Customer-Led Network Revolution

Electrical Energy Storage 2 (100kVA/200kWh) Powerflow Management

CLNR Trial Analysis

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Executive Summary

As part of the Customer Led Network Revolution (CLNR) project, an Electrical Energy Storage (EES) facility has been installed in part of the Rise Carr network, at High Northgate, Darlington. The secondary substation, where the EES is installed, feeds 213 customers. The EES facility, titled EES2, has a converter rated at 100 kVA and a battery rated at 200 kWh. Trials of EES2 under autonomous control were carried out during June 2014. This report details the validation, extension, extrapolation, enhancement and generalization (VEEEG) of these trials.

The EES gave great help in the trials for mitigating current excursions. An IPSA2 simulation of the HV, with lumped LV load, was used to model the network. There was general agreement between trials and model, but some differences. These were due to the autonomous controller using terminal voltage to estimate the battery state of charge, which gives lower accuracy than the alternative methodology used in the model.

Using the model together with input data representing the actual profiles of low carbon technology users – air source heat pumps (ASHP), electric vehicle charging (EV) and photovoltaic generation (PV) – the headroom of the existing network for additional load can be calculated, both with and without EES2. In each case, the addition of EES2 is shown to increase the headroom and therefore to allow the connection of additional customers. In the case of ASHP, the additional headroom provided by EES2 could accommodate an extra 58 customers. The corresponding number for EV customers is 98 and for PV customers it is 26.

Sensitivity analysis shows that increasing the size of the EES system (both battery and converter simultaneously) results in an almost proportional increase in headroom for extra customer connections. This applies equally to ASHP, EV and PV.

The WS3 defined thermal headroom from this device is equal to the power rating of the device in this case 50kW.

1 Introduction

The work detailed in this document is conducted using the IPSA2 models of Rise Carr network to evaluate the capability of High Northgate HV/LV 0.350 MVA transformer in accommodating LCT following the deployment of EES2 (100kVA, 200kWh). This has been achieved using validated network models and a combination of real and synthesised load and generation data

Steady-state IPSA2 models have been previously developed and validated using SCADA data. This model has been extended by the addition of a detailed LV network model using Northern Powergrid supplied data.

The load data for the VEEEG study cases are derived from actual data from the SCADA system of this network. This is supplemented, in order to create realistic future scenarios, with load profiles derived through analysis of smart meter measurements, of 9000 customers, and LCT profiles derived from salient literature and real data from trials.

This study focuses on the Autonomous power flow management trials for the CLNR trial network at High Northgate, Rise Carr that was carried out towards the start of the trial period beginning in May 2014. In addition, the baseline trial that is required to evaluate the headroom uplift accruing to the network interventions can be evaluated.

2 Methodology and assumptions

In order to ensure that the objectives of the CLNR project are met, a programme of systematic evaluation of the results from the network flexibility field trials has been developed at Newcastle University. This approach is derived from previous experience of trials at Newcastle University and from the outline approach referred to previously. It is required that the results from the trials are firstly used to validate the network and network component models [1]. The results from the trials should then be extended and augmented to ensure that the results are applicable to 80% of the GB distribution network. The systematic approach proposed by Newcastle University consists of five steps:

1. Validation
2. Extension
3. Extrapolation
4. Enhancement
5. Generalization

This methodology is designated as VEEEG (Validation, Extension, Extrapolation, Enhancement, and Generalization) and is illustrated diagrammatically in Fig. 1.

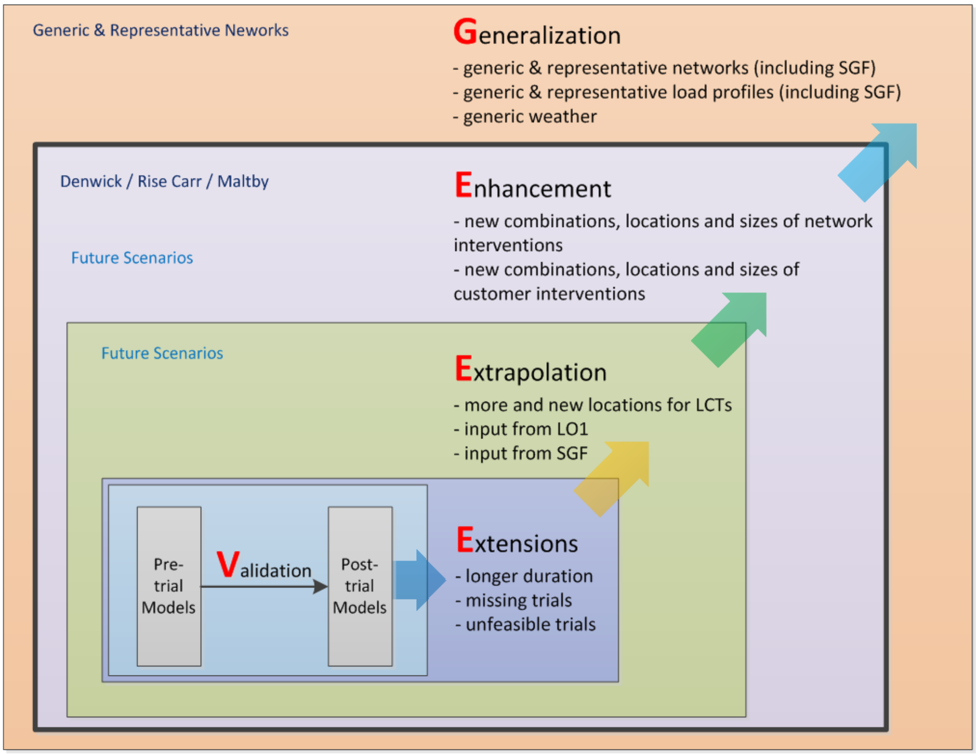

Fig. 1 Post-trial methodology VEEEG [1, 2]

3 Trial Results and Validation

3.1 High Northgate network model

Fig. 2 shows the single line diagram of Rise Carr trial network, in which the location of High Northgate is highlighted.

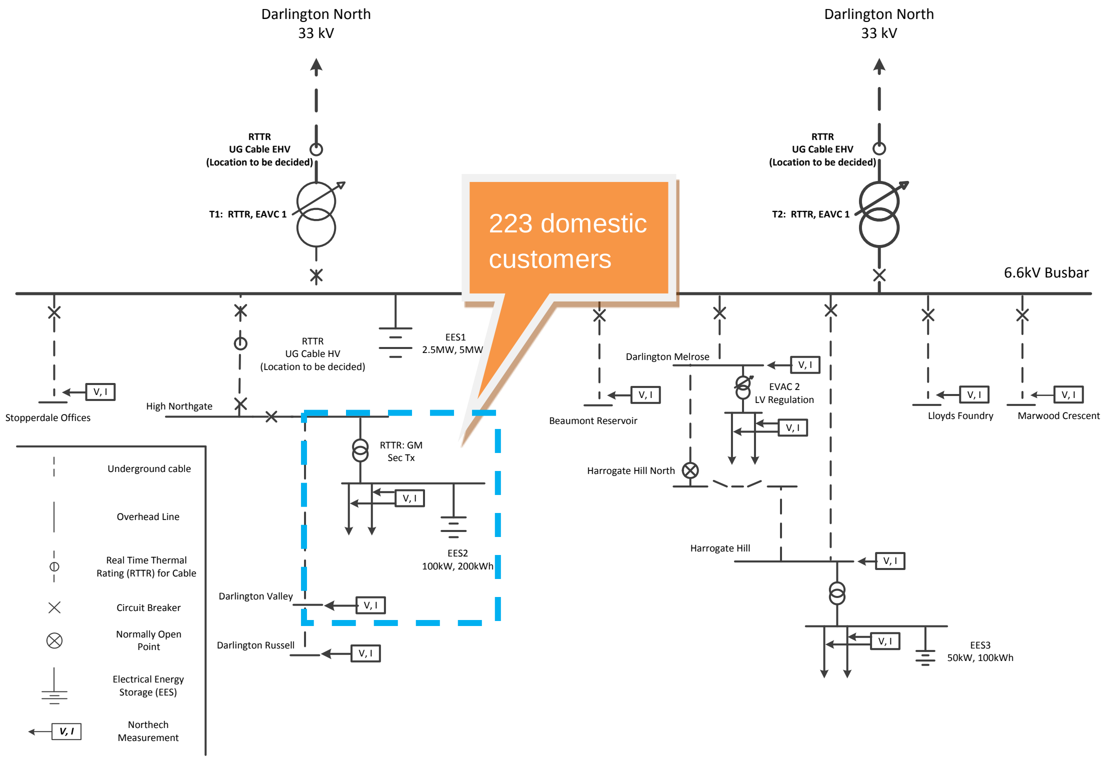

Fig. 2 Single line diagram of Rise Carr network

The power flow profiles are used in combination with the LCT profiles to derive power flow profiles in future scenarios where large concentrations of LCT are connected to the secondary transformer at High Northgate.

A detailed validated model of the LV feeders connected to secondary transformer is not currently available. A simplified model which consists of a lumped LV feeder impedance, transformer, lumped load/generation and EES2, as illustrated in Fig. 3, is used in this analysis. Totally, 223 customers are lumped.

