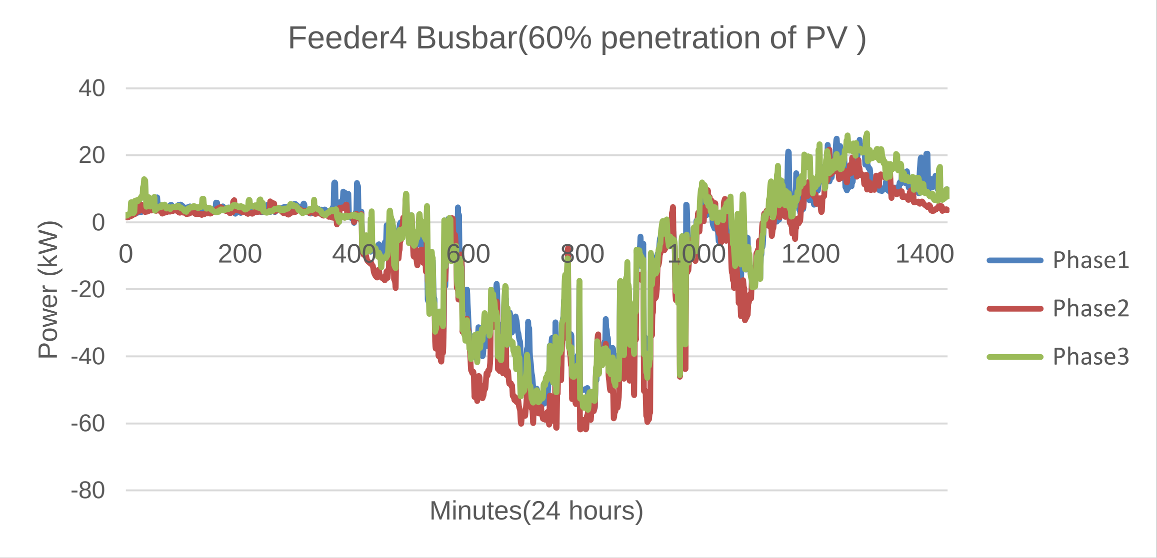


Figure 21.Net Aggregated Power Generation and Consumption for Feeder4 (60%)

Conclusions: Peak time (around 13.30 pm) power generation reach around 60 kW-per minute for feeder4. After 60% of PV deployment, system undergoes voltage rise issues. To solve this problem, network should have more demand or storage and good infrastructure. According to energy results, with 100% penetration of PV, generated energy reached up to 7647 kWh and feeder4 has extra available energy at almost 5000 kWh after one day of electricity consumption. As previously mentioned, if deployment of PVs is 100% in this grid, it can provide for a large number of customers electrical energy demands.

4.2 Domestic Load Profile's interactions with Electric Vehicles

The aim of this part is to show interactions of electricity demand profiles on the Landgate network.

This sub-section focuses on the aggregated demand profiles of EVs and domestic base loads. 60%, 70%, 80%, 90% and 100% penetration levels of EV (Considering UK EV charging time behaviour) were examined for a specific day in summer and winter for the Landgate network.

According to overall energy results (**Table 2**), electricity consumption of 351 customers on winter weekday was slightly higher than summer weekday's electricity consumption. The reason of this was that domestic base demand profiles for summer weekday have lower demand profile as people are spending most of their time outside in summers, compared to winters. When the penetration level of EVs was increasing, reactive and active power losses were also increasing in the similar manner.

Table 2. Overall Energy Results for Landgate (Considering EVs and base loads)

	Summer	Weekday			
EnergyMeter	Busbar				
Penetration of EVs	**60%**	**70%**	**80%**	**90%**	**100%**
kWh	5085	5326	5631	5884	6201
kvarh	1232	1261	1301	1335	1386
Load Losses kWh	93	102	114	126	144
Load Losses kvarh	285	314	354	388	439
	Winter	**Weekday**			
EnergyMeter	Busbar				
Penetration of EVs	**60%**	**70%**	**80%**	**90%**	**100%**
kWh	5277	5518	5825	6078	6394
kvarh	1322	1353	1395	1431	1485
Load Losses kWh	99	109	123	134	153
Load Losses kvarh	314	344	387	423	477

In order to demonstrate the effects of EV penetration level on voltage statutory limits ($V_{Maximum}$= 253V, $V_{Minimum}$= 216.2V), Feeder4 was selected. Basically, peak time of aggregated demand started around at 7 pm, and stopped at 11 pm. It was observed that voltage of at the end of the Feeder4 reached 207V, which is considerably low level, in the case of 100% penetration level of EVs. The voltage of the Feeder4's end-user decreased at a rate in the ratio of 9%, compared to base voltage limits (Figure 22).

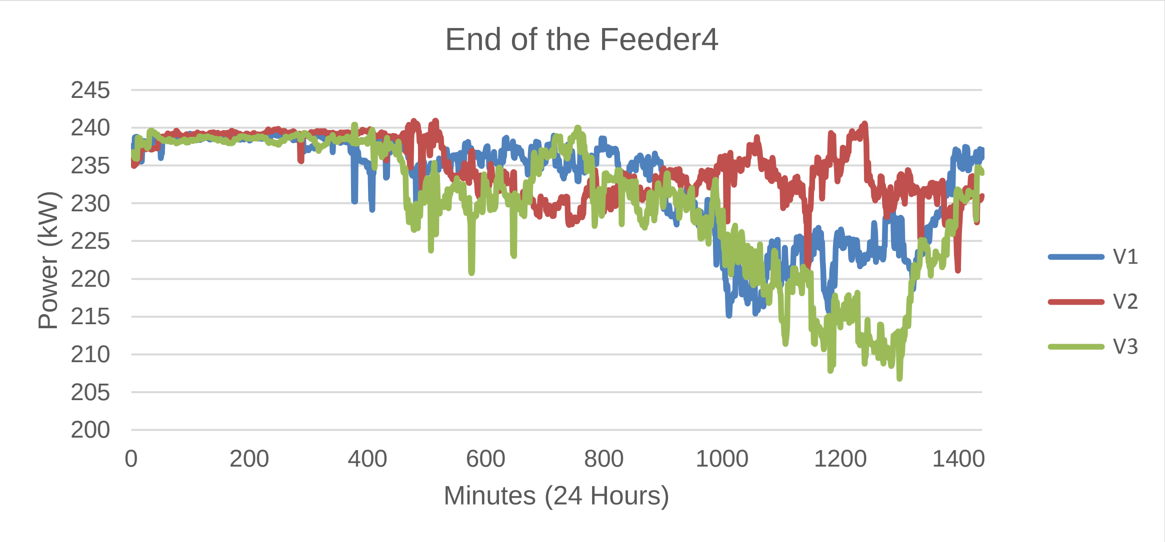


Figure 22. 100% Penetration level of EV's effects on the network

Figure 23 shows a 60% penetration level of EV's impacts on Feeder 4 is presented. At the end of the Feeder4, in the case of 60% EV deployment, it can almost cope with voltage drop (it is around 218V on the peak time) but to say that it is a definite no, all customers should be taken into consideration instead of one feeder.

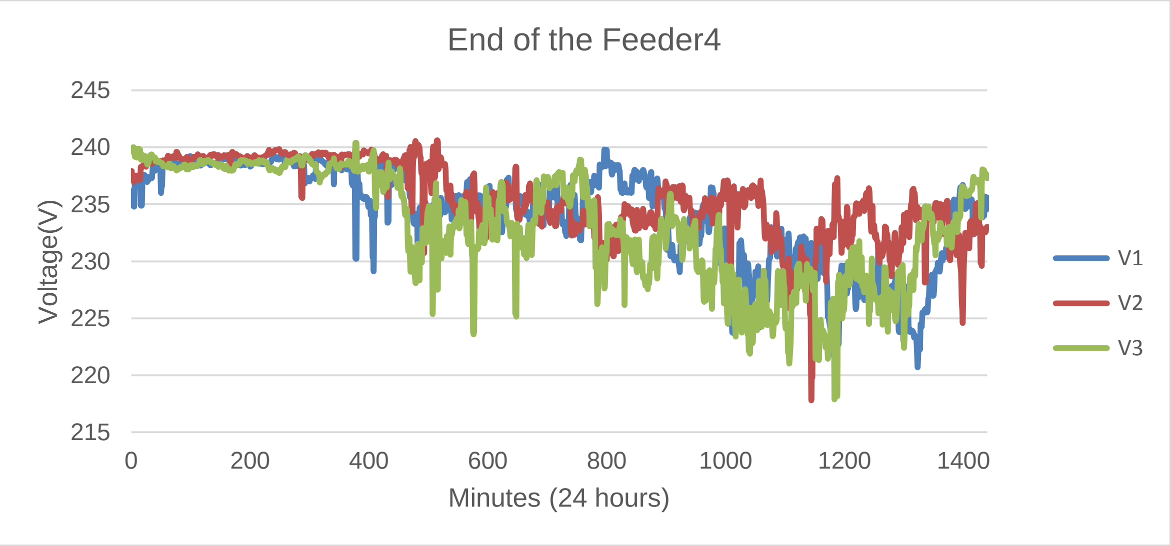


Figure 23. 60% Penetration level of EV's effects on the network

Also, it can be seen from Figure 24 and Figure 25 that power consumption on-peak time for 60% and 100 % penetration level of EVs were around 60 kW and 80 kW (respectively) on Feeder4 Busbar. Despite this fact that deployment rate of EVs is 60%, there is still huge power density between 6pm and 11pm as seen in the Figure below.

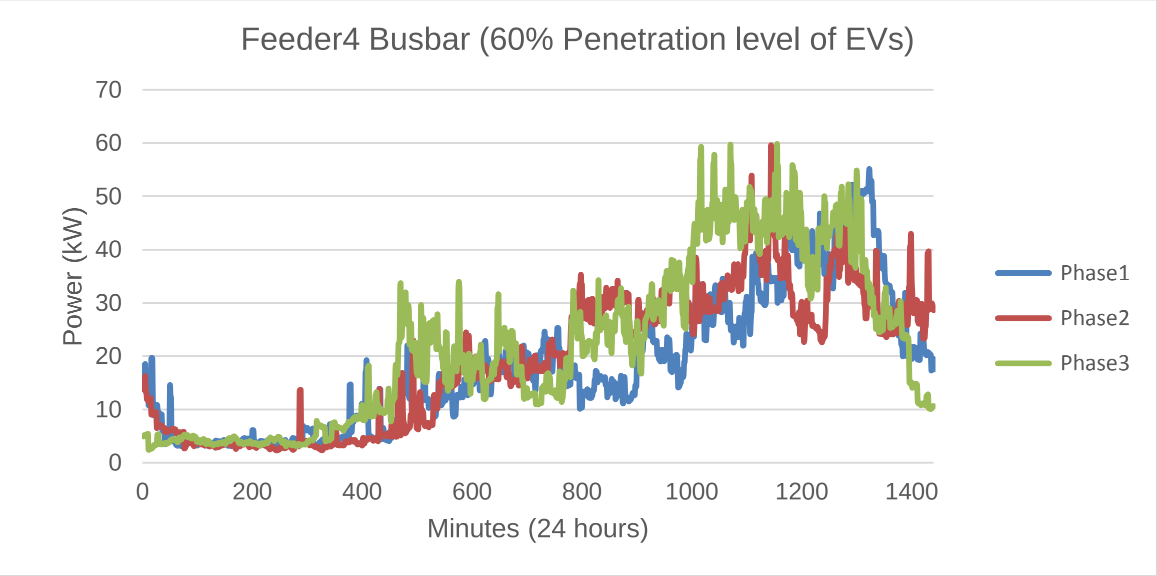


Figure 24. Net Aggregated Power Consumption for Feeder4 Busbar (60%)

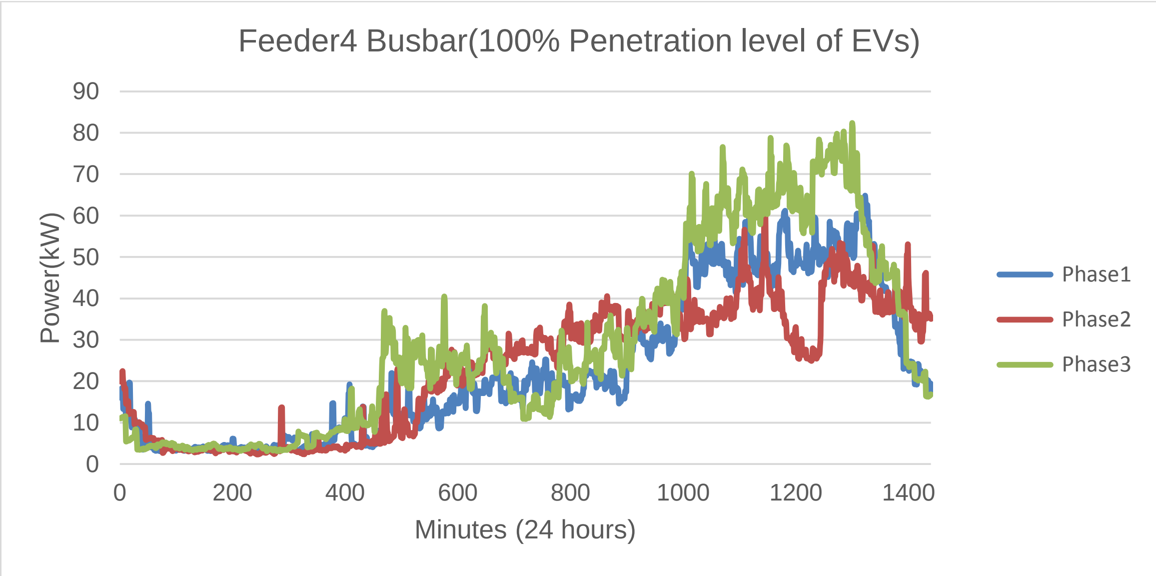


Figure 25. Net Aggregated Power Consumption for Feeder4 Busbar (100%)

To assess voltage limits on the customer level, Figure 26 is presented which illustrates average number of customers who have voltage limit issues for winter and summer weekdays on Feeder4. It is apparent from this bar graph that when applying 60% penetration levels of EV, not many customers have voltage drop problems in both seasons' weekdays (around 5 customers out of 100). In contrast, if full deployment levels of EVs are applied, more than 30 customers in winter and 28 customers in summer have voltage drop issues.

