Customer-Led Network Revolution

Analysis of I&C DSR for Powerflow Management

Post-trial Analysis

DOCUMENT NUMBER
CLNR-L117

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ISSUE DATE
22/12/2014

Customer-Led Network Revolution

Contents

1 Executive summary

The application of Industrial and Commercial (I&C) demand side response (DSR) can yield numerous network benefits, such as reduction of the generation margin and improvements to the investment and operational efficiencies of both transmission and distribution systems [1].

This report describes the results of demand side response (DSR) trials carried out with a test group of 6 large industrial and commercial (I&C) customers located throughout the Northern Powergrid region which were called by the GUS supervisory control system that has been deployed as part of Customer-Led Network Revolution (CLNR) project. The results of these trials are applied in simulation to the CLNR test-bed at Rise Carr, and used to draw conclusions of relevance to the UK as a whole.

DSR for periods of 2-4 hours was called at different times of day during a period of 13 days commencing on 13 March 2014. The 6 customers included 2 without their own generation, 3 who used their own generation to reduce net load to approximately zero, and another who used their own generation to become a net exporter during the DSR call periods. There were between 3 and 8 calls per customer during the 13 day period, 31 calls in total. The analysis in the present report concentrates in detail on 5 calls made on different customers between 16:00 and 18:00 on 24 March.

DSR responses were called, from a number of service providers, to mitigate thermal overloads that the GUS control system observed. As the distribution networks where GUS has been deployed have been selected to be robust, thermal overloads are highly unlikely to occur during the trial. As per the trial design methodology developed as part of CLNR the thermal limits on the item of infrastructure under investigation are reduced in order to stimulate a response from the GUS control systems. In addition, real-time thermal ratings (RTTR) are simulated instead of conventional static ratings as part of the trials. The trials therefore demonstrate how DSR can be fully integrated with a distribution network management system which utilises transformer RTTR to evaluate its control actions. The theory and validation of this RTTR algorithm will be included in a future report.

It was found that the delay time of DSR depends on the type of DSR. Load type DSR services have longer delays to react to a call to reduce load and sometimes are not available when called for. Generation type of DSR customers tend to have shorter delay times and are available on a more consistent basis;

On the 24 March, the total net load shed by the 5 customers was around 5,600 kW, which equates to 240 A through each of 2 transformers at 6.6 kV. These trial results are used with a validated network, by the CLNR team at Newcastle University, to simulate I&C DSR trials. The models were then used to estimate how much additional low carbon load, either electric vehicles (EV) or air source heat pumps (ASHP), could be accommodated on the network as a consequence of DSR.

The first, extension stage of modelling (and subsequent stages) considered the n-1 situation where only a single transformer (23MVA) is available to supply the whole Rise Carr load. It then evaluated the impact of assuming that all 6 DSR customers were connected to the Rise Carr network, with the consequent potential to shed 5,600 kW of load between 16:00 and 18:00. However this did not enable connection of additional load in this network, as the present peak occurs later in the evening.

The second, extrapolation stage used data gathered from actual electric vehicle (EV) and air source heat pump (ASHP) consumers, from within the CLNR programme (LO1) and sought to evaluate the benefit of DSR with the different load profiles that could be expected following significant EV or ASHP penetration. This phase of analysis determined that these DSR responses did not enable connection of additional LCT based load, however, as the peak load period, with significant additional EV or ASHP connected, is outside the times (16:00 to 18:00) of the contracted DSR responses.

The third, enhancement phase of analysis evaluated DSR that could be called whenever the new peak time occurs, and assumes it will allow the same amount of load to be shed at that time. In this scenario, with