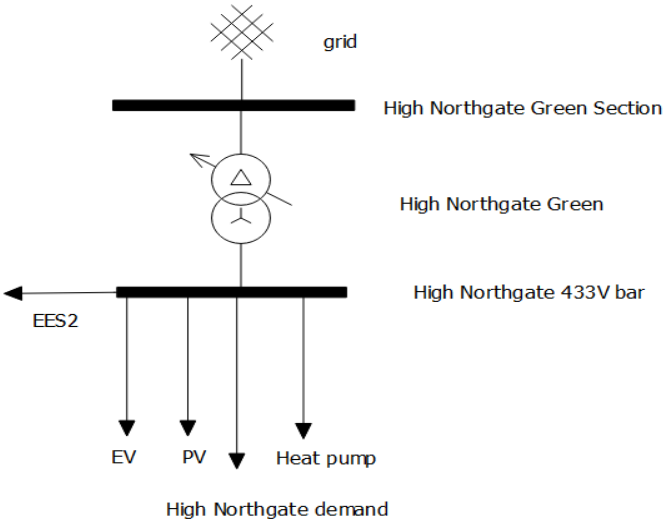

Fig. 3 High Northgate lumped feeders

3.2 High Northgate EES2 power flow management trial profiles

3.2.1 Simulation profiles and results

The profiles (presented in Figures 4-6) downloaded from data warehouse were implemented into the model presented in section 2.1 to observe EES2's response in autonomous power flow management. The simulation results would be compared with the real trial results to validate the power flow management control algorithm.

The transformer load data of High Northgate on 14th June 2014 had been downloaded from the data warehouse system. This data is adopted for validate the power flow management control algorithm. Fig. 4 shows per-minute real and reactive load of transformer.

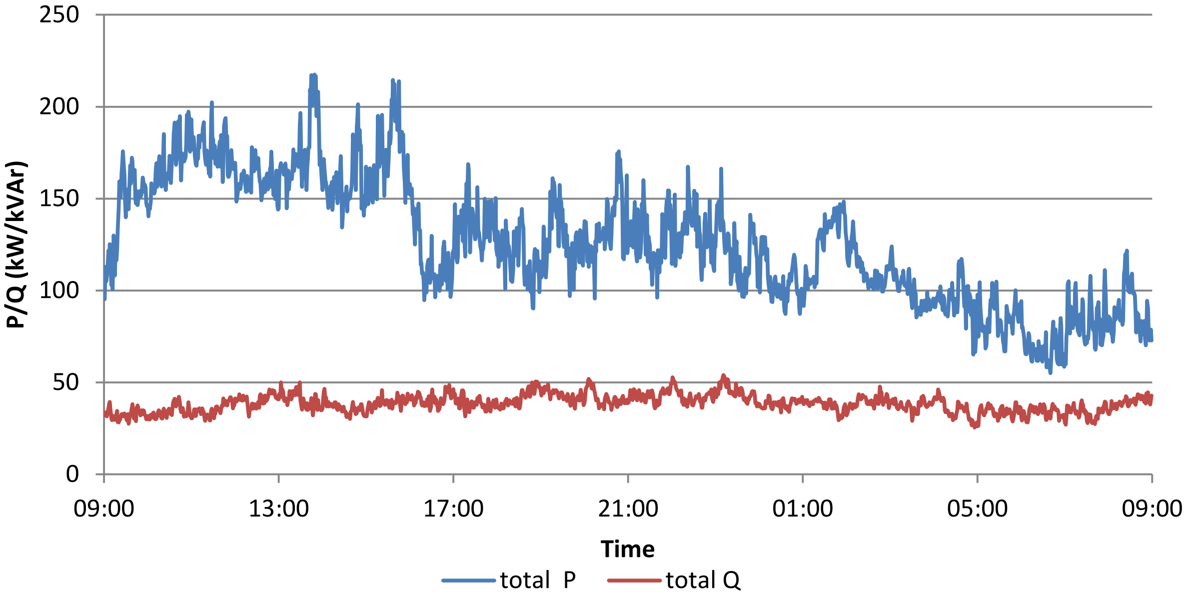

Fig. 4 High Northgate transformer P and Q load on 14/06/2014

Fig. 5 shows the transformer ampacity at 14/06/2014. Ambient temperature and current loading conditions are used to predict the ampacity constrain in 30 minutes. The detailed method of ampacity determination is not discussed in this report, and it shows in [2]. The RDC control would determine the EES2 power generating or loading based on the difference between ampacity and load current.

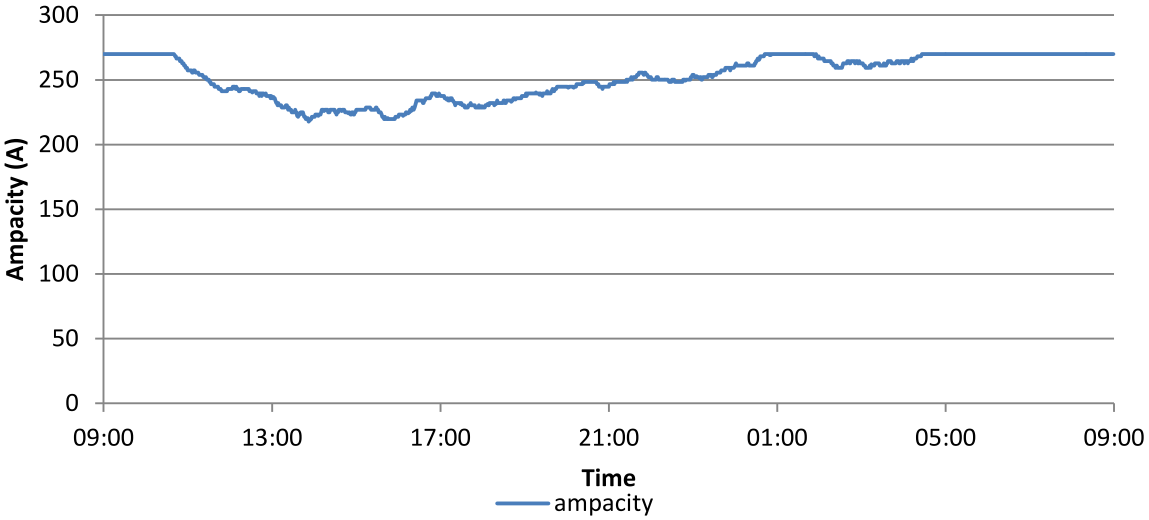

Fig. 5 High Northgate transformer ampacity limit on 14/06/2014

Fig. 6 shows High Northgate EES2 State of Charge (SOC) constraints. The battery SOC should be maintained in this constraint if there is no intervention required. This constraint is set by Northern Powergrid.

The reason for constraining the setting is not in Newcastle University's research scope. This SOC constrain is used to manage battery SOC if there is no thermal excursion. The battery may not follow the SOC constrains if excursion happens. But for battery protection purpose, the SOC would never be allowed lower than 5% of its fully capacity.

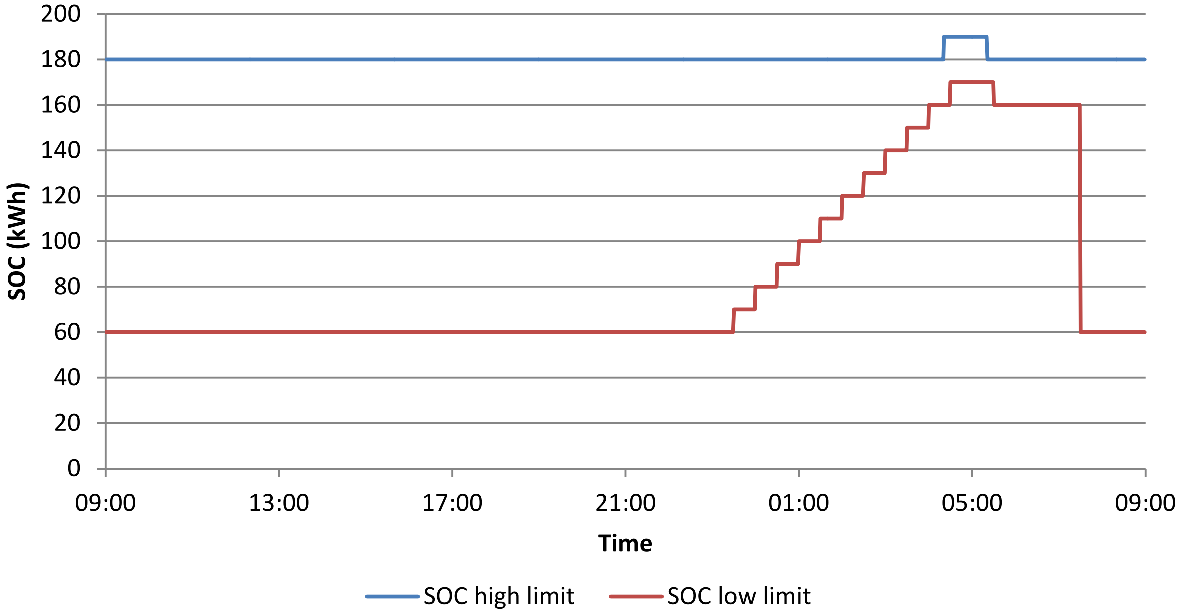

Fig. 6 High Northgate EES2 SOC management constrains on 14/06/2014

3.3 Comparison between simulation and trial results

The simulated EES2 response profile is presented in Fig. 7. It is compared with the real trial results presented in Fig. 8.