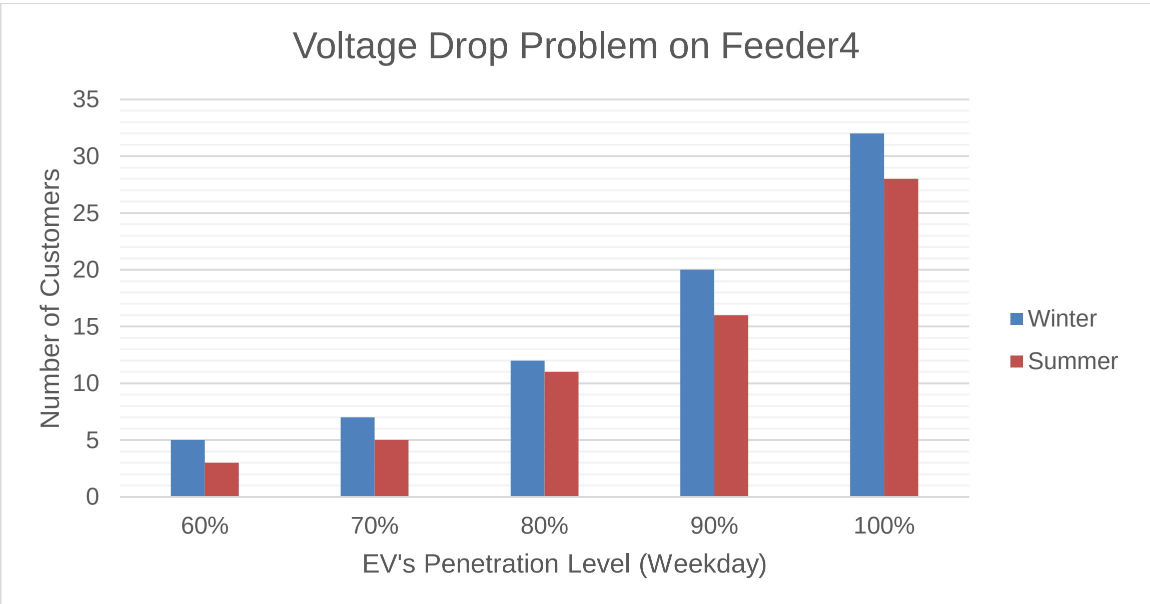


Figure 26. Number of people who complaints voltage drop issue on Feeder4

As shown in Figure 26, there is a slight difference in the number of customers who have voltage problems for any penetration levels for summer and winter weekdays. As previously mentioned, this slight disparity depends on domestic base load profiles i.e. in summer weekdays' base demand was less than winter weekdays' base demand.

Conclusions: In this part, aggregated demand of EV and domestic base load was examined. The peak time of aggregated demand was between 6 pm and 11pm. It can be concluded that for up to 60% penetration of EVs, Feeder 4 can deal with the voltage problems without any need for control systems.

4.3 DSM Interactions of Electric Vehicles

In this section deals with possible DSM solutions, considering EVs, domestic base load demand and PVs.

4.3.1 DSM Scenario 1 (EV Charging After Midnight)

As mentioned in Section 3.4.1, the base EV demand profile named as UK_EV (No DSM) was created. In order to suggest optimum DSM solution for decreasing peak demand, DSM Scenario 1 was implemented into the Landgate network. Although this scenario was applied to all feeders, only Feeder4's situation was analysed and presented (which has 100 customers and the biggest feeder in the Landgate network).

In this sub-section, base EV demand profiles (EV_UK, No DSM) and DSM Scenario 1 (EV-After Midnight) are applied separately. Mainly for the scenario 1, in order to show Landgate network behaviour, winter conditions are considered. Firstly, EV_UK's Feeder4 (Busbar) power diagram and voltage graph of end of the Feeder 4 were demonstrated. Secondly, customers who have voltage drop and rise issues were investigated for 80%, 90% and 100% penetration levels of EV on the Feeder4. All these steps were also applied for DSM scenario 1 and results were presented.

EV_UK (No DSM):

It can be clearly seen from **Figure 27** that when applying 100% EV penetration level and PVs on Feeder 4 (winter conditions), end of the feeder 4 does not have any voltage rise issues, on the other hand, end-user of Feeder 4 is facing a voltage drop issue on-peak demand time. Following statements are showing results:

- $V_{Maximum}$ of end-user was reached 245V on-peak generation time.
- $V_{Minimum}$ of end-user was reached around 207V on-peak power consumption time

In this case, voltage statutory limits are accepted as 230 +10% (V_{Max}) and 230 -6% (V_{Min}).

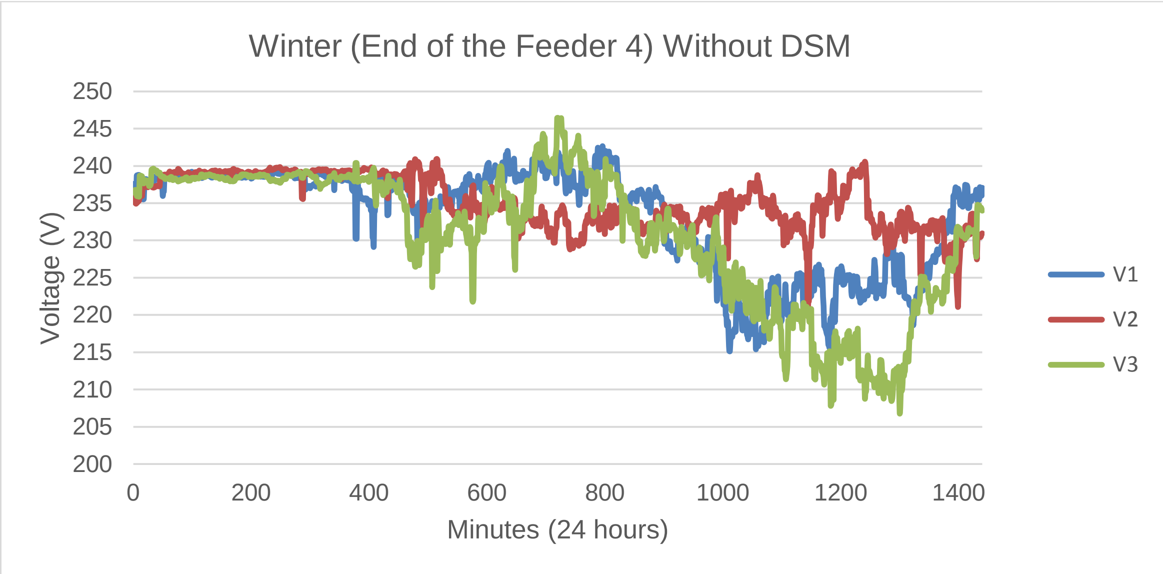


Figure 27. Voltage Diagram of End of the Feeder4 - UK_EV (No DSM)

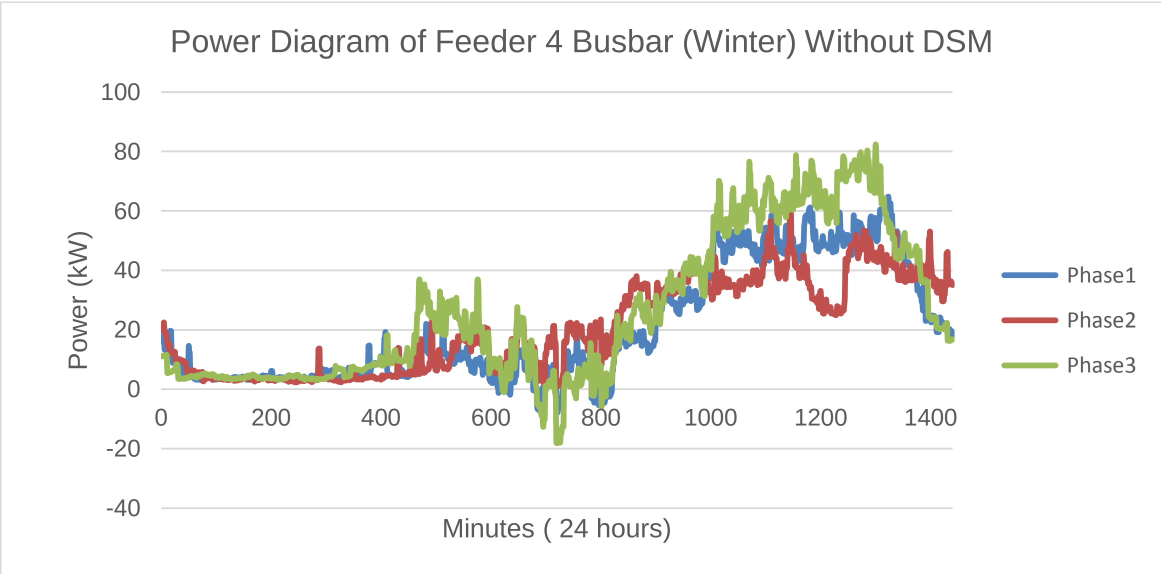


Figure 28. Power Diagram of Net Aggregated demand of EVs-PVs for UK (No DSM)

Above line graph represents net power consumption and generation considering EV_UK and winter PV profiles on Feeder 4 busbar. At the peak generation time, power generation was much higher than power consumption. Between 10 am and 1.30 pm, net demand reached almost 20 kW on the Feeder 4. On the contrary, power consumption at the on-peak time (from 7pm till 11 pm) reached 80 kW on the Feeder 4. In normal winter conditions for Landgate location, according to peak times, power consumption was likely to be 4 times larger than power generation.

From this moment, results of Table 3 is analysed in following page.

Table 3. Number of Customers who has voltage drop issues (Without DSM)

Penetration level of EVs	Winter		Summer	
	weekday	weekend	weekday	weekend
80%	12	12	11	12
90%	20	34	16	18
100%	32	38	28	29

Above table represents number of customers who have voltage drop issues on the Feeder 4 in winter and summer considering the EV penetration levels base conditions (UK_EV). In this case, PV profiles are changing according to relevant season. Furthermore, weekday and weekend's domestic base load profiles were examined to understand grid behaviour. In general, when deployment of EVs was increased, voltage drop issues were also rising considerably. The voltage drop issues were more on weekends in winters as compared to summer weekdays. When implementation of EV was 100%, more than 30 customers out of 100 for winter and almost 30 customers in summer will have voltage drop issues.

DSM Scenario 1 (With DSM):

It can be clearly seen from **Figure 29** that when applying 100% EV penetration level and PVs on Feeder 4 (winter conditions), end of the feeder 4 did not have any voltage rise issues, on the other hand, end-user of Feeder 4 faced with voltage drop issues on-peak demand time. Remarkably, end of the Feeder 4 is affected by demand shifting positively. Voltage improvement can be observed compared to conditions of EV_UK (Figure 27).

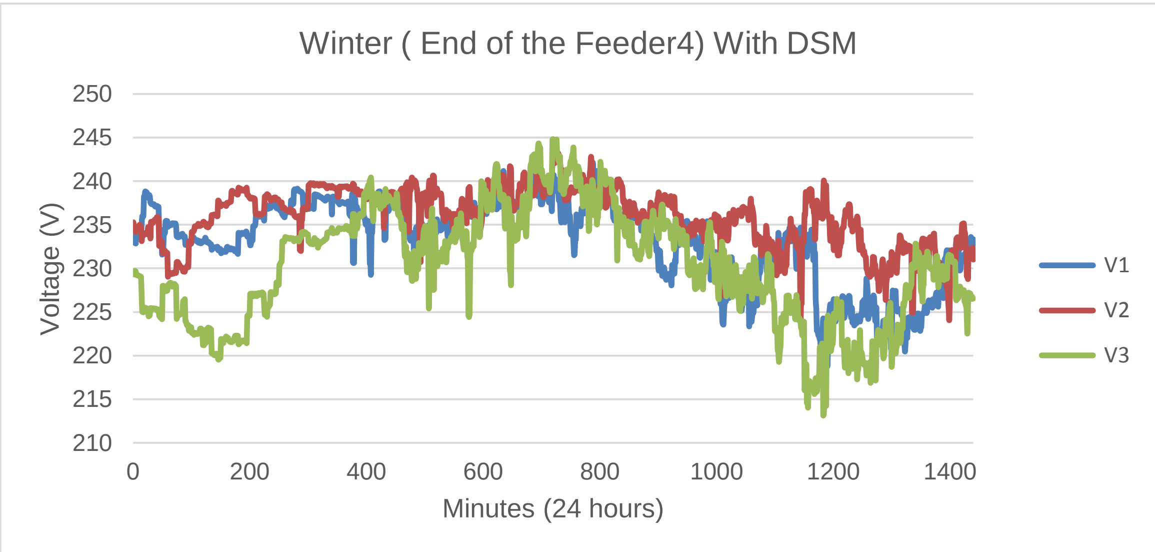


Figure 29. Voltage Diagram of End of the Feeder4 Midnight EV charge (With DSM)

Following statements show end of the Feeder 4 voltage limit conditions:

- $V_{Maximum}$ of end-user was reached 245V on-peak generation time.
- $V_{Minimum}$ of end-user was reached around 215V on-peak power consumption time

In this case, voltage statutory limits are accepted as 230 +10% (V_{Max}) and 230 -6% (V_{Min}). In normal base conditions (UK_EV), there was no voltage drop between at 24.00 and at 05.00. After demand shifting, in spite of the fact that there was considerable amount of voltage drop, end of the feeder could cope with that problem in voltage statutory limits.