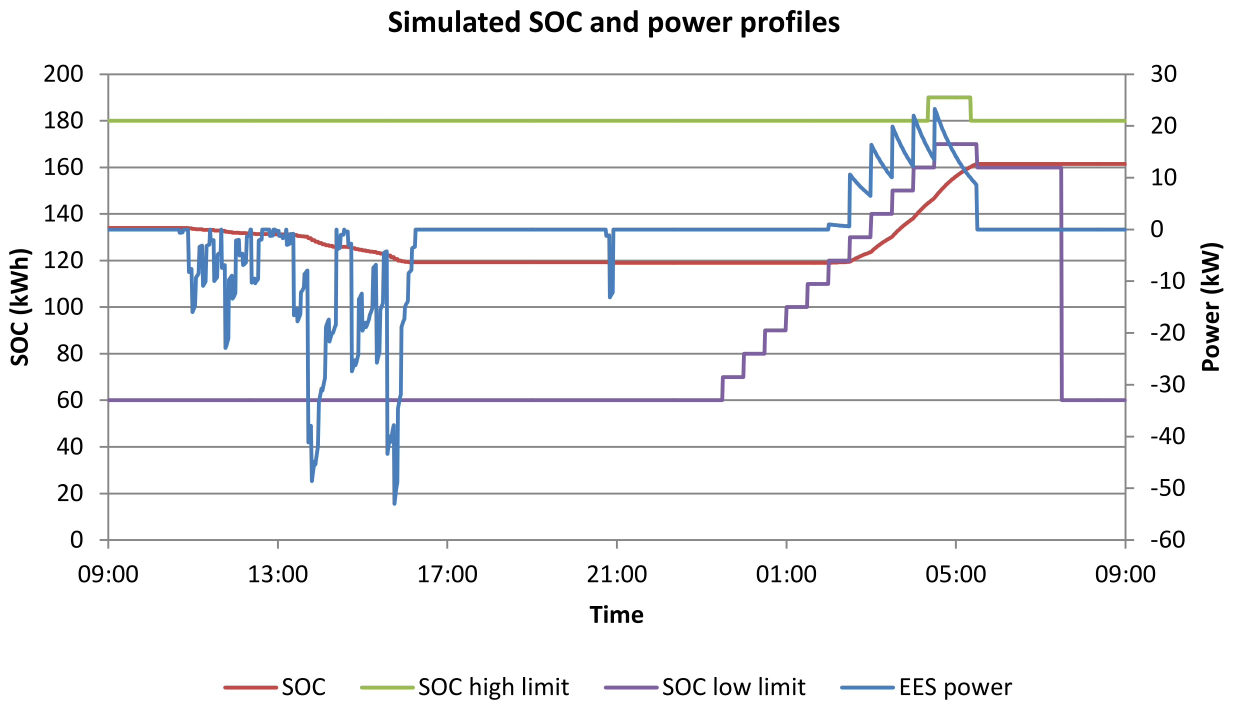

Fig. 7 Simulated High Northgate EES2 response and SOC profiles on 14/06/2014

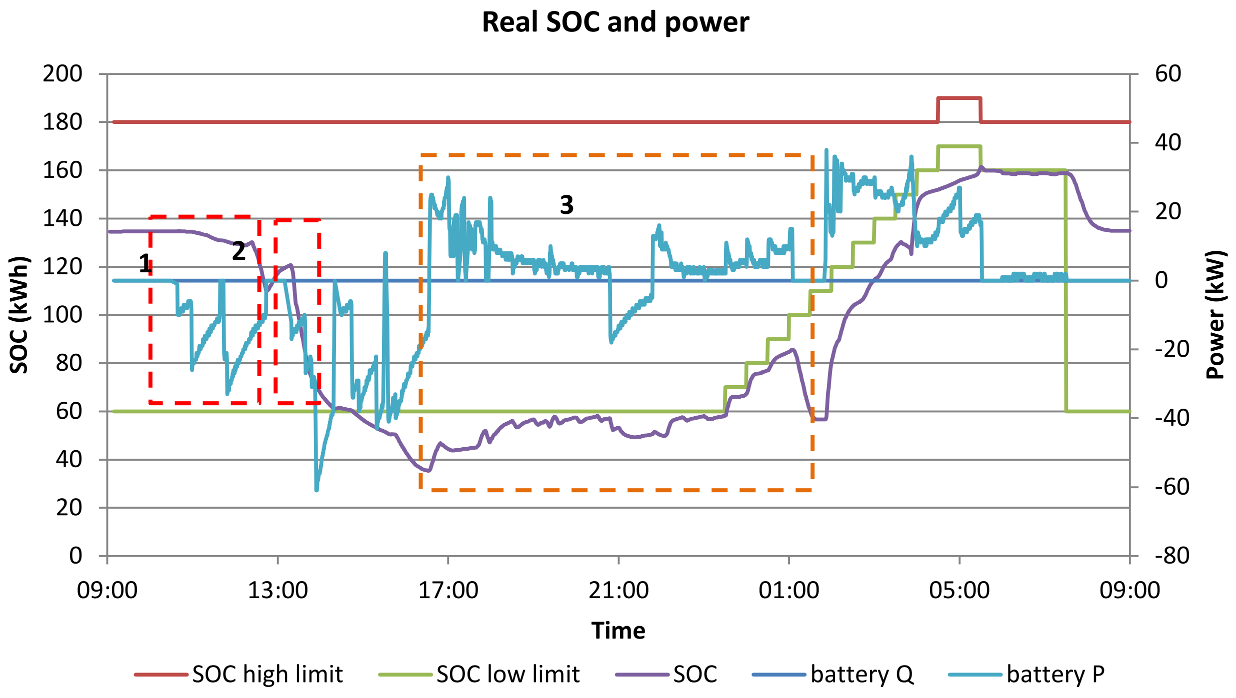

Fig. 8 Real trial High Northgate EES2 response and SOC profiles on 14/06/2014

Comparing Fig. 7 and 8, there is some difference, especially as shown in area 3, Fig. 8. This difference is resulted from the battery SOC indication system.

In CLNR, A123 battery system use terminal voltage as the reference to indicate battery SOC. This battery SOC indication system may have significant error when current rate is high. In discharging processing, when current is high, the voltage drop on the internal impedance is high, therefore the terminal voltage is lower than that in low discharging current situation. As shown in Fig. 8, areas 1 and 2, when battery discharging at small current (area 1), even relatively large amount of energy had been discharged, the SOC drops very a little. However, when battery discharges at high current (as shown in area 2), even the amount of energy discharged is very little, the SOC drops significantly. This misleading can result in the improper EES response as shown in area 3 (actually, the SOC should not be lower than the SOC lower limit, and consequently the EES response is improper).

In simulation work, Cullen counting method was adopted which avoids the impact of current rate on SOC measurement accuracy.

By comparing Figs. 7 and 8, except the period from 17:00 p.m. to 1:00 a.m., the simulated and real trial EES response is very similar.

Figs. 9 and Fig. 10 presents the simulated and real trial transformer current profiles.

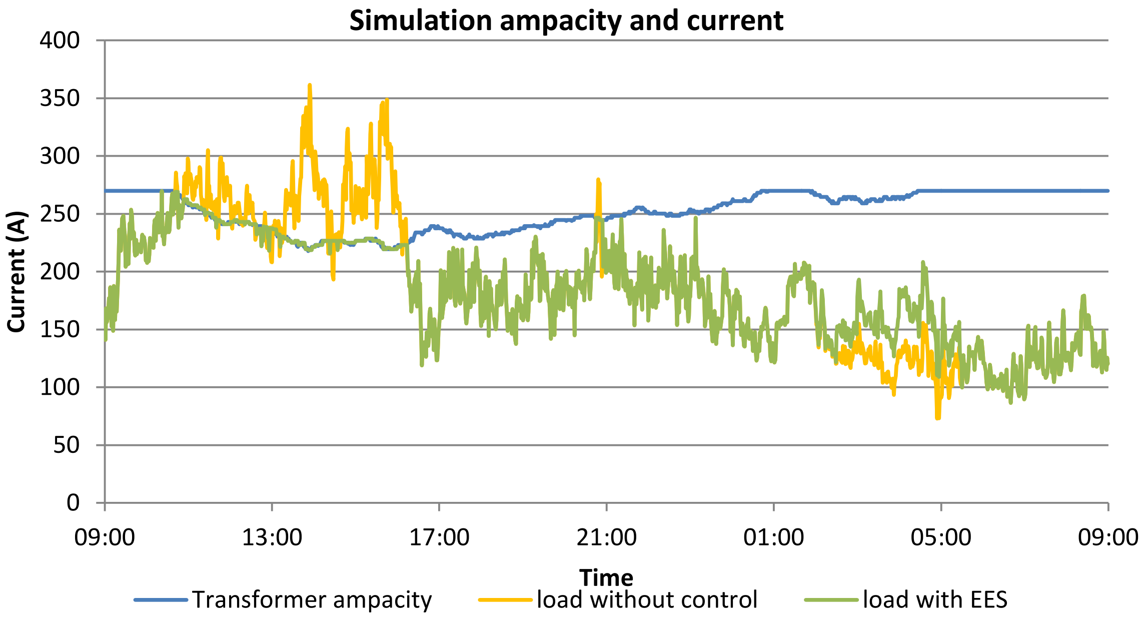

Fig. 9 Simulated High Northgate transformer current profile with/without EES on 14/06/2014