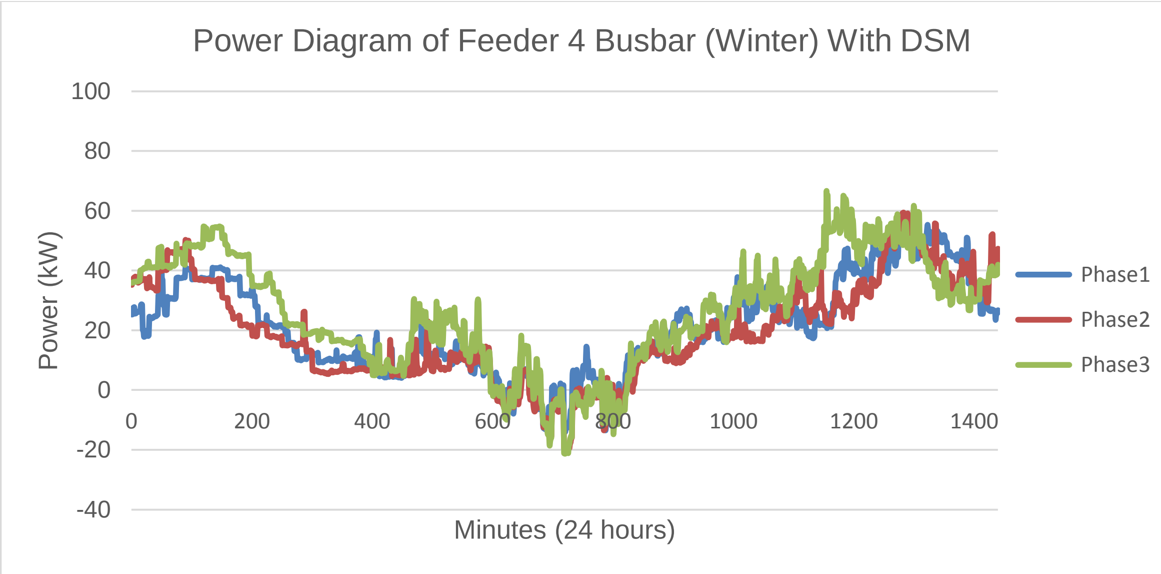


Figure 30.Power Diagram of Net Aggregated demand of EVs-PVs for UK (With DSM)

Above line graph represents net power consumption and generation considering DSM Scenario 1 and winter PV profiles on Feeder 4 busbar. At the peak generation time, power generation was much higher than power consumption. Between 10 am and 1.30 pm, net demand reached above 20 kW on the Feeder 4. On the contrary, power consumption at the on-peak time (from 7pm till 11 pm) reached 60 kW on the Feeder 4. In normal winter conditions for Landgate location, according to peak times, power consumption was likely to be 3 times higher than power generation. Important points are:

- Shifting demand after midnight can decrease the peak time power consumption.
- In perspective of power generation, shifting demand to after midnight can increase net power profile (power consumption and generation) on-peak generation times (between 10 am and 1.30 pm). (By means of Figure 28 and 30)
- In DSM Scenario 1, demand shifting can cause some thermal stress on the network after midnight.

Table 4. Number of Customers who have voltage drop issues (With DSM)

Penetration level of EVs	Winter		Summer	
	weekday	weekend	weekday	weekend
80%	8	10	5	6
90%	16	17	6	8
100%	18	18	8	10

Above table represents number of customers who have voltage drop issues on the Feeder 4 in winter and summer time considering the EV penetration levels DSM Scenario 1 conditions. In this case, PV profiles are changing according to relevant season. Furthermore, to understand network reaction, weekday and weekend's domestic base load profiles were evaluated. When penetration level of EVs was increased, voltage drop issues were also generally rising. Basically, on a weekend in winter, voltage drop issues were more compared to a weekday in summer. If deployment of EVs is 100%, 18 customers out of 100 for winter and almost 10 customers in summer were having voltage drop issues.

Table 5.Number of Customers who have voltage rise issues

Penetration level of EVs	Winter		Summer	
	weekday	weekend	weekday	weekend
80%	0	0	28	38
90%	0	0	24	38
100%	0	0	23	38

Table 5 represents number of customers who have voltage rise issues considering DSM Scenario 1. From Table 5, we can see that there was no voltage rise issue in winter. However, when penetration level of EVs increases voltage rise issues decreases but at a slow rate. Surprisingly, despite the fact that deployment of EVs were increasing in the Feeder 4, number of customers who complain about voltage rise was the same amount, 38. Probably, customers' distance to the busbar affected the end-user complaints.

<u>**Conclusion:**</u> Main findings are as follows:

- ❖ In both seasons, by means of DSM scenario 1, voltage drop issues declined dramatically. In some cases, the gain of the scenario reached around 50%.
- ❖ This scenario can deal with voltage drop issues, but existing voltage rise issues in summer cannot be sorted out.
- ❖ Electricity consumption cannot be met from the sun because of low availability of sunlight.

- ❖ In summer, although electricity generation is high, DSM scenario 1 cannot make big difference in the context of diminishing the peak demand.

4.3.2 DSM Scenario 2 (Demand Shifting to Afternoon)

As stated Section 3.4.2, the base EV demand profile was created and named as UK_EV (No DSM). In order to propose optimum DSM concept for maximising generation and minimising peak demand, DSM Scenario 2 was applied into the Landgate network. Although the scenario was implemented on all feeders, only Feeder 4's situation was analysed and presented (it has 100 customers and the biggest feeder in the Landgate network).

In this sub-section, base EV demand profiles (EV_UK, without DSM) and DSM Scenario 2 (EV-Afternoon, with DSM) were applied separately. Mainly for the scenario 2, in order to demonstrate Landgate network behaviour, summer conditions were considered. First, EV_UK's Feeder4 (Busbar) power diagram and voltage graph of end of the Feeder 4 were introduced. Secondly, customers who have voltage drop and rise issues were investigated for 80%, 90% and 100% penetration levels of EV on the Feeder4. All these steps were also applied for DSM scenario 2 and results are presented.

EV_UK (No DSM):

It can be clearly seen from Figure 14 that when applying 100% EV penetration level and PVs on Feeder 4 (summer conditions), end of the feeder 4 has huge voltage rise issues, additionally, end-user of Feeder 4 is facing with voltage drop issues on-peak demand time as well.

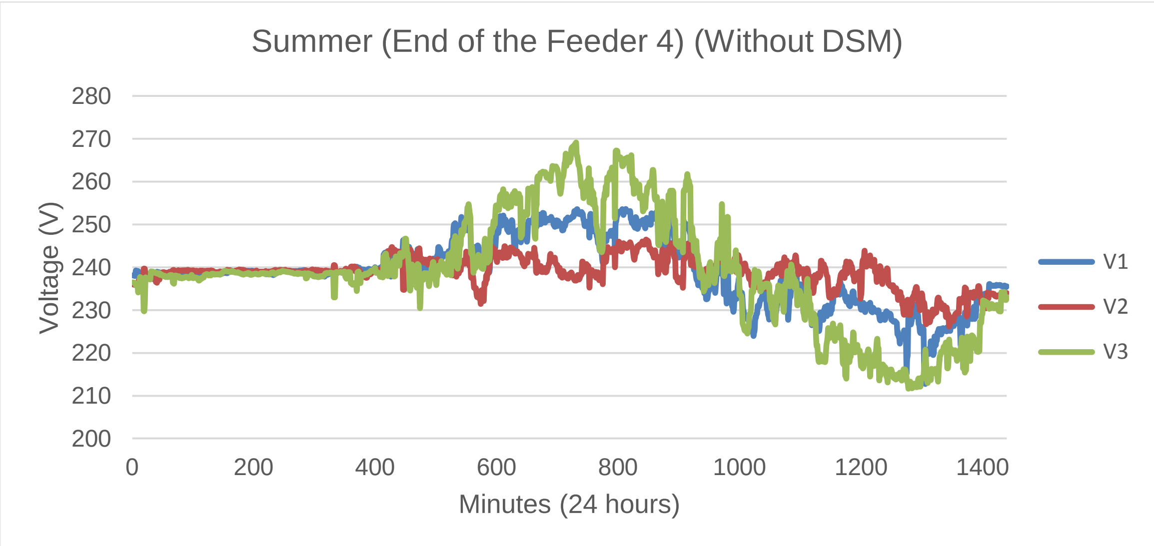


Figure 31. Voltage Diagram of End of the Feeder 4 EV_UK charge (Without DSM)

Following statements describe end-user's voltage situation:

- $V_{Maximum}$ of end-user was reached 270V on-peak generation time.
- $V_{Minimum}$ of end-user was reached around 211V on-peak power consumption time

In this case, voltage statutory limits are accepted as 230 +10% (V_{Max}) and 230 -6% (V_{Min}).

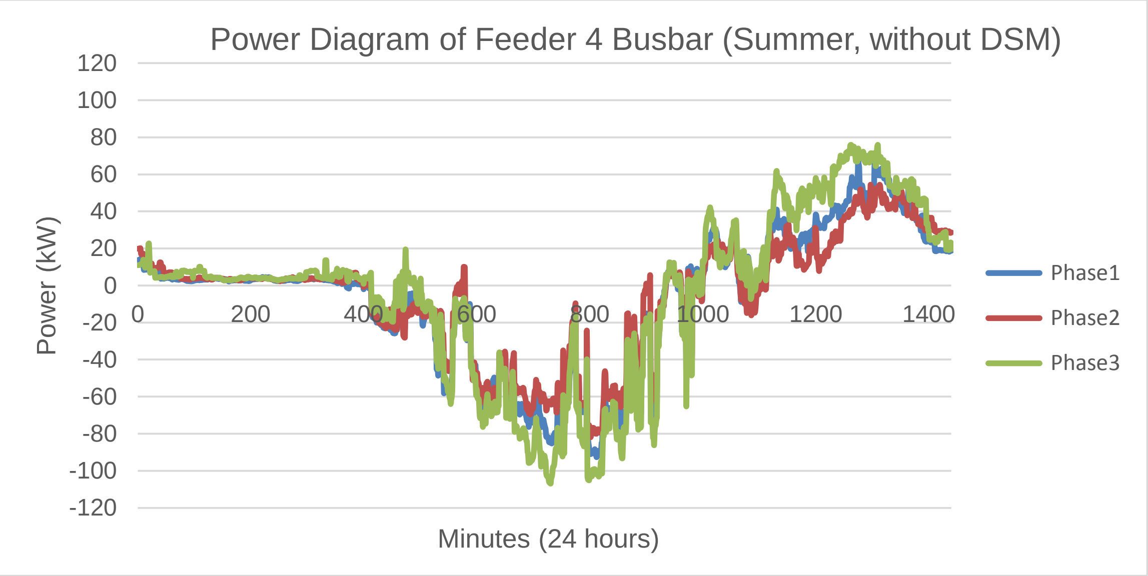


Figure 32. Power Diagram of Net Aggregated demand of EVs-PVs for UK (No DSM)

Above line graph represents net power consumption and generation considering EV_UK and summer PV profiles on Feeder 4 busbar. At the peak generation time, power generation was much higher than power consumption. Between 10 am and 2.30 pm, net demand rose to above 100 kW on the Feeder 4. On the contrary, power consumption at the on-peak time (from 7pm till 11 pm) reached almost 80 kW on the Feeder 4. In normal summer conditions for Landgate location, difference between power generation and consumption was approximately 20 kW, on peak times.

Table 6. Number of Customers who have voltage rise issues (Without DSM)

Penetration level of EV	Winter		Summer	
	weekday	weekend	weekday	weekend
80%	0	0	26	39
90%	0	0	26	39
100%	0	0	28	39

Above table represents number of customers who have voltage rise issues on the Feeder 4 in winter and summer time considering the EV penetration levels base conditions (UK_EV). In this situation, PV profiles changed according to relevant season.

Furthermore, when deployment of EVs was increased, number of voltage rise issues was almost the same. This was likely due to the random change of customers' selection when EV penetration level was changed. In terms of winter conditions, customers didn't face voltage rise issues because of low generation rate in winter. On the other side, in summer, number of customers who has voltage rise issues was around 27 and 39 for weekdays and weekends respectively.

DSM Scenario 2 (With DSM):

It can be clearly seen from Figure 33 that when applying 100% EV penetration level and PVs on Feeder 4 (summer conditions), end of the feeder 4 has voltage rise issues. It has diminished, compared to Figure 31 and voltage drop issues of end-user in Feeder 4 have considerably declined on-peak demand time. Basically, end of the feeder 4 was also affected by demand shifting positively. Voltage improvement was observed as compared to conditions of EV_UK (Figure 31).

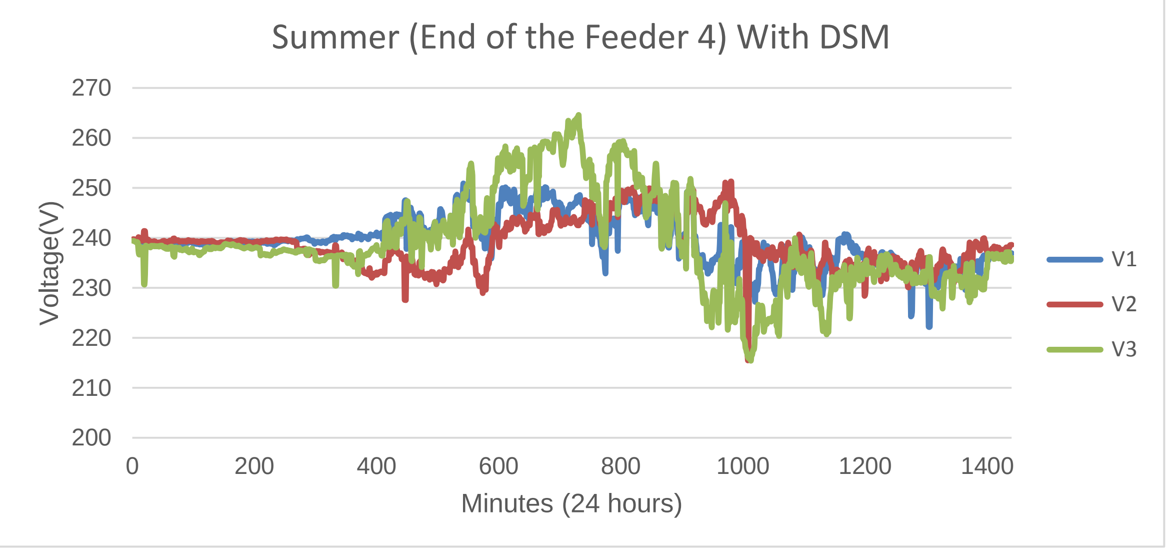


Figure 33.Voltage Diagram of End of the Feeder4 Afternoon EV charging (With DSM)

- ❖ $V_{Maximum}$ of end-user reached around 260V on-peak generation time, which is not in the voltage limit range. Compared to summer EV_UK base scenario, it has less value.
- ❖ $V_{Minimum}$ of end-user reached around 215V on-peak power consumption time.