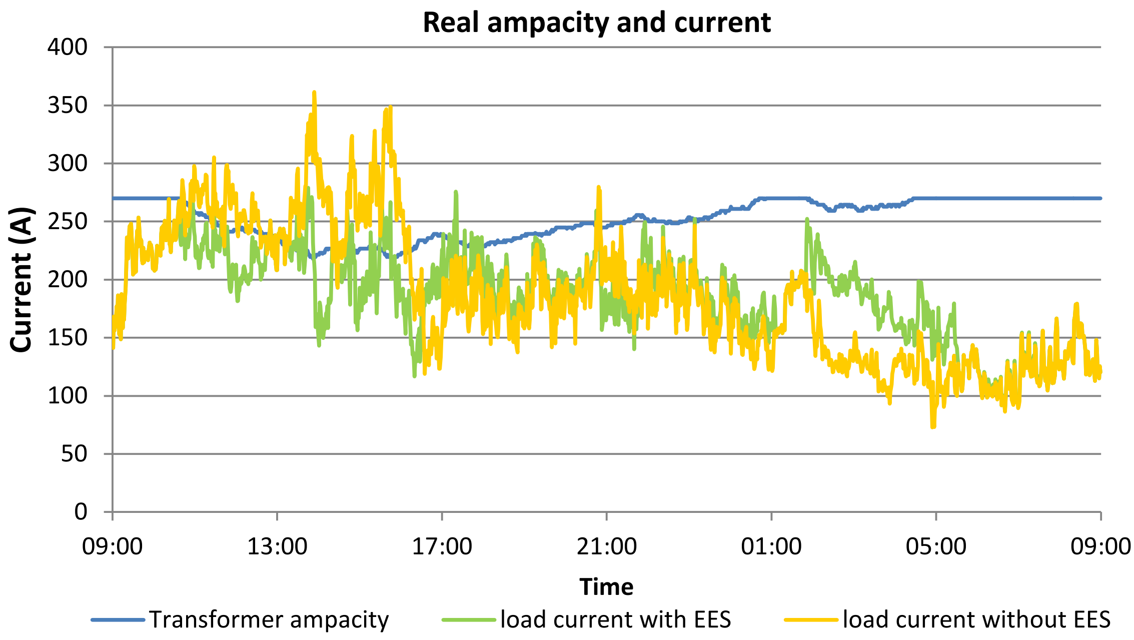

Fig. 10 Real trial High Northgate transformer current profile with/without EES on 14/06/2014

From both figures, it can be seen that EES helped to mitigate the current excursion. However, in the real trial, some current excursion still exists, this may be due to the measuring device error and control system decay (when the new set-point is determined, the power output decays for 5 minutes and EES would not respond to excursion in this 5 minutes). The simulated power flow management controller has better performance than the real one.

4 Post-trial Analysis

4.1 Extension, Extrapolation

In this section, the capability of High Northgate transformer of LCT connection would be evaluated. The validated power flow management control algorithm would be implemented into the network model to control EES response and evaluate how much penetration of LCT can be connected to the network without exceeding the thermal constrain.

4.1.1 Winter and summer load profiles

The winter and summer High Northgate loading profiles are presented in Figs. 11 and 12. As known, the winter loading is heavier than summer time's. Consequently, the winter load would be used to estimate the penetration of EV and heat pump, connected to grid and the summer load would be used to determine the PV penetration.

Fig. 11 shows the typical load (P and Q) profile in January 2014, downloaded from data warehouse.

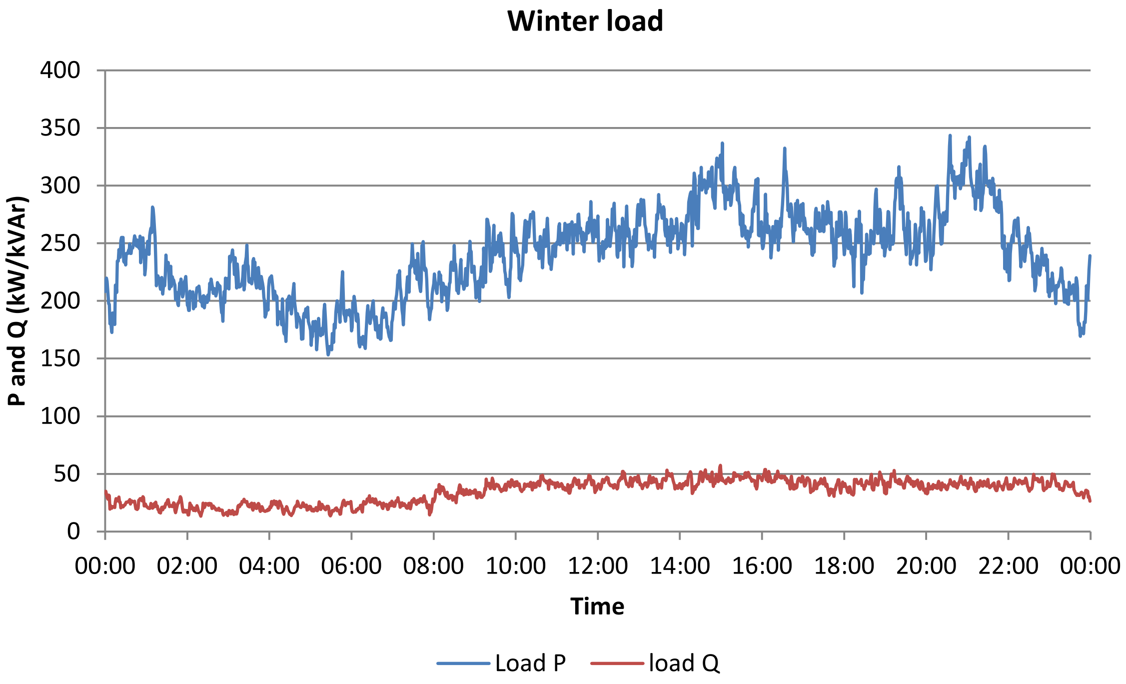

Fig. 11 Winter High Northgate transformer active (P) and reactive (Q) power profiles

Fig. 12 shows the typical load (P and Q) profile in June 2014, downloaded from data warehouse.

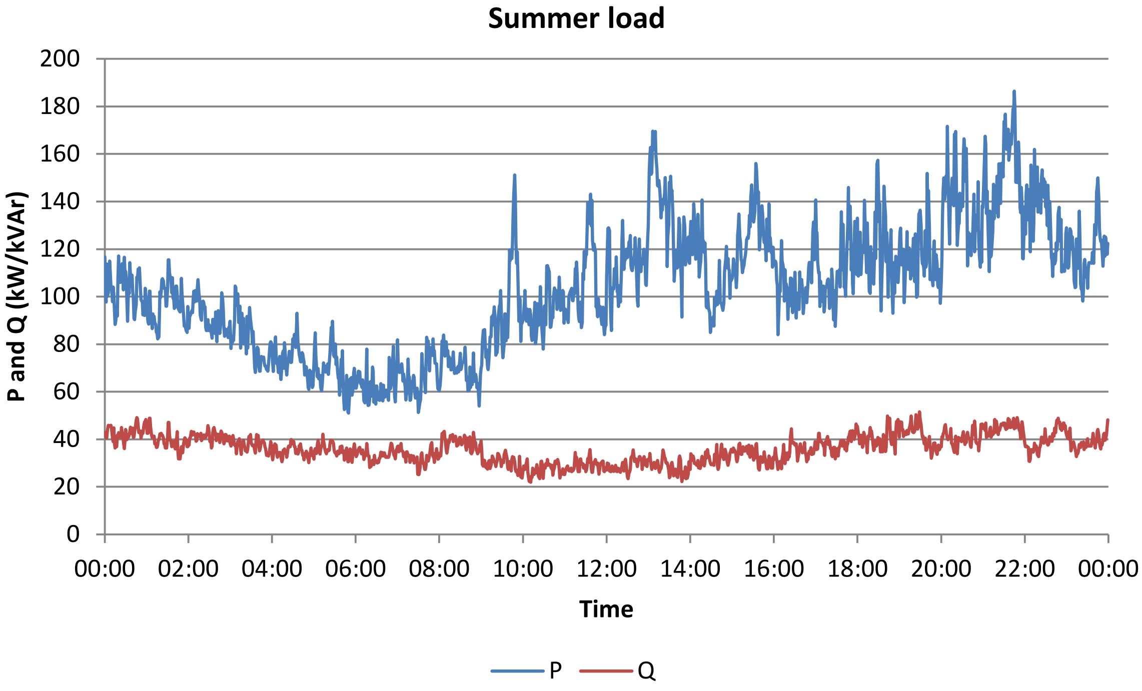

Fig. 11 Summer High Northgate transformer active (P) and reactive (Q) power profiles

4.1.2 ASHP model development

The air source heat pump profile is from CLNR Learning Outcome 1: Initial Heat Pump Load Profiles from CLNR Low Carbon Technology Trials [3]. The 95th percentile profile on 17th Jan 2013 is used in this VEEEG study to represent the worst case scenario in terms of loading this network. This profile is shown in Fig. 12.