In this case, voltage statutory limits are accepted as 230 +10% (V_{Max}) and 230 -6% (V_{Min}). In normal base conditions (UK_EV), there was less voltage rise at on-peak generation time. After some demand shifting to afternoon, it can be seen there was a slight amount of voltage drop in feeder 4.

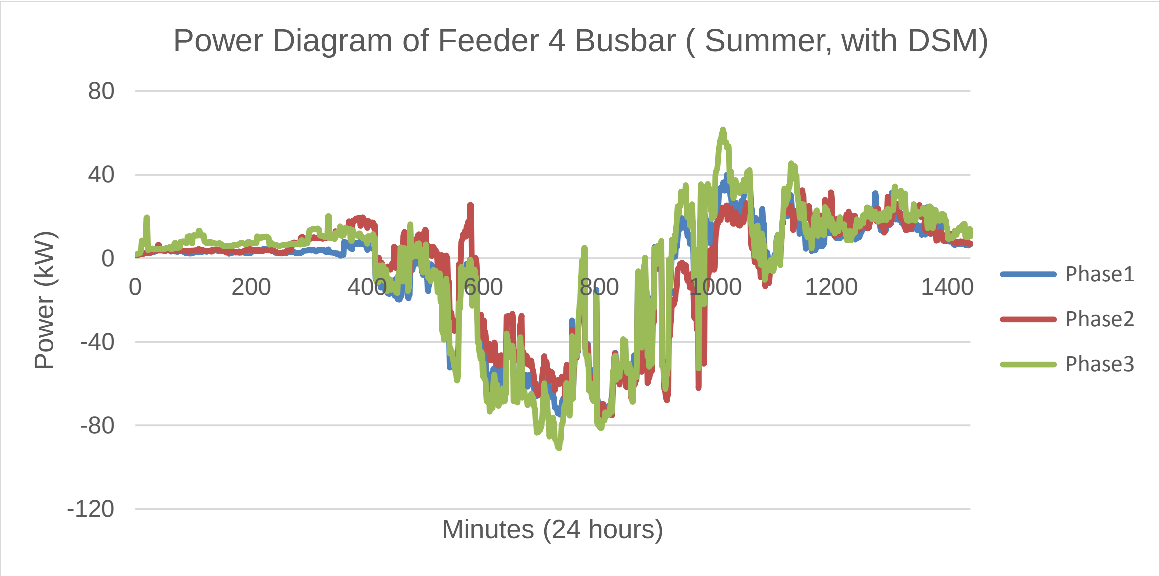


Figure 34. Power Diagram of Net Aggregated demand of EVs-PVs for UK (with DSM)

Above line graph describes net power consumption and generation considering DSM Scenario 2 and summer PV profiles on Feeder 4 busbar. At the peak generation time, power generation was much higher than power consumption. Between 10 am and 2.30 pm, net demand reached above 80 kW on the Feeder 4. On the other hand, power consumption at the on-peak time (from 7pm till 11 pm) reached 40 kW on the Feeder 4. In normal summer conditions for Landgate location, according to peak times, power consumption was 2 time less than power generation. Essential findings are as follows:

- ❖ One of the main results is that shifting demand to afternoon can decrease the peak time power consumption. Also, generated power from the PVs was used more.
- ❖ In perspective of power generation, shifting demand to afternoon can diminish net power profile (power consumption and generation) on-peak generation times (between 10 am and 2.30 pm). (By the help of Figure 32 and 34)
- ❖ In DSM Scenario 2, demand shifting can help in maximising usage of PV generation, but the implemented scenario was not very appropriate for real life conditions.
- ❖ In general, voltage drop issues declined dramatically, however voltage rise problem changed but at a very low level.

Table 7. Number of Customers who have voltage rise issues (With DSM scenario 2)

Penetration level of EV	Winter		Summer	
	weekday	weekend	weekday	weekend
80%	0	0	24	31
90%	0	0	23	26
100%	0	0	23	22

Above Table shows number of customers who have voltage rise issues on the Feeder 4 in winter and summer time considering the EV penetration levels DSM Scenario 2 conditions. The weekday and weekend domestic base load profiles were assessed to understand network reaction. When penetration level of EVs is dropped, voltage rise issues increased slightly. When penetration level of EVs is 100%, no customer in winter and almost 23 customers out of 100 in summer have voltage rise issues.

Table 8.Number of Customers who have voltage drop issues (With DSM Scenario 2)

Penetration level of EV	Winter		Summer	
	weekday	weekend	weekday	weekend
80%	9	10	0	0
90%	24	26	0	0
100%	34	35	6	0

Table 8 represents number of customers who have voltage drop issues considering DSM Scenario 2. From the Table 8 above, there was no voltage drop issue in summer, except summer weekday (6 customers). When penetration levels of EVs increased, the number of people who face voltage drop issues also increased.

Conclusion: Main findings are given in an order as follows:

- ❖ In both seasons, by means of DSM scenario 2, voltage drop issues declined dramatically. Comparing base situation (EV_UK) in summer days, the voltage drop issues were considerably low in DSM Scenario 2.
- ❖ DSM scenario 2 can deal with voltage drop issues in summer, however this scenario shouldn't be implemented in winter as there is not much difference, considering EV_UK base situation.
- ❖ The aim of DSM scenario 2 is achieved in summer, but for winter.

4.4 DSM interactions of Electric Heat Pumps

In this section, in order to assess DSM interactions of EHPs, of PVs and domestic base loads, winter conditions was selected and implemented into the Landgate network. Results of EHP's scenario is presented.

4.4.1 Evaluation of Ambient Temperature Changes

As previously mentioned in section 3.5, the impact of ambient temperature changes were evaluated in the context of DSM solution. 18°C and 21°C room temperatures were considered. First of all, Landgate network behaviour on voltage and power profiles were examined and presented for winter weekday conditions. In order to show these profiles' status, Feeder 4 was chosen. After that, EHP's effects on Feeder 4's customers were also examined by considering penetration level of EHPs.

21°C Ambient Temperature:

21°C degree of ambient temperature was selected for condition of Feeder 4's customers. Below line graphs show end of the Feeder 4's voltage and power diagrams keeping in mind 100% penetration level of EHPs (Note: 50% penetration level of EHP is also presented in Appendix 1).Voltage statutory limits are accepted as 230 +10% (V_{Max}) and 230 -6% (V_{Min}). Voltage and power profiles are described as follows:

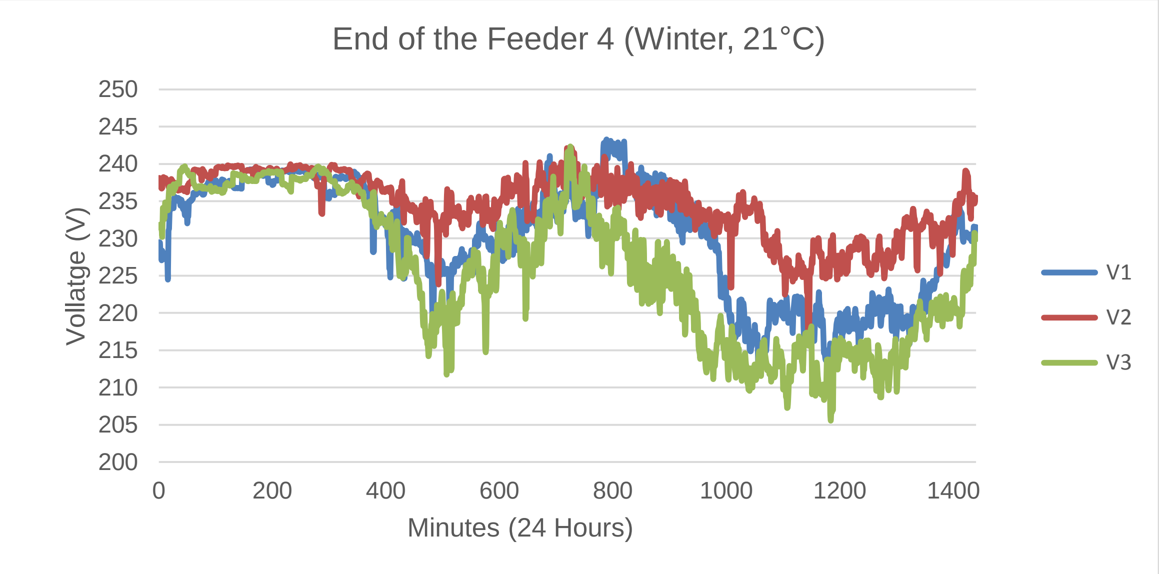


Figure 35. Voltage diagram of end of the Feeder 4 - 100% penetration of EHP (21°C)

End-user's voltage status is as follows:

- $V_{Maximum}$ of end-user reached 240V on-peak generation time.
- $V_{Minimum}$ of end-user dropped under 210V on-peak power consumption time.

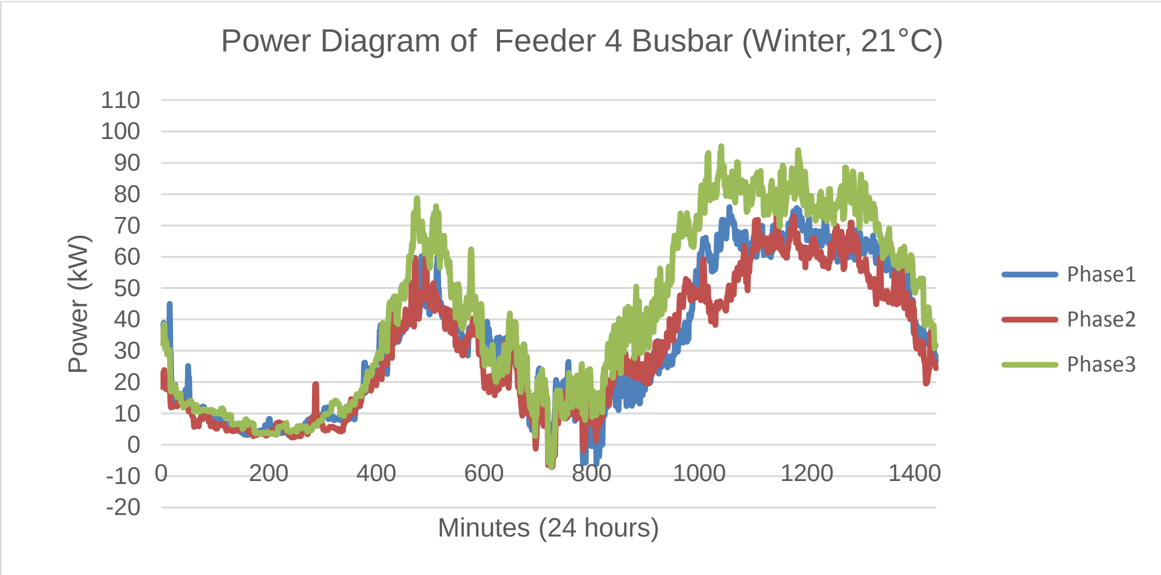


Figure 36. Power diagram of Feeder 4 (Busbar) - 100% penetration of EHP (21°C)

Above line graph describes net power consumption and generation considering 21°C ambient temperature (winter) on Feeder 4 busbar. At the peak generation time, there was low power generation, compared to summer time. On mornings (7am – 10am) and evenings (5pm - 9.30pm), net aggregated demand reached, at the peak time, 80kW and 90 kW for Feeder 4 respectively. Although there was power generation, it does not make major difference in the net demand of Feeder 4.

18°C Ambient Temperature:

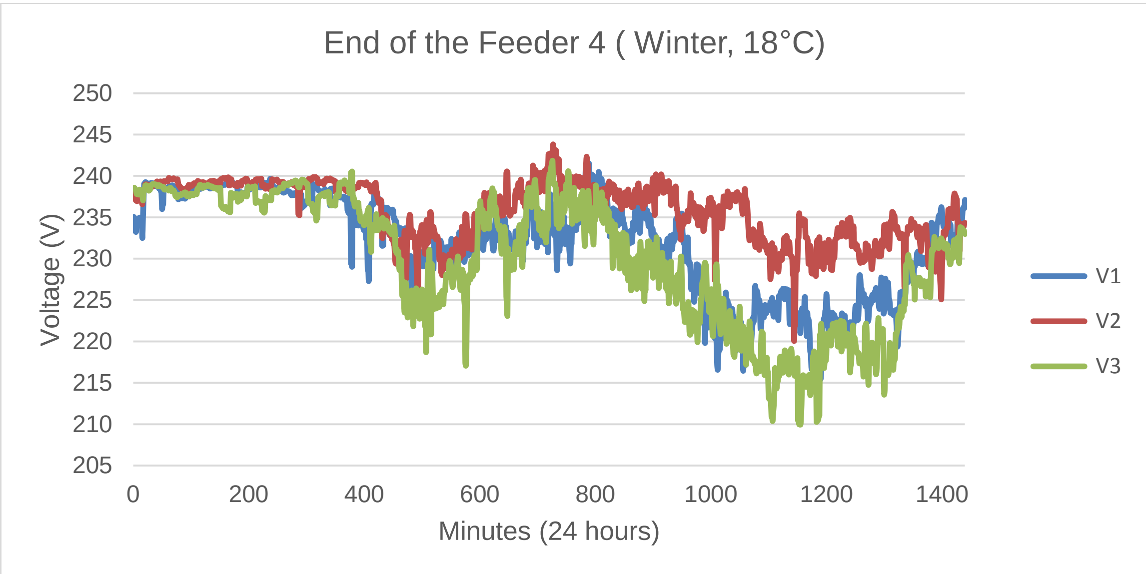


Figure 37. Voltage diagram of end of the Feeder 4 - 100% penetration of EHP (18°C)

To apply DSM solution in network, changing ambient temperature to 18°C is considered.

Above figure 37 illustrates voltage diagram for end of the Feeder 4. End-user's voltage situation is as follows:

- ❖ $V_{Maximum}$ of end-user reached around 240V on-peak generation time.
- ❖ $V_{Minimum}$ of end-user dropped to 210V on-peak power consumption time. Compared to the 21°C, voltage improvement was slightly achieved.

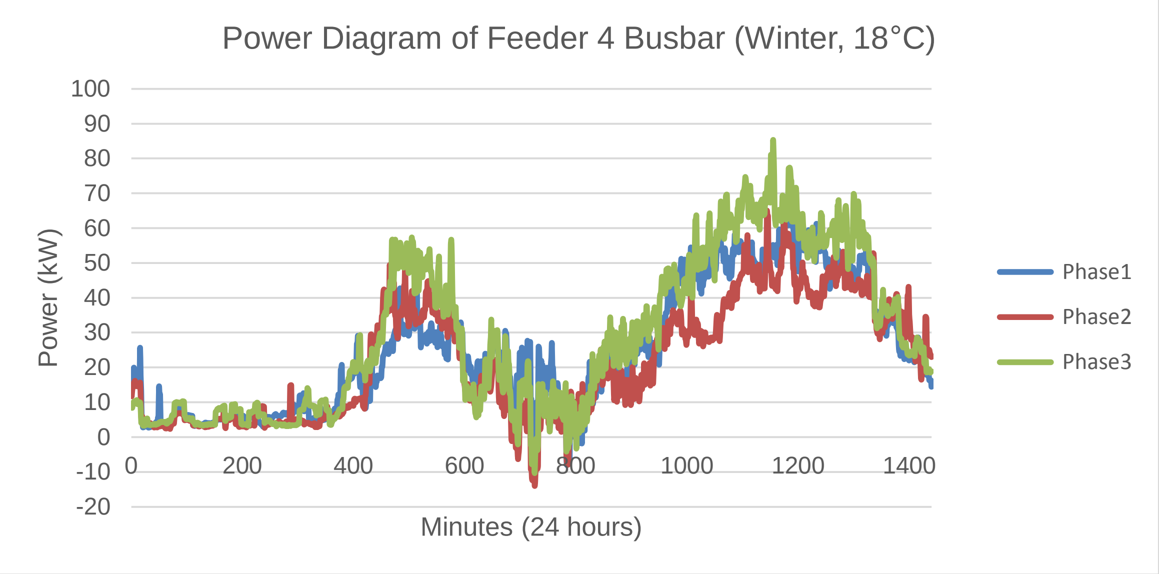


Figure 38. Power diagram of Feeder 4 (Busbar) - 100% penetration of EHP (18°C)

Above line graph describes net power consumption and generation considering 18°C ambient temperature (winter) on Feeder 4 busbar. In the morning (7am – 10am) and evening (5pm - 9.30pm), net aggregated demand reached around 60kW and 80 kW at the peak time for Feeder 4 accordingly. In Figure 38, power generation on-peak time was the same as Figure 36, but there was a small difference on net aggregated demand because of disparity of power consumption in on-peak generation time.

50%, 60%, 70%, 80%, 90% and 100% penetration levels of EHPs were implemented into Landgate network considering winter conditions. The Figure 22 compares EHP's deployment on the Feeder 4 in the context of voltage drop issues of customers. For both temperature cases, 100 customers' voltage diagrams were controlled one by one. In general, voltage drop started to become problematic after 50% deployment of EHPs. It can be clearly seen from Figure 39 that there was a drastic increase in number of customers who faced voltage drop issues in the Feeder 4 after 80% penetration level of EHPs. When EHP's implementation levels reaches 100%, problems on the network was maximized. For 21°C, number of voltage drop complaints was 55 out of 100 and for 18°C, the number of voltage drop complaints was only 36 customers.

EHPs	50%	60%	70%	80%	90%	100%
18°C	1	3	3	7	23	36
21°C	3	7	10	34	48	55

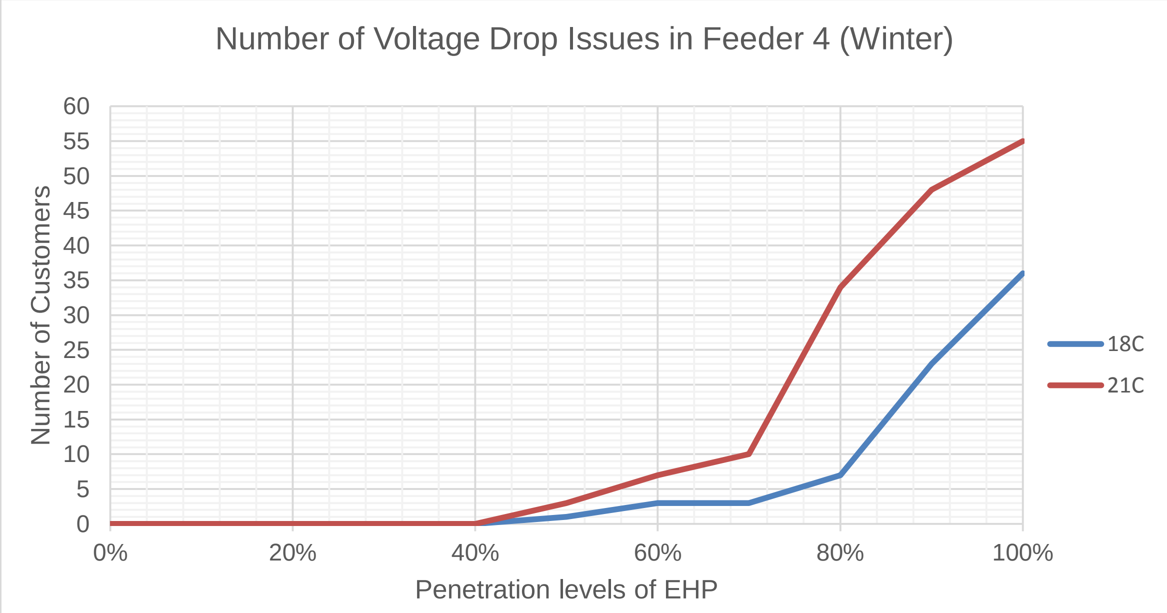


Figure 39. Number of Customers who have voltage drop issues in Feeder 4 (winter)

In order to understand EHP's behaviour, energy meter was applied on the Landgate network. Following Table 9 describes overall energy results regarding PVs, EHPs and base loads in both temperature cases. As seen from Table 9, energy consumption in case of 21°C was quite higher than in case of 18°C. In perspective of active energy and reactive energy, when the penetration level of EHPs are increasing, energy consumption between 21°C and 18°C scenarios were also growing in parallel.

Table 9.Overall Energy Results for winter (Considering EHPs, PVs and base loads)

			18°C			
Energy Meter	Busbar					
Penetration of EHPs	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
kWh	4343	4721	5106	5505	5851	6351
kvarh	1239	1275	1317	1364	1411	1482
(PV) Gen kWh	681	681	681	681	681	681
			21°C			
Energy Meter	Busbar					
Penetration of EHPs	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
kWh	5041	5556	6124	6708	7270	7982
kvarh	1308	1364	1438	1520	1608	1730
(PV) Gen kWh	681	681	681	681	681	681

5 Conclusion

In this part, main results are analysed and the study's key points and possible future works are highlighted.

5.1 Conclusions

In this dissertation project, one low voltage distribution network has been assessed in the context of low carbon technologies. The low carbon technologies are modelled as close as possible to real conditions. Generation and domestic load profiles were modelled and tested on the real network with various penetration levels of low carbon technologies. The potential impacts of green technologies were examined. By the help of DSM scenarios, voltage and power diagrams, advantages and disadvantages of DSM concept were described as much as possible and overall energy results of system were presented. In order to observe DSM solutions' impacts on grid, feeder4, which has 100 customers, was chosen. To evaluate DSM interactions with EVs, two scenarios were developed. For EHPs, changing ambient temperature of system was implemented. For these applied scenarios' important results on the Landgate Network are highlighted as follows:

5.1.1 Key Findings

- Considering voltage statutory limits of UK's low voltage networks, the Landgate network can cope with voltage rise issues for up to 60% penetration level of PVs without any electricity generation control element (No smart PV on-off control mechanism). However, PV capacity (60%) is dependent to the clearness of sky. Voltage rise issues can be decreased if smart control mechanism is used by communication of customer and generation system (Generation Curtailment Signal, not in the context of DSM). Another solution can be storage system, but it is likely to bring extra cost for customers.
- Domestic load profiles of weekends in winter have bigger power consumption than weekdays in summer. It was probably based on assumption that people spend more time at home on weekends in winter than that of weekdays in summer.
- Generally, the Landgate network can deal with voltage drop issues up to 60% penetration level of EVs without any intelligent control mechanism.
    1. Applying **DSM Scenario 1**;
        - Voltage drop issues drop to 50% and 70% considering base case (EV_UK) in winter and summer respectively because electricity

generation in summer is high; voltage drop issues were lesser than winter time.

- In this scenario, customer's EV charging routine time was assumed to change after midnight. It can be implement into real life conditions if electricity price after midnight is considerably cheaper than peak times. The customers tend to change their EV charging habits on when they find it advantageous.
- This scenario does not help to alleviate the voltage rise issues in summer positively, which arises from PVs.
- Peak demand in the Feeder 4 decreased 25%, compared to base case scenario (EV_UK for winter).

2. Applying **DSM Scenario 2**;
   - The aim of this scenario is to maximize usability of PVs and decrease peak power consumption. It was assumed that people have advantage on electricity price when they charge their EVs in the afternoon. Taking that into consideration, voltage drop issues of Feeder 4 was slightly minimized in winter, on the other side, it was decreased considerably highly in summer. This result came out because of PV's usage.
   - In this scenario, voltage rise issues declined, compared to base scenario (EV_UK). However, demand shifting to afternoon did not make huge difference for the voltage rise issues. In order to sort it out, storage options should be brought onto the solution options.
   - Generally, people have little EV charging habits in the afternoon. As a result of this, DSM Scenario 2 is not appropriate for real life conditions. Hence DSM Scenario 1 is more applicable to network.
   - Peak demand in the Feeder 4 declined 50%, compared to base case scenario (EV_UK for summer).

- Basically, EHPs can be implemented into the Landgate network up to 50% deployment level. Beyond that level, voltage drop issues started to arise sharply in both cases of different temperatures.
- Decreasing ambient temperature by 30C can reduce power consumption and thereby releasing stress on the network. In some penetration cases, network can obtain a voltage drop of around 50% in the 18°C profile. But, graphs in part 4.4.1 showed network can still have voltage drop issues with 100% penetration level of EHPs. We can clearly see that the gain from DSM was achieved.

- In EHP scenario, it was assumed that houses have good insulation conditions. Customer's comfort should be analysed when decreasing ambient temperature to 18°C.
- Dropping 3°C of ambient temperature is provided around 10% reduction on the peak demand.
- According to Landgate network's location, concept of maximizing PV generation in winter is likely to be achieved with thermal storage system to supply EHPs. On the contrary, due to the lack of EHP usage in summer, PV generation usage cannot be increased to a higher level.

5.1.2 Project Limitations

- Due to limited time, DSM scenarios could not be improved very well for EHPs and EVs. With high quality coding, DSM scenarios can be implemented and analysed as an hour by hour concept.

- In perspective of EHP's load profile, modelling load profiles can be improved if the developer can consider not only ambient temperature, but also insulation condition of house.

- EV load profiles could have been developed to a better quality in this project if more field trial results could be taken into consideration.

- In this project, storage systems were not taken into account. As a general perspective, battery systems can maximize PV generations and minimize on-peak electricity demands but without any storage systems, the usage of PV generation brings capacity issues to the grid. Reverse power is generated in the line, which is undesirable.

5.1.3 Future Works

- In the context of maximizing PV generation, by means of smart system (such as smart meters etc.), customers or DNOs can communicate with generation system for more or less electricity production depending on the demand. The customer can control PVs in an intelligent way to facilitate their energy requirement (one or two way communication). In this case, operators or customers can change PV system behaviour with remote control. Implementing storage system on the network can raise usage of PVs. It is likely that battery option seems best choice.

- In perspective of DSM, smart metering system can enable the implementation of time-varying pricing. Accordingly customers can change their EV charging habits looking at the price signals. In future works, price signalling can be taken into consideration.

- Considering EHPs, thermal comfort of customers is as important as electricity price. In some cases, price signals cannot work properly to reduce peak demand. Thermal heat storage systems can be possible DSM options. Last but not least, if customers know their forecasting of future electricity demand, they can avoid the peak demand time hazardous effects. One of the future works can be end-user's electricity demand forecasting.