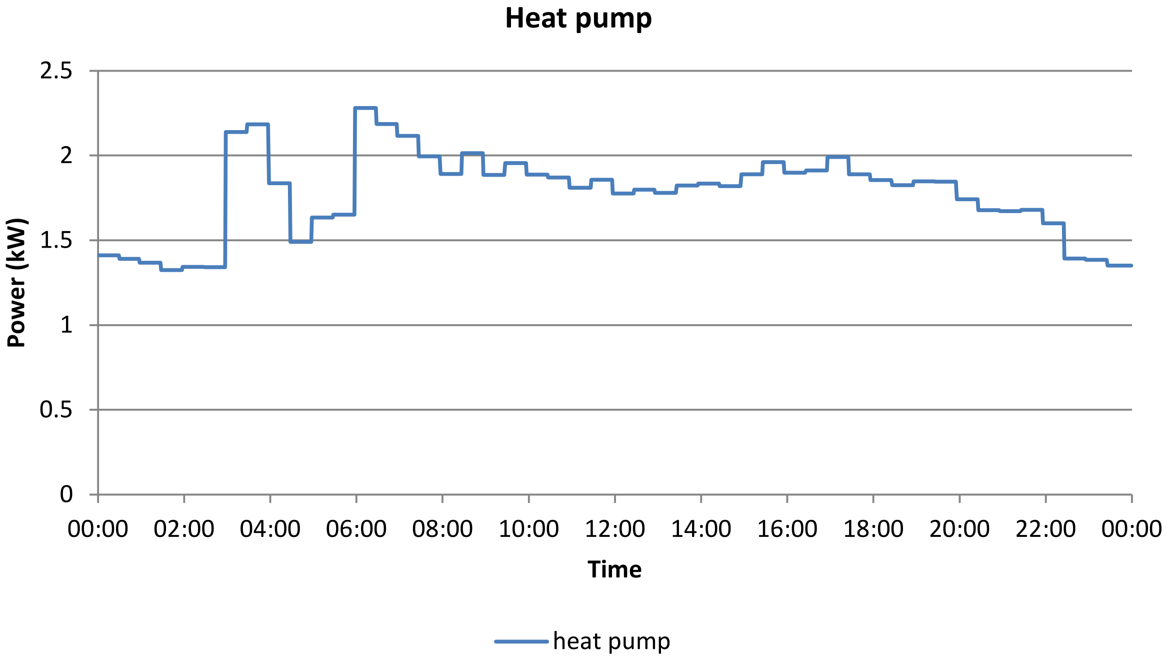

Figure 12: Generic GB winter peak ASHP installation daily load profile (95th percentile) [3]

4.1.3 Electric Vehicle model development

The EV consumer model used in this work was based on profiles developed previously in [4]. These profiles are based on real trial data from 19,872 charging events of 340 vehicles (electric, pure hybrid and fuel cell vehicles) from December 2009 to June 2011.

In order to create the profiles a number of assumptions were made. The average mileage covered per day was 12.5 miles [4] which is in line with the average trip commute distance for the case study area [5]. It was also assumed that every car drives the average daily distance and charges at home on a daily basis. The analysis considers the residual charge left in the battery, which will effectively reduce the charging time, but not the peak current drawn from the network.

The typical EV profile is shown in Fig. 13.

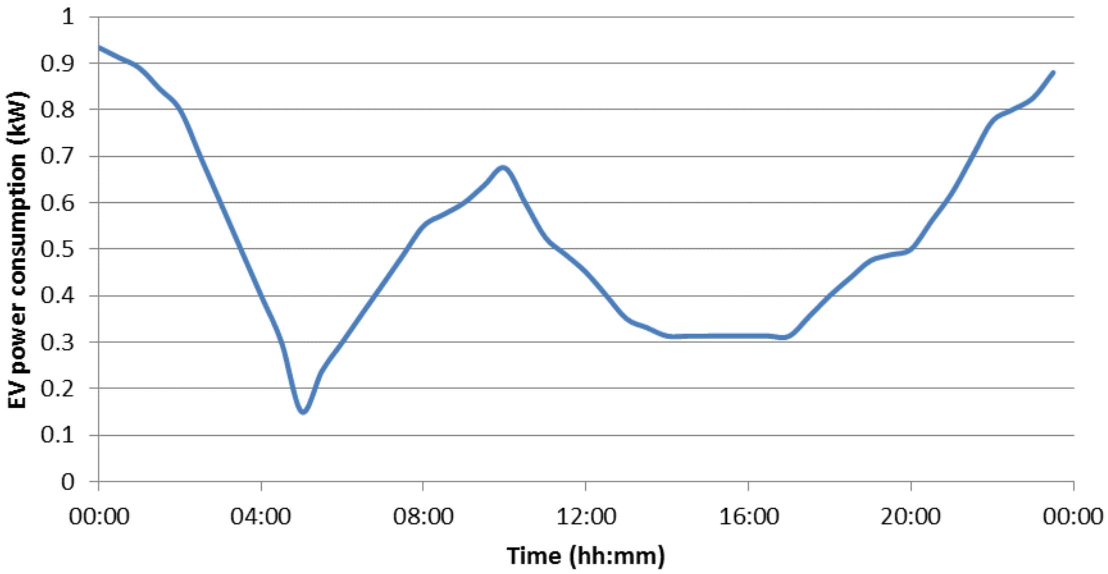

Fig. 13 Typical EV daily consumption profile

4.1.4 PV model development

PV generation profile is from Initial Load Profiles form CLNR Intervention Trials [4]. The 95th export percentile of PV derived from the smart meter data is applied in this study to represent the worst case scenario. This PV generation profile is shown in Fig. 14.

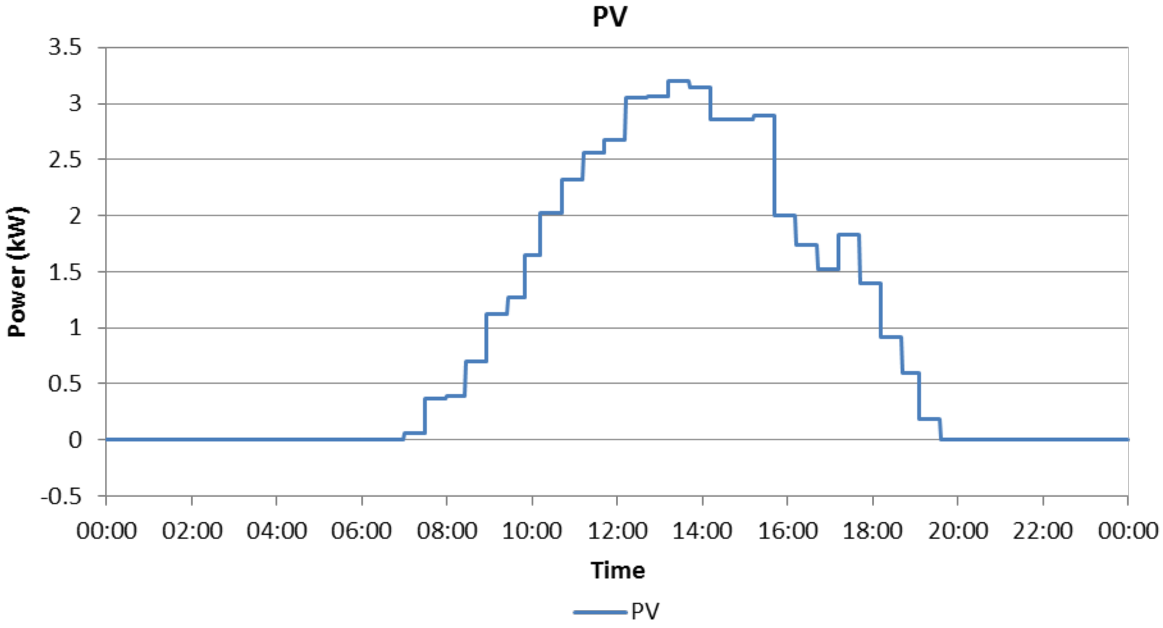

Figure 14. Generic GB summer minimum PV installation daily generation profile (95th percentile)

4.1.5 ASHP clustering on case study LV network

The ASHP power consumption profile presented in section 3.1.2 is used in this study. Due to the lower usage of HP in summer, only the winter (January 2014) scenario is discussed. Therefore, the winter load profile presented in section 3.1.1 is implemented into the network model.