6 References

[1] DECC, “2050 Pathways Analysis,” 2010.
[2] DECC, “UK Renewable Energy Roadmap Update 2013,” 2013.
[3] L. F. Ochoa, C. J. Dent, and G. P. Harrison, “Using OPF With Voltage Step Constraints,” IEEE Trans. POWER Syst., vol. 25, no. 1, pp. 296–304, 2010.
[4] S. Kärkkäinen, “Integration of Demand Side Management , Distributed Generation , Renewable Energy Sources and Energy Storages,” 2010. [Online]. Available: http://energy-storage.org/files/dsm_k_rkk_inen.pdf.
[5] POST, “Residential Heat Pumps,” Postnote, no. 426, 2013.
[6] POST, “Electric Vehicles,” Postnote, no. 365, pp. 1–4, 2010.
[7] DECC, “UK Solar PV Strategy Part 1: Roadmap to a Brighter Future,” 2013.
[8] P. Clipping, “The Concept of Demand-Side Management for Electric Utilities,” no. 10, pp. 1468–1470, 1985.
[9] J. Eto, “The Past , Present , and Future of U . S . Utility Demand-Side Management Programs,” 1996.
[10] E. D. Hausman, S. Associate, and R. D. Tabors, “The Role of Demand Underscheduling in the California Energy Crisis,” vol. 00, no. C, pp. 1–8, 2004.
[11] S. D. Braithwait, K. Eakin, and L. R. C. Associates, “THE ROLE OF DEMAND RESPONSE IN ELECTRIC POWER,” 2002. [Online]. Available: http://www.smartgridnews.com/artman/uploads/1/sgnr_2007_12014.pdf.
[12] G. Strbac, “Demand side management: Benefits and challenges,” Energy Policy, vol. 36, no. 12, pp. 4419–4426, Dec. 2008.
[13] P. Kadar, “Understanding customer behaviour,” in 2008 IEEE/PES Transmission and Distribution Conference and Exposition: Latin America, 2008, no. 1, pp. 1–4.
[14] G. Hoogsteen, A. Molderink, V. Bakker, and G. J. M. Smit, “Integrating LV network models and load-flow calculations into smart grid planning,” IEEE PES ISGT Eur. 2013, pp. 1–5, Oct. 2013.
[15] P. Navarro, Alejandro; Ochoa F.Luis; Mancarella, “Learning from residential load data: Impacts on LV network planning and operation,” in 2012 Sixth IEEE/PES Transmission and Distribution: Latin America Conference and Exposition (T&D-LA) p. 1-8, 2012, pp. 2011–2014.
[16] H. of Parliament, “Electricity Demand-Side Response,” 2014. [Online]. Available: http://www.parliament.uk/business/publications/research/briefing-papers/POST-PN-452/electricity-demandside-response.
[17] “Photovoltaic History,” 2013. [Online]. Available: http://www.sunlightelectric.com/pvhistory.php. [Accessed: 24-Sep-2014].
[18] E. Energy, “A History of UK Solar Photovoltaics,” 2012. [Online]. Available: http://www.evoenergy.co.uk/i/uk-solar-pv/. [Accessed: 24-Sep-2014].
[19] A. Navarro, G. S. Member, L. F. Ochoa, S. Member, and D. Randles, “Monte Carlo-Based Assessment of PV Impacts on Real UK Low Voltage Networks,” 2013, pp. 1–5.
[20] M. Batman and F. Bagriyanik, “An evaluation of demand side management in a grid-connected PV system in Istanbul, Turkey,” North Am. …, 2011.
[21] J. Widén, E. Wäckelgård, and P. D. Lund, “Options for improving the load matching capability of distributed photovoltaics: Methodology and application to high-latitude data,” Sol. Energy, vol. 83, no. 11, pp. 1953–1966, Nov. 2009.
[22] M. Guarnieri, “When cars went electric, part one,” Ind. Electron. Mag. IEEE, no. March, pp. 61–62, 2011.
[23] W. Nichols, “History of the electric car: nineteenth-century novelty to 21st-century style,” 2011. [Online]. Available: http://www.theguardian.com/electric-vision/history-of-the-electric-car. [Accessed: 24-Sep-2014].

[24] A. Maitra, P. Richardson, A. Keane, J. Taylor, and M. Moran, "Impact of electric vehicle charging on residential distribution networks: An Irish demonstration initiative," Institution of Engineering and Technology, 2013.
[25] N. Saker, M. Petit, and J.-C. Vannier, "Electric Vehicles charging scenarios associated to Direct Load Control programs (DLC)," 2011 North Am. Power Symp., no. Dlc, pp. 1–7, Aug. 2011.
[26] DECC, "Renewable Heat Incentive," 2011. [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48041/1387-renewable-heat-incentive.pdf.
[27] I. Richardson, M. Thomson, D. Infield, and C. Clifford, "Domestic electricity use: A high-resolution energy demand model," Energy Build., vol. 42, no. 10, pp. 1878–1887, Oct. 2010.
[28] P. Mancarella, C. K. Gan, S. Member, and G. Strbac, "Evaluation of the impact of electric heat pumps and distributed CHP on LV networks," 2011.
[29] a. Arteconi, N. J. Hewitt, and F. Polonara, "Domestic demand-side management (DSM): Role of heat pumps and thermal energy storage (TES) systems," Appl. Therm. Eng., vol. 51, no. 1–2, pp. 155–165, Mar. 2013.
[30] S. Nykamp, a. Molderink, V. Bakker, H. a. Toersche, J. L. Hurink, and G. J. M. Smit, "Integration of heat pumps in distribution grids: Economic motivation for grid control," 2012 3rd IEEE PES Innov. Smart Grid Technol. Eur. (ISGT Eur., pp. 1–8, Oct. 2012.
[31] R. Dugan, "OpenDSS," 2010. [Online]. Available: http://sourceforge.net/apps/mediawiki/electricdss/index.php?title=OpenDSS_Uniqueness. [Accessed: 25-Sep-2014].
[32] I. Richardson and M. Thomson, "Domestic electricity demand model simulator (CREST)," 2010. [Online]. Available: https://dspace.lboro.ac.uk/2134/5786. [Accessed: 25-Sep-2014].
[33] Office for National Statistics, "Statistical Bulletin Families and Households , 2012," 2012. .
[34] L. Zhang, "Techno-Economic Modelling and Control of Distributed Energy Resources for Demand Response," 2013.
[35] N. Good and L. Zhang, "Physical modeling of electro-thermal domestic heating systems with quantification of economic and environmental costs," EUROCON, 2013 …, no. July, pp. 1164–1171, 2013.

7 Appendix 1

Power and Voltage Diagrams: (50% penetration level of EHPs for 21°C)

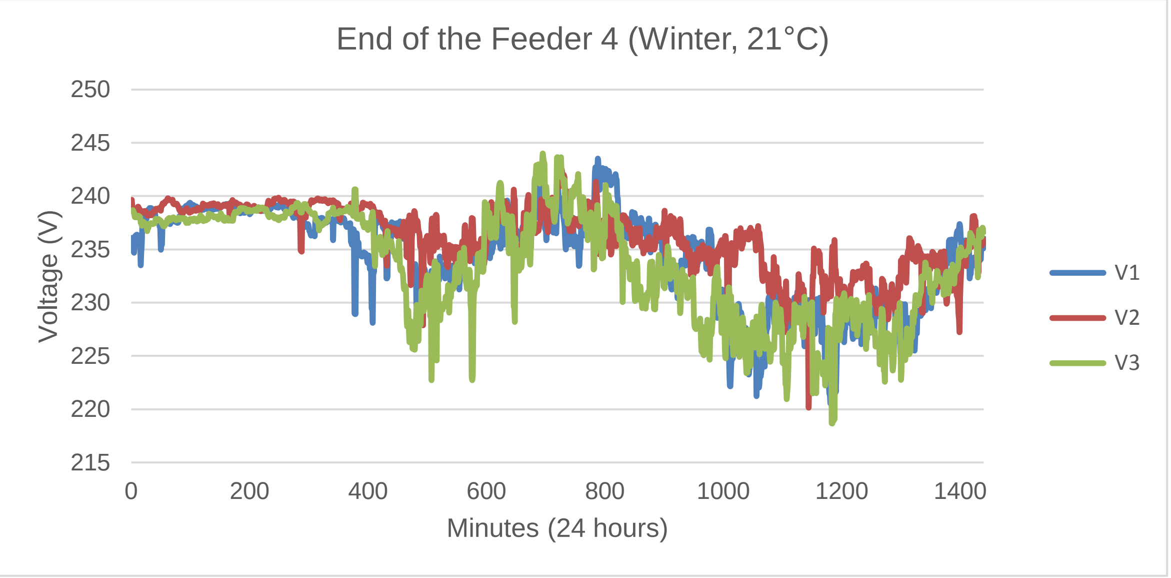


Figure 40 Voltage diagram of end of the Feeder 4 - 50% penetration of EHP (21°C)

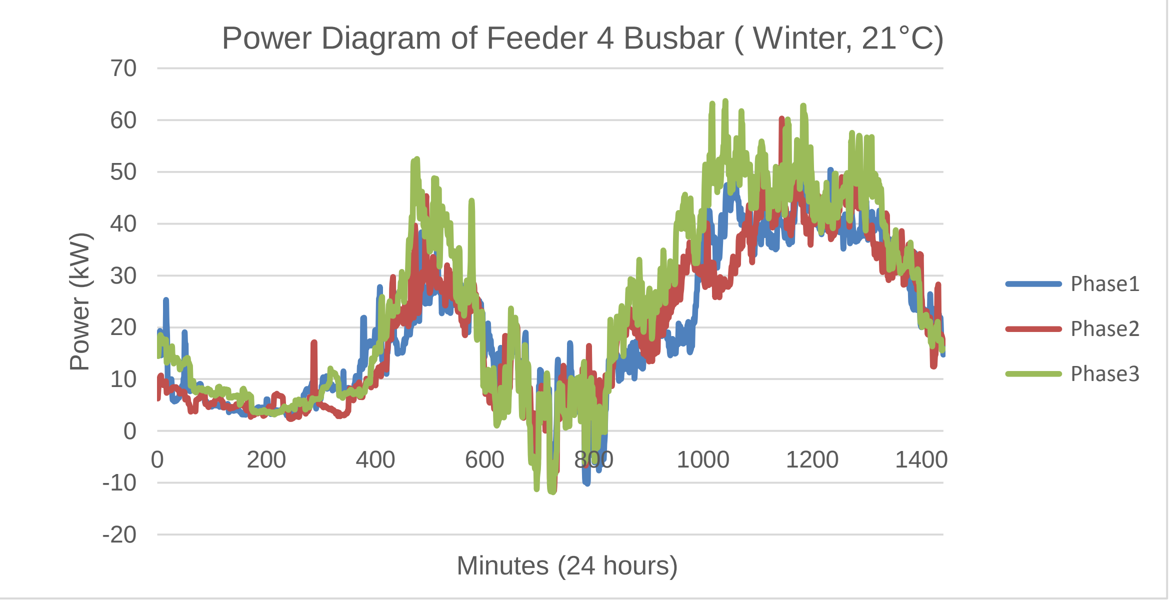


Figure 41. Power diagram of Feeder 4 (Busbar) - 50% penetration of EHP (21°C)

Power and Voltage Diagrams: (50% penetration level of EHPs for 18°C)

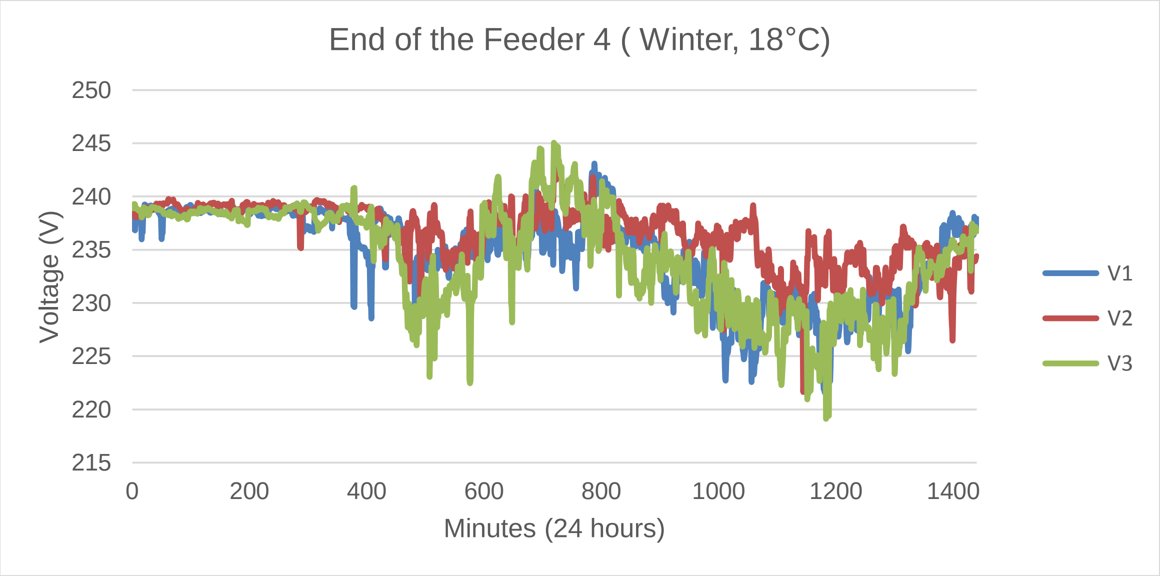


Figure 42. Voltage diagram of end of the Feeder 4 - 50% penetration of EHP (18°C)