Based on the validated control algorithm, the increase of allowed penetration of ASHP due to EES2 connection is determined and presented in Table 1. If there is no EES, the maximum penetration of ASHP connected to the grid is 87%. With EES the maximum penetration increases from 87% to 113%

Table 1. Allowable ASHP penetration

	Based line	EES2 (80 kW/200kWh)
	Installation / Penetration (%)	ΔInstallation / ΔPenetration (%)
Heat pump	194 / 87%	58 / 26%

Fig. 15 demonstrates the EES2 response when 133% penetration of ASHP connected to grid. The maximum EES2 real power generation is limited to 80 kW. Around 3:45 a.m., the power exported from EES reaching to its rated value to mitigate the current excursion. If the penetration is still increasing, the EES would loss its ability to maintain the load current within the transformer thermal constrain.

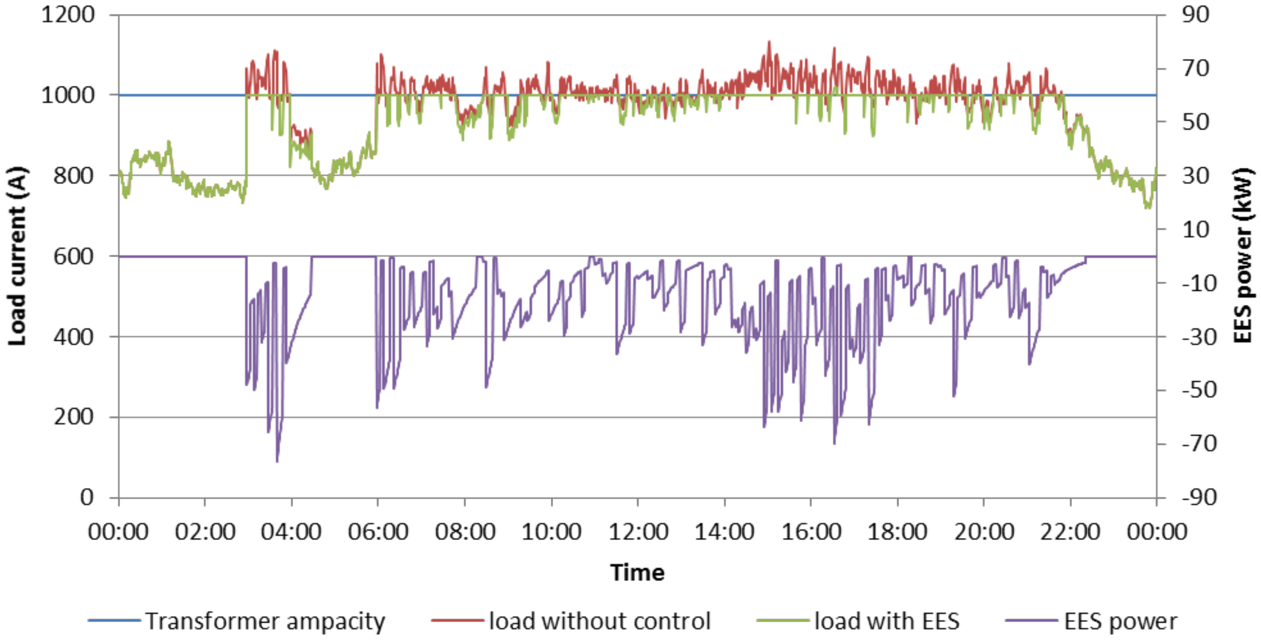

Fig. 15 133% penetration of ASHP connection and EES2 response

Assume the EES is fully charged initially, then it has maximum capability to support ancillary service to the grid. For battery protection purpose, 90% is its maximum SOC limitation. Fig. 16 shows the SOC profiles, it decreases from 180 kWh (90%) to 42 kWh (21%) which does not break the SOC limits.

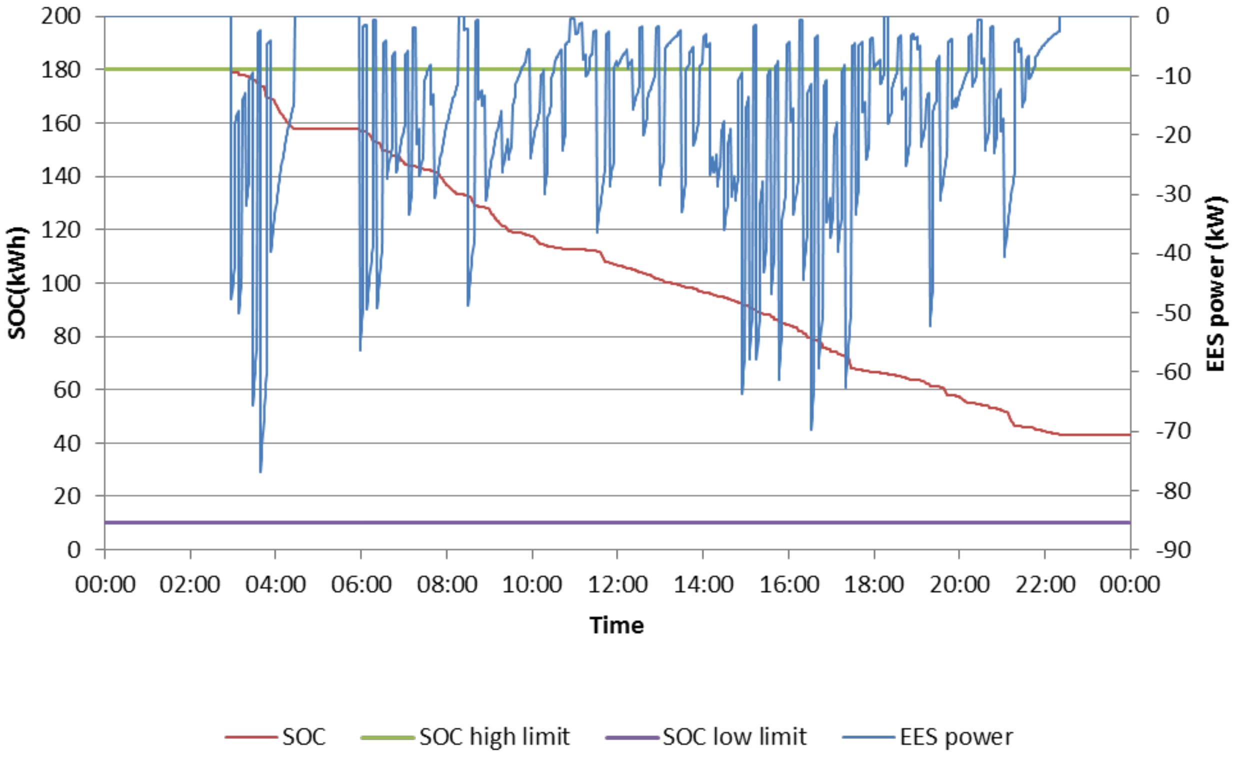

Fig. 16 EES2 response and SOC profile when 133% penetration of ASHP connected

4.1.6 EV clustering on case study LV network

The EV power consumption profile presented in section 3.1.4 is used in this study. Due to the winter (January 2014) loading is much higher than summer loading, consequently, only winter scenario is discussed as the worst case scenario. Therefore, the winter load profile presented in section 3.1.1 is implemented into the network model.

Based on the validated control algorithm, the increase of allowed penetration of EV due to EES2 connection is determined and presented in Table 2. If there is no EES, the maximum penetration of EV connected to the grid is 216%. With EES, the maximum penetration increases from 216% to 260%

Table 2. Allowable EV penetration

	Based line Installation / Penetration (%)	EES2 (80 kW/200kWh) ΔInstallation / ΔPenetration (%)
EV	482 / 216%	98 / 44%

Fig. 17 demonstrates the EES2 response when 260% penetration of EV connected to grid. The maximum EES2 real power generation is limited to 80 kW. Around 1:00 a.m., the power exported from EES reaching its rated value to mitigate the current excursion. If the penetration is still increasing, the EES would loss its ability to maintain the load current within the transformer thermal constrain.