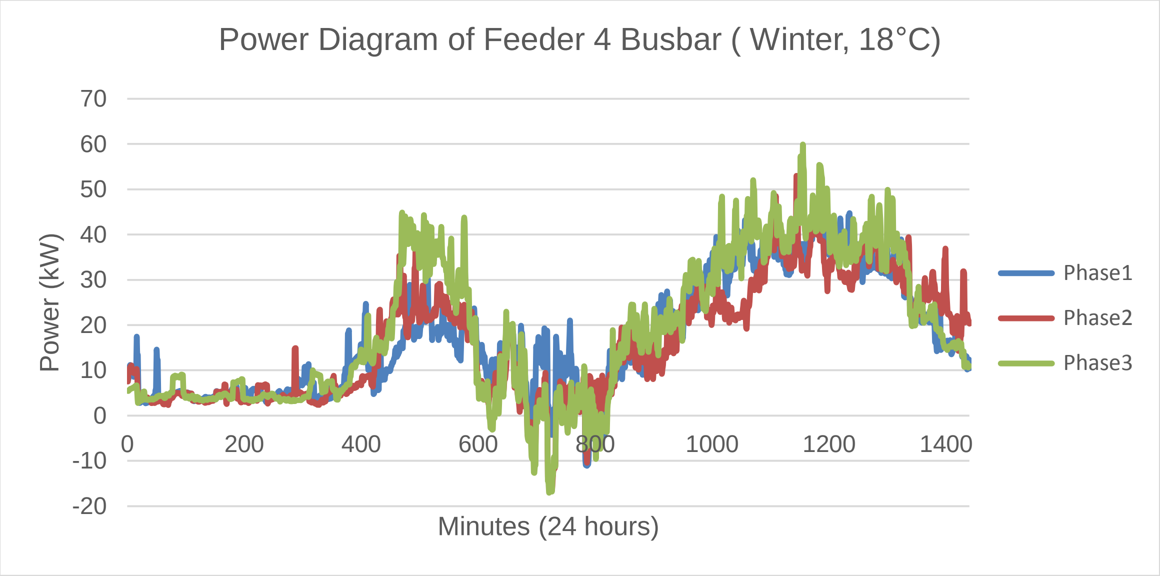


Figure 43. Power diagram of Feeder 4 (Busbar) - 50% penetration of EHP (18°C)

The University of Manchester

8 Appendix 2 (Feasibility Study Report)

Abstract

Most countries around the world have announced decarbonisation pathways and projections, such as United Kingdom has goals that 80% CO2 emission reduction in energy and transport by 2050 below 1990 levels, additionally, more than 30% of electricity generated, 12% of heat generated and 10% of transport fuels will be from renewable resources by 2020 [1], [2].Generally, governments have been encouraging people with financial incentives for eco-friendly technologies in order to achieve the targets. Starting from this point of view, the adoption of low-carbon technologies such as electric vehicles (EVs), small-scale Photovoltaic (PV) panels and electric heat pumps (EHPs) will reach vital levels on low voltage distribution systems. On the other hand, the diversified generation peak from PVs and diversified large charging levels of EVs will create network issues (Reverse power flow, Voltage rise-drop etc.). In the operational perspective, Distribution Network Operators (DNOs) concerns about these fatal influences on distribution lines. To avoid these impacts, the understanding of the penetration level of PV panels and EVs play essential key roles on network design stage as well as in the context of demand-based controls (Demand side management (DSM).

INTRODUCTION

Project Background

Low carbon technologies, for instance, small-scale photovoltaic (PV) power generation, Air and Ground Source Heat Pumps (ASHPs, GSHPs respectively), and Electric Vehicles (EV) will be important decarbonisation components in the climate system, and will play a key role in smart grids and existing electricity distribution networks. Most countries have announced decarbonisation pathways and projections, such as United Kingdom has goals of 80% CO_2 emission reduction in energy and transport by 2050 below 1990 levels [1]. In addition to, more than 30% of electricity generated, 12% of heat generated and 10% of transport fuels will be from renewable resources by 2020 [2]. It is likely indicated these targets that electrification of transport, electrification of heating and generation by renewables will be important points for the system sustainability.

Until a short while ago, distribution network operations were dominated by conventional generation systems. Along with the penetration of decentralized generations into the electricity market, many problems appeared not only in the low voltage, but also in medium voltage networks such as, voltage issues, frequency changes and, overloading [3], [4]. It is possible that all these problems address to raise electricity system reliability and flexibility, which are based on interaction between electricity generations and demand of end-users. In order to cope with the aforementioned issues, network reinforcement can be applied, but this comes with high capital costs. However, intelligent distribution network control systems (Demand-Side Management (DSM), Active Network Management (ANM) etc...) can relatively be a new approach in the energy industry and consider understanding of supply and demand.

Motivation of Project

As stated previously, governments have declared their low carbon strategies and scenarios because of the energy systems' sustainability and legally-binding decarbonisation targets [1], [2]. These projections generally rely on minimizing fossil-fuel consumption, maximizing renewable resource usage, energy conservation and last but not least energy-efficiency.

In order to reach these objectives, investors and small customers have been encouraged by means of financial incentives for micro-PVs, EVs, and Electric Heat Pumps (EHPs) in UK [2], [5], [6]. Considering that usage of these technologies has been increasing drastically [1]. As a result of this, transmission line, MV and especially LV networks will be affected significantly. Due to electricity demand is inelastic, uncontrollable, unmonitored and passive in current distribution networks, LV and MV distribution lines will struggle with problems of voltage rise and drop, frequency changes, peak demand increase and, reverse power flow. Having in mind those issues, DSM is likely to be a possible solution for LV networks. Traditionally, when peak demand increase in the network, electricity generation level raises immediately to meet enhanced demand. On the other hand, looking at DSM perspective, it makes an agreement with end-users to reduce consumption in specific time periods, instead of more generation.

This work will be focused on interactions between DSM and low carbon technologies. First of all, demand response (DR) can be clearly discussed, especially its related concepts' (such as time-of-use prizing) impacts on the LV-grids. Secondly, by the help of a distribution system simulator, the penetration of micro-PV generations will be analyzed considered to DSM into the current network. Following that it can be observed possible influences of EVs and EHPs on the network during the peak time. This project will quantify at what extend low carbon technologies can go beyond current usage levels considering the minimization of their impacts.

Objectives of the Project

1. To understand the behavior of LV networks by using low carbon technologies.
2. To understand potential Demand-Side Management (DSM) interactions among Electric Vehicles, Electric Heat Pumps and Photovoltaic (PV) in the context of maximizing PV generation and minimizing peak demand.
3. To simulate time-series profile models of EVs, domestic EHPs and small-scale PVs. The low voltage grid will be implemented by the help of a visual basic (VBA) software that interfaces OpenDSS (Distribution System Simulator) and VBA Excel in the context of time series profiles.
4. To analyze the influence of different low carbon technologies' penetrations in LV grids.
5. To suggest optimum DSM solutions within the context of maximizing power generation and decreasing peak demand.
6. Learn how to implement techniques into the grid that could be used by relating engineers, project managers and Distribution Network Operators (DNOs).
7. To be a master using the art open source software OpenDSS developed by EPRI (USA).
8. To make a report and presentation

LITERATURE REVIEW

Demand Side Management (DSM)

Although managing power supply, DSM is utilized to control demand. The main point of Demand-side management, also called Demand Response (DR), is that reduces peak demand by the help of the peak shifting, shaving and valley filling. DR is likely to increase flexibility between demand and supply, energy-efficiency, reduce energy-prices and protect from the “Blackout” in some cases. In the perspective of DNOs, DSM can mainly be categorized into three groups. These are direct-load control that DNOs manage customer load and generation, local-load control which is self-control at peak times and operator-load control (DNOs arrange real-time prices) [7].

In the literature [7], it is mentioned that there are several DSM techniques for reducing peak demand in the UK. The first one is that economy 7 tariffs are applied for night-time heating via load shifting. Similarly, these kinds of method are succeeding in other countries. Secondly, peak and off-peak prices (time-of-use pricing) are commonly used in many places. This method associates with at the price level for domestic electric heating. While examples show that DR has advantages for customers, DNOs and government, on the other hand, it consists of some challenges and disadvantages. These can be ordered as follows:

- The shortage of smart communication infrastructure.
- In the fully unbundling electricity market, demand-based methods are frequently not competitive compared to conventional industry.
- DSM is increasing the system complexity, compared to a conventional approach.
- Traditional market approach cannot be suitable for DR and its structure cannot be driven lack of financial incentives.

As mentioned previously, there are important numbers of DSM studies carrying out all over the world. The understanding of load behavior is one the essential parts demand-side response. On the basis of this characteristic, domestic appliances have been examined. Household appliances were divided into 4 parts and washing groups (passive loads) were focused on this case study [8]. It was expected that usage time of washing appliances was able to be moved to off-peak time for the reduction peak demand. It was also assumed that DNOs could manage washing group machines. These appliances were shifted in a random way and peak demand was investigated for all dwellings. In the analysis, it found that peak demand could decrease minimum 2%, average 12 % and maximum 32 % by shaving [8]. Furthermore, in order to reach achievement, case study was implemented in a real LV network. From this work, it was measured that the maximum peak demand reduced 14 % [8]. It can be brought some questions for case studies as follows:

• What is the potential role of green technologies (PV panels, EHPs and EVs) on peak demand shaving and their penetration impacts on the distribution network?

In an operational perspective on LV-grids, considering above questions, this study will be analysed a critical role of DSM for future network operating.

Photovoltaic (PV) Generation

As previously briefly mention that integration of micro-PV panels in low-voltage networks is rising in western industrialized countries dramatically. By means of government's encouragement on investors, 1.7GW out of 2.4GW total installed capacity is reached domestic-scale PVs with incentive tariffs in UK [9].It can be clearly indicated from [9] that ambitious future targets on the small-scale PV generation will affect LV networks significantly.

In recent years, there has been an increasing amount of literature on the large and small-scale PV generation's influences in the context of distribution network operations. From the LV network perspective, there is only limited amount of case studies considering thermal, overloading and voltage issues that have been carried out.

Analysis of PV impacts on LV networks was performed in [10] In this work, a "Monte Carlo" technique was implemented with PV integration on two real LV-grids in view of artificial data for load and electricity production. Defined load profiles were based on UK characteristic data. Following that the result of case study was investigated. In overload feeders, voltage issues are likely to show up to average 40 % of small-scale PV integration, on the other hand, small feeder could not affect if the number of customer and length are considerably low level (less than 35 people and 1 km respectively) [10]. The impact of micro-generation PVs on the grid was proved. There can be suggested some traditional solutions such as reinforcement which is expensive, but demand-side management can be cost-effective.

From this point of view, a broader perspective has been adopted by [11]. This work was presented newish approaches to previously mentioned issues (overloading, voltage rise/drop etc.), which included load matching method. The implemented study was analysed the impacts of the PV generation in terms of array orientation, DR and storage. It was shown that the most sufficient implement at high PV levels was storage option, but DSM was as much as productive taking into consideration of low overproduction levels. According to study, DSM is able to be alternative option for storage technologies in the context of maximizing PV generation.

Electric Heat Pumps (EHPs)

Electrification of heating has been one of the biggest challenges in the context of decarbonisation for meeting the global targets. For this reason, Electric Heat Pumps' (EHPs) integration on the LV-grids has been increasing recent years. EHP is an electro-thermal device that extracts heat from air/water or ground and injects it into dwellings[5]. As highlighted previously, there are mainly two types of EHPs, which are Air-Source Heat Pump (ASHP) and, Ground-Source Heat Pump (GSHP). The performance of EHP is defined as its COP (Coefficient of Performance), which is the proportion of injected heat (or cooling) to input electricity. It is shown as follows:

$$COP_{Heating\ or\ Cooling} = \frac{Q_{injected}}{W_{input\ electricity}} = \frac{1}{1-\frac{T_{Low}}{T_{High}}}$$ (Formula 1)

By the help of "Carnot Cycle" theorem, theoretical performance factors can be investigated. In one UK trial, optimum working COP values of ASHP and GSHP was able to find 1.2 - 2.2 and 1.6 - 3.4 considering different size EHP and weather conditions[5]. Taking account into the size of EHP, weather conditions and season time, performance factor of EHP was changed dramatically in Germany and Switzerland [5]. In this case, outside temperature plays the key role on COP characteristics.

According to low voltage design procedure, after diversity maximum demand (ADMD) has been important in maximum demand and it is formulated as the following equation:

$$Maximum\ demand = (a \times N\ + P)kW$$ [12] (Formula 2)

$$a = Average\ After\ Diversity\ Maximum\ Demand\ per\ customer\ (kW)$$

$$N = Number\ of\ customer\ group\ \ on\ the\ network$$

$$P = Load\ allowance\ (kW)$$

As can be seen above that, ADMD factor has massive impacts on network design stage. If either only EHP or EV penetrates on LV-grids, maximum demand can reach huge levels. To illustrate that, despite the fact that the average ADMD value in the UK is around 2 kW without electric heating, the new value of ADMD factor can be increased significantly [12]. Therefore, distribution networks are likely to be faced voltage drop, thermal overload and flicker issues.

There was a case study about EHP impacts on urban and rural LV networks. EHP-based approach brought that increasing level of EHP-loading contribute to voltage drops and violated thermal and voltage statuary limits [13]. Moreover, the peak demand measures 2.6 times bigger than base case, if EHP-loading level is 100% [13]. It was seen that thermal issues was higher than voltage issues in rural areas compared to urban areas. As a result of this, if EHP-penetration on the network is increasing significantly, reinforcement can be required.

So as to cope with issues, network reinforcement can be a possible solution, but investment on conductor brings huge capital cost. Other possible solution is likely to be demand response opportunities such as smart metering level can be applied in the context of dynamic pricing scenarios.

Electric Vehicles (EVs)

Although electric vehicles (EVs) were invented many years ago, the deployment of these low-CO_2 vehicles has been increasing because of climate change targets. Supporting with financial incentives to these vehicles , It is most likely reached in UK that electric and plug-in hybrid vehicles will dominate 60% of mileage on transport until 2050 [1]. Thus, DNOs will come up with EV's potential issues on medium voltage and residential networks. In order to understand EV's interaction with distribution networks, EV's features, power demand, charging requirements and customer behaviour are essential.

It is worthy of note that there is a large volume of published studies describing the role of EVs' impacts on distribution networks. In the [14] case study, it focuses on the residential network operation in the context of EV. It is selected that charging places considered worst-case scenario.

In this trial, it was indicated that the energy requirement of specific EVs (the charge rate of 3.3-6.6 kW) was between 8 and 9 kW per day [14] . This data illustrates the maximum demand of residential areas rise considerably according to ADMD factor and distribution network faces with voltage drop issues. It is apparent in [14] that large-scale charging connection of EVs on the grid is from 16.00 until 23.00 each day. In around 11.pm, the network reached maximum charging demand of EV [14]. On the basis of peak demand, diversified charging on EVs can lead to a voltage drop as well as thermal overloading. In this case, in order to minimize EVs observed impacts on peak demand, the smart charging method, which is kind of control mechanism, was implemented on the LV-grids.