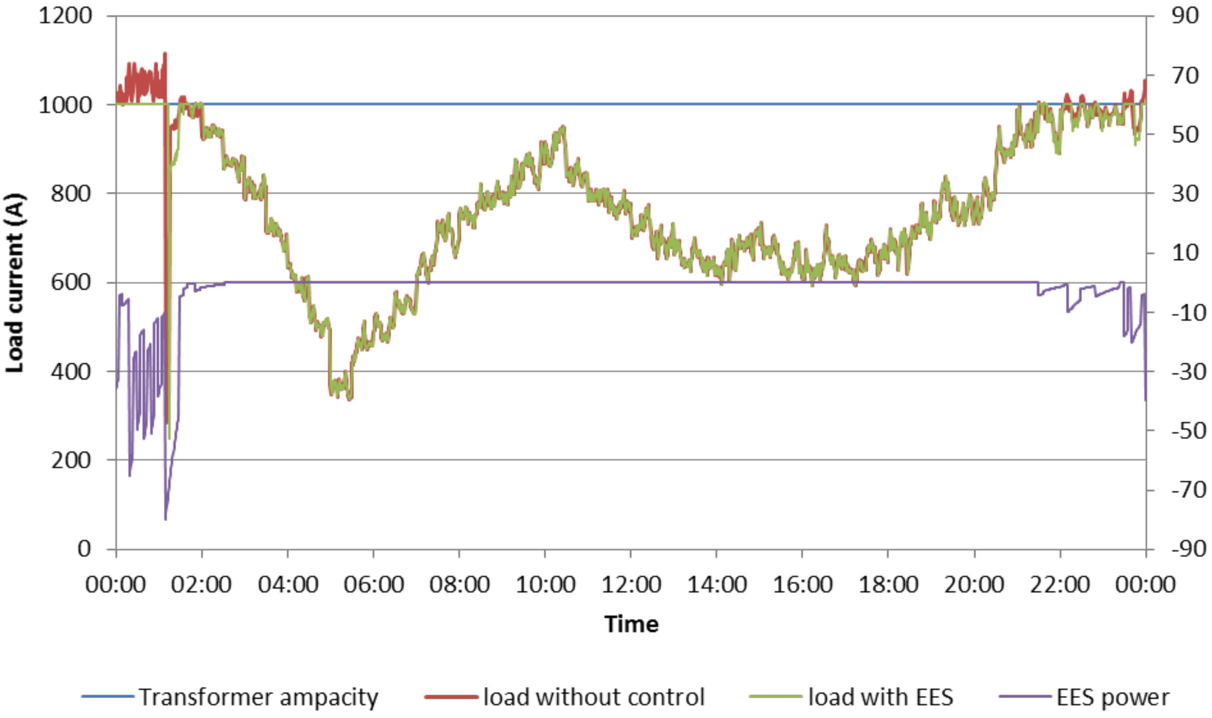

Fig. 17 260% penetration of EV connection and EES2 response

Assume the EES is fully charged initially, it has maximum capability to support ancillary service to grid. For battery protection purpose, 90% is its maximum SOC limitation. Fig. 18 shows the SOC profiles, it decreases from 180 kWh (90%) to 150 kWh (75%) which does not break the SOC limits.

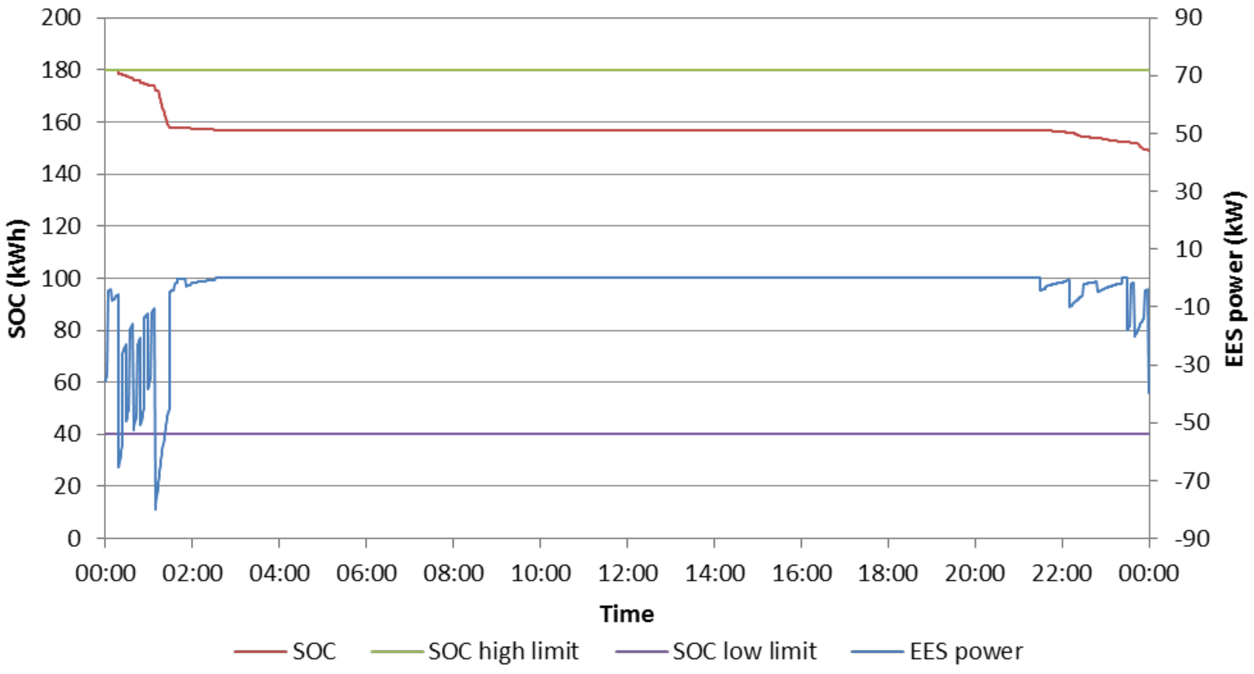

Fig. 18 EES2 response and SOC profile when 260% penetration of EV connected

4.1.7 PV clustering on case study LV network

The PV power generation profile presented in section 3.1.3 is used in this study. Due to the winter (January 2014) loading is much lower than summer loading, consequently, only summer scenario is discussed as the worst case scenario. Therefore, the summer load profile presented in section 3.1.1 is implemented into the network model. For the high PV penetration scenario, excursion thermal violation only occurs when reverse power flow exceeds the transformer thermal constraint. It is assumed that transformer reverse thermal constraint is the same as normal thermal constraint. In simulation work, in order to clearly state EES response and its impact on transformer thermal loading, thermal constraint is present as " - 1000 A". Where " – " indicates reverse power flow.

Based on the validated control algorithm, the increase of allowed penetration of PV due to EES2 connection is determined and presented in Table 3. If there is no EES, the maximum penetration of EV connected to the grid is 118%. The EES enables the maximum penetration to be increased from 118% to 130%.

Table 3. Allowable PV penetration

	Based line	EES2 (80 kW/200kWh)
	Installation / Penetration (%)	**ΔInstallation / ΔPenetration (%)**
PV	263 / 118%	26 / 12%

Fig. 19 demonstrates the EES2 response when 130% penetration of PV connected to grid. The maximum EES2 real power charging rate is limited to 80 kW. Around 1:45 p.m. the power absorbed by EES is reaching its rated value to mitigate the current excursion. If the penetration is still increasing, the EES would loss its ability to maintain the load current within the transformer thermal constrain.

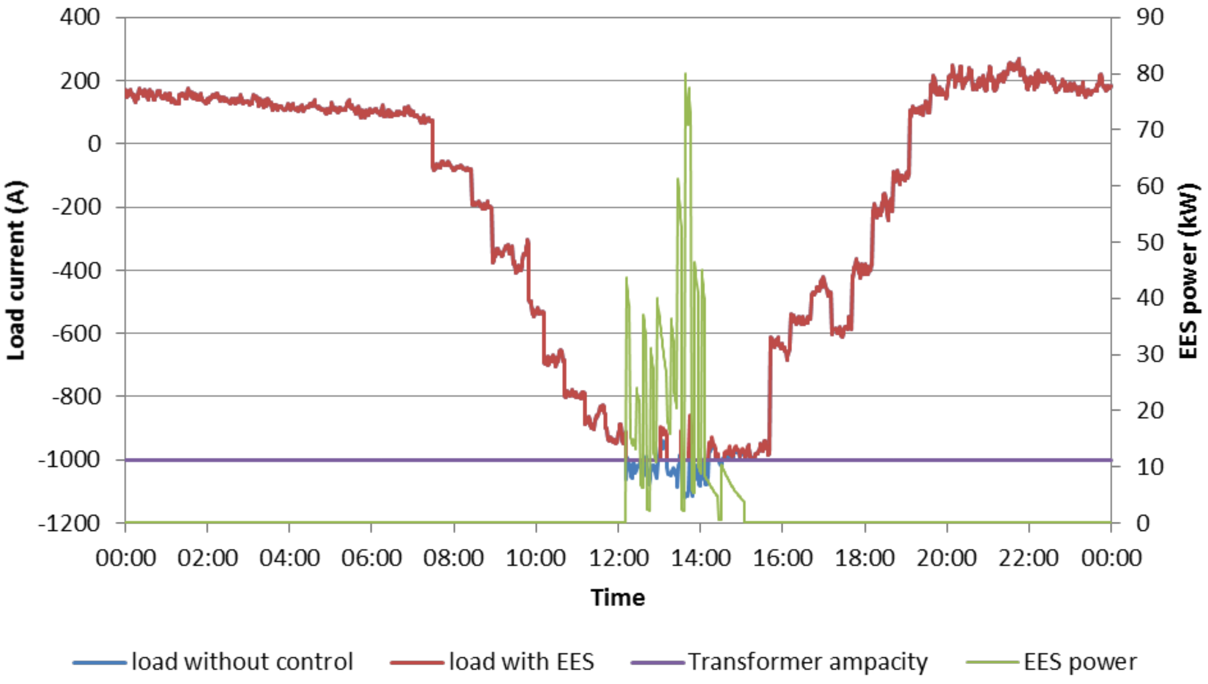

Fig. 19 118% penetration of PV connection and EES2 response

Assume the EES is fully discharged initially, it has maximum energy storing capability to offer ancillary service to grid. For battery protection purpose, 5% is its minimum SOC limitation. Fig. 20 shows the SOC profiles, it decreases from 10 kWh (5%) to 35 kWh (17.5%) which does not break the SOC limits.