As a result of this, peak demand can be shaved in the network and shaved-demand of EVs is able to fill demand valleys on off-peak times.

It is possible to hypothesise that these conditions of EVs are more likely to occur in the future distribution network.

METHODOLOGY

Problem Approach and Modeling Procedure

This project will examine the DSM interactions among low carbon technologies (PVs, EVs etc.) on the LV networks. The main aim of this study is to achieve maximum penetration level of domestic scale PVs on LV-grids by means of DR. In modeling perspective, time series profiles of PVs, EVs and EHPs will build with a synthetic approach. In order to reach the achievement, the residential network will be simulated by using the open source Distribution System Simulator (OpenDSS). Although there are similar software programs (such as DIgSILENT, CYMDIST and PowerWorld) for simulating components and solving problems on the networks, the uniqueness of OpenDSS is selected [15]. Because of ability to quasi-static solution mode, n-phase design mode and integrate familiar programming codes; OpenDSS is chosen [15]. By the help of OpenDSS's flexibility, Microsoft Office Excel with Visual Basic (MS Excel with VBA) will be integrated in the modeling stage. As a result of this, an interface on MS Excel will be built for external input data. Also, this interface will present results. With the heuristic approach (considering penetration levels), an optimum integration level of eco-friendly technologies on the network will be determined. As can be seen below **Figure 2** demonstrates the project structure.

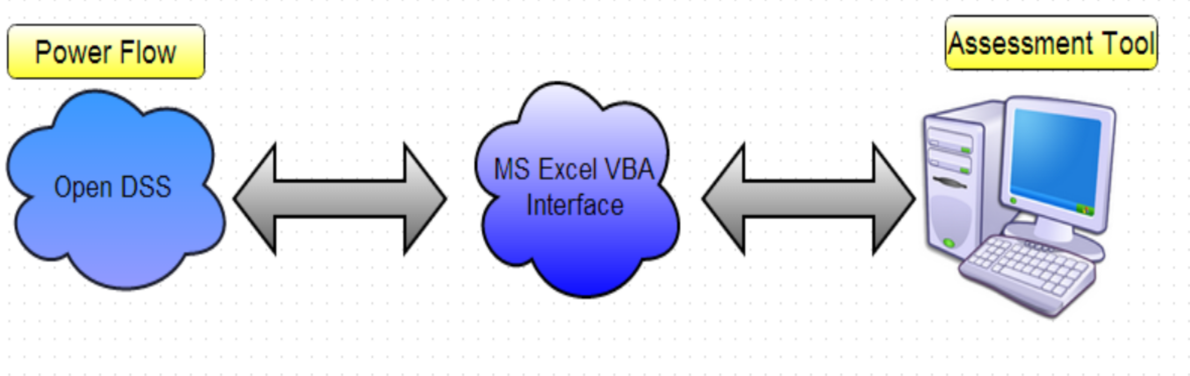


Figure 2: Clip-art design of Project

Modeling Time-Series Profiles

The definition of time series is well-defined data items (such as energy generation, consumption over the year, etc.) consisting of measurements in the context of repeated time. In order to model profiles of the time-series, it is well-known that system component behaviours should be well understood. In distribution system operator's perspective, understanding of environmentally-friendly technology specifications, household appliances (loads), seasonal trends and last but not least customer behaviour on components play key roles on design stage. Due to a modelling design stage consists of complex structures; data either can be created by software programs (for example, CREST software tool).

Assessment Tools

- **<u>OpenDSS:</u>**

In order to optimize and observe utilization of electric distribution systems, the Distribution System Simulator (DSS) was invented by the Electric Power Research Institute (EPRI) [16]. As previously mentioned that, it is called OpenDSS which is open source software to analyse the distribution networks and to understand future smart grids. The OpenDSS is applied mainly two parts. The first one is as an independent EXE program which provides multiple-user scripts for building interface and the second one is a COM interface that gives an opportunity to simulate and to define model data more properly. It is capable of evaluating power flows, fault problems and harmonics. Also, there are great deals of OpenDSS's ability of building interface with Matlab, Ms Excel with VBA and PYTHON [16]. According to some OpenDSS-experienced programmers, visual basic interface is more quickly than matlab interface considering response stage. In this case, the project will be driven MS Excel with VBA.

- **<u>CREST Tool:</u>**

This load model simulator is developed by the department of Electronic and Electrical Engineering of Loughborough University (CREST) [17]. The aim of this simulation tool is to determine characteristics of domestic load profile by a specific approach. In this case, this tool will be important for modelling of time-series profiles. CREST model is dependent on UK's residential household statistics, which is essential for demand side management evaluation.

Project Planning

The Project Planning is demonstrated below in **Figure 3** as a schedule.

ID	Task Name	Duration	Start	Finish
1	Feasibility Study Report	15 days	Mon 21/04/14	Fri 09/05/14
2	Oral Presentation for Feasibility Study	1 day	Tue 27/05/14	Tue 27/05/14
3	EXAMINATIONS	12 days	Thu 15/05/14	Fri 30/05/14
4	Literature Review	35 days	Mon 02/06/14	Mon 21/07/14
5	Stage 1:Programming	41 days	Mon 02/06/14	Mon 28/07/14
6	Learning of Open DSS software application	7 days	Mon 02/06/14	Tue 10/06/14
7	Learning of Excel with Visual Basic (VBA)	15 days	Mon 02/06/14	Fri 20/06/14
8	Learning how to build interface on Excel (VBA)	9 days	Tue 10/06/14	Fri 20/06/14
9	Modelling time-series profiles	21 days	Sat 21/06/14	Fri 18/07/14
10	Testing Models	7 days	Fri 18/07/14	Mon 28/07/14
11	Stage2: Analysis	7 days	Thu 31/07/14	Fri 08/08/14
12	Analysis on DSM interaction with Small-scale PVs	7 days	Thu 31/07/14	Fri 08/08/14
13	Analysis on DSM interaction with EVs	7 days	Thu 31/07/14	Fri 08/08/14
14	Analysis on DSM interaction with EHPs	7 days	Thu 31/07/14	Fri 08/08/14
15	Stage 3: Report	48 days	Mon 23/06/14	Wed 27/08/14
16	Dissertation Report writing	41 days	Mon 23/06/14	Mon 18/08/14
17	Dissertation Report editing	7 days	Mon 18/08/14	Tue 26/08/14
18	Final Revision	3 days	Wed 27/08/14	Fri 29/08/14
19	Preparing for Oral Presentation	8 days	Thu 21/08/14	Sun 31/08/14
20	Submission	1 day	Mon 01/09/14	Mon 01/09/14

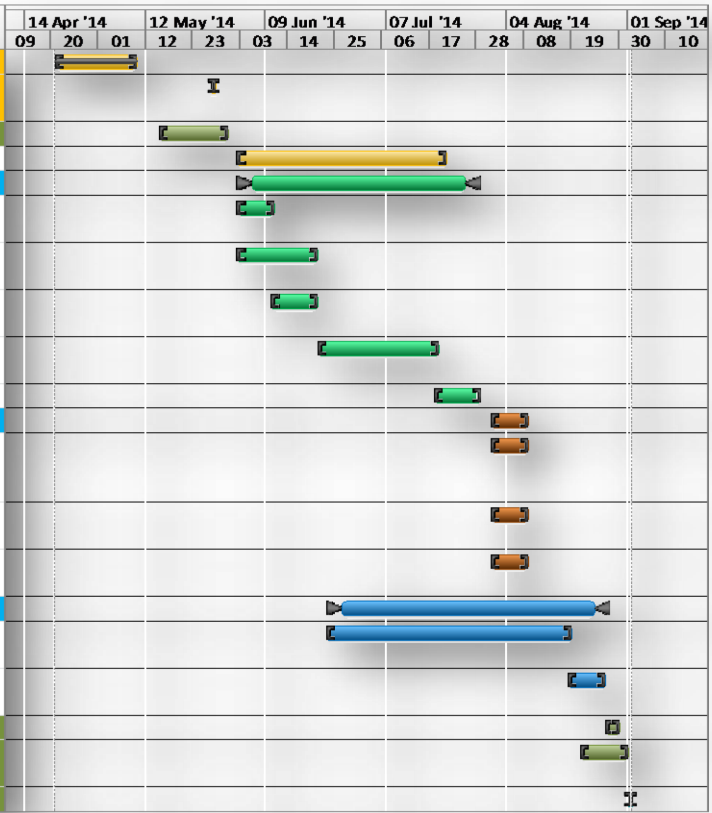


Figure 3: Project Gantt char

Risk Assessment

In most cases, there is always the potential risk on project coordination, timetable and unforeseen technical issues. To minimize those risks, identification of them is essential before starting the project. In this work, potential risks are divided into 3 parts as follows:

- **Time-scale Risks:**

Considering the time shortage for this project (3 months), unless the project parts well-situated, the project can end up with failure. To avoid this risk, the project Gantt chart should be determined as a professional. It can be clearly seen that the Gantt chart (**Figure 3**) shows the characteristics of project and progress time for every task in a reasonable manner.

- **Operational Risks:**

There is an essential risk of usage of CREST tool and OpenDSS with MS excel VBA. Due to experience of modelling on these software are less, project builder should start to develop small low voltage networks on OpenDSS as soon as possible and to study Visual basic programming too. Moreover, in order to model the profiles, CREST tool will be vital. To familiarize with it, the software can be downloaded before the first week of the project schedule. These suggestions can minimize harmful effects for project achievement.

- **<u>Technical Risks:</u>**

Computer breakdowns, virus diffusion on software parts on PC and hardware malfunctions can contribute to lose project data and files during the design stage. In order to decrease those potential risks, project documents and design files can be saved every day into online storage drives (such as Google Drive and Dropbox) or in the University of Manchester's online drive.

Conclusion of Report

This report has examined the aims and objectives of the project and defined possible solutions for each component. As previously detailed, one of the essential targets of the project is that develop a model for DSM interactions among the low-carbon technologies on the low voltage network. Another important target is, by using demand response technique, how to maximize small-scale PV generations considering system limits (thermal, voltage, etc…). In the background and literature review parts, these crucial consequences on distribution networks are detailed. Previous studies in the context of this project have been critically discussed. Following that the methodology of the project is clearly explained. In the last part of the report, to indicate schedule of the project, Gantt chart is used. Also, potential project risks are highlighted and their influences are explained.

Expectations

This project is expected to show how to maximize penetration levels of low carbon technologies on the grids. According to previous works, in order to achieve maximizing deployment of eco-friendly technologies and minimizing their dangerous effects on LV-grids, DSM or similar approaches can be good choices. Previous studies demonstrates the feasibility of this project and also the target of the project is challenging, however, it can be done successfully. Additionally, if the project achieves before the time schedule, mix integration of low-carbon technologies will be examined.

REFERENCES

[1] DECC, “2050 Pathways Analysis,” 2010.

[2] DECC, “UK Renewable Energy Roadmap Update 2013,” 2013.

[3] L. F. Ochoa, C. J. Dent, and G. P. Harrison, “Using OPF With Voltage Step Constraints,” IEEE Trans. POWER Syst., vol. 25, no. 1, pp. 296–304, 2010.

[4] S. Kärkkäinen, “Integration of Demand Side Management , Distributed Generation , Renewable Energy Sources and Energy Storages,” 2010.

[5] POST, “Residential Heat Pumps,” Postnote, no. 426, 2013.

[6] POST, “Electric Vehicles,” Postnote, no. 365, pp. 1–4, 2010.

[7] G. Strbac, “Demand side management: Benefits and challenges,” Energy Policy, vol. 36, no. 12, pp. 4419–4426, Dec. 2008.

[8] P. Navarro, Alejandro; Ochoa F.Luis; Mancarella, “Learning from residential load data: Impacts on LV network planning and operation,” in 2012 Sixth IEEE/PES Transmission and Distribution: Latin America Conference and Exposition (T&D-LA) p. 1-8, 2012, pp. 2011–2014.

[9] DECC, “UK Solar PV Strategy Part 1: Roadmap to a Brighter Future,” 2013.

[10] A. Navarro, G. S. Member, L. F. Ochoa, S. Member, and D. Randles, “Monte Carlo-Based Assessment of PV Impacts on Real UK Low Voltage Networks,” 2013, pp. 1–5.

[11] J. Widén, E. Wäckelgård, and P. D. Lund, “Options for improving the load matching capability of distributed photovoltaics: Methodology and application to high-latitude data,” Sol. Energy, vol. 83, no. 11, pp. 1953–1966, Nov. 2009.

[12] I. Richardson, M. Thomson, D. Infield, and C. Clifford, “Domestic electricity use: A high-resolution energy demand model,” Energy Build., vol. 42, no. 10, pp. 1878–1887, Oct. 2010.

[13] P. Mancarella, C. K. Gan, S. Member, and G. Strbac, “Evaluation of the impact of electric heat pumps and distributed CHP on LV networks,” 2011.

[14] A. Maitra, P. Richardson, A. Keane, J. Taylor, and M. Moran, “Impact of electric vehicle charging on residential distribution networks: An Irish demonstration initiative,” Institution of Engineering and Technology, 2013.

[15] R. Dugan, “OpenDSS,” 2010. [Online]. Available: http://sourceforge.net/apps/mediawiki/electricdss/index.php?title=OpenDSS_Uniqueness. [Accessed: 07-May-2014].

[16] R. Dugan, “OpenDSS,” 2014. [Online]. Available: http://sourceforge.net/apps/mediawiki/electricdss/index.php?title=Main_Page. [Accessed: 07-May-2014].

[17] I. Richardson and M. Thomson, “Domestic electricity demand model simulator (CREST),” 2010. [Online]. Available: https://dspace.lboro.ac.uk/2134/5786. [Accessed: 07-May-2014].