4.2 Enhancement

Additional studies were undertaken to complete the enhancement phase of the methodology. In these studies, similar EES systems to the High Northgate system with different power ratings and energy capacities were investigated using varying penetrations of PV and ASHPs to determine what power rating and energy capacity an EES system would need in these scenarios. The increases in power rating and energy capacity are in steps of 80kW/200kWh as per the High Northgate EES system. The results of these studies are presented in Table 4.

Table 3. LCT penetration incremental when EES power and energy capacity increasing

	Based line Installations/ Penetration (%)	EES2 (80 kW/200kWh) ΔInstallations/ ΔPenetration (%)	EES2 (160 kW/400kWh) ΔInstallations/ ΔPenetration (%)	EES2 (240 kW/4600kWh) ΔInstallations/ ΔPenetration (%)
Heat pump	194 / 87%	58 / 26%	102 / 44%	131 / 59%
EV	482 / 216%	98 / 44%	201 / 91%	330 / 148%
PV	263 / 118%	26 / 12%	52 / 23%	78 / 35%

It can be seen from Table 4 that increasing the size of the EES systems almost result in a proportional increase in the number of ASHP or PV units that can be connected in the downstream LV network.

4.3 Generalization

Figs. 21 – 23 summarise the power and energy rating per customer when heat pump, EV and PV connected to grid. The power rating per customer for these three kinds LTC are almost constant. For heat pump, the energy rating per customer is increasing with penetration increasing, but for EV, the energy rating per customer is decreasing with penetration increasing.

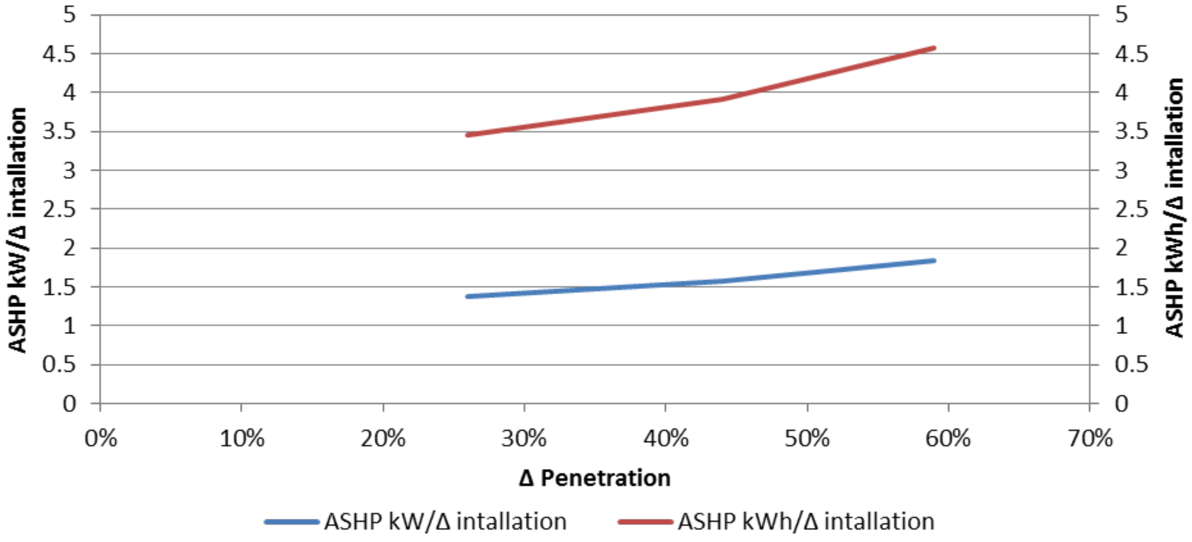

Fig. 21: EES energy capacity/customer and additional penetration of heat pump (ΔPenetration)

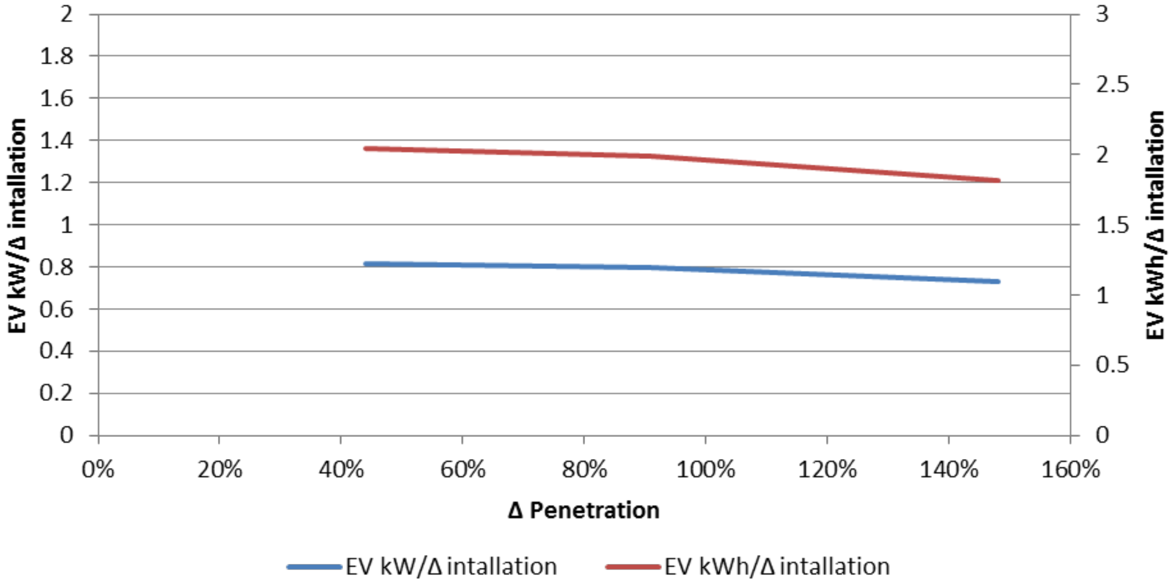

Fig. 22: EES energy capacity/customer and additional penetration of EV (ΔPenetration)

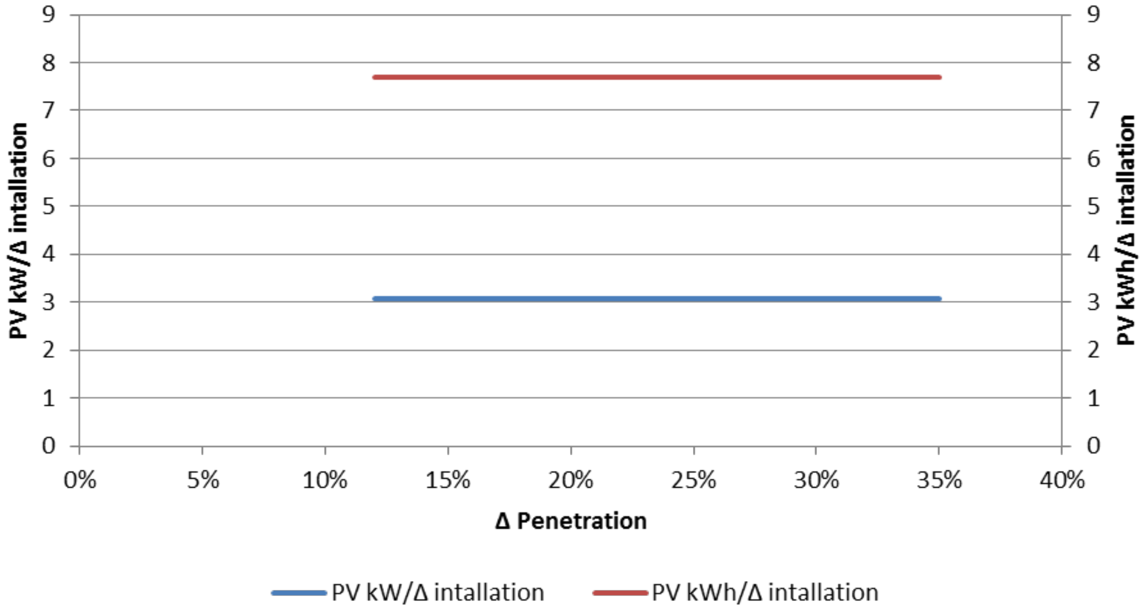

Fig. 23: EES energy capacity/customer and additional penetration of PV (ΔPenetration)

As the future load/generation profiles for the clustered networks are derived from representative and generic load and generation models, it can be shown that increasing penetrations of LCT may have a similar impact on the import and export profiles of other transformers with proportionally similar distributions of customers. Thus, similar relationships between energy storage rating and energy capacity with increasing LCT penetration, as shown in Figs. 21 - 23, can be established.

5 Conclusions

The EES2 autonomous power flow management control system has been validated by comparing the simulation and real trial results. There is some error existing which is due to the inaccurate SOC indication deployed in A123 battery system. In real trial, A123 battery adopts terminal voltage as the reference to estimate the energy storage SOC, which might over-estimate the SOC when current rate is large. Consequently, the EES control system would responded incorrectly due to collected inaccurate SOC information.

The allowable LCT penetration is increased due to the EES's contribution.

The study is enhanced by increasing EES's power and energy rate to determine the headroom of network when high penetration of LCT connected.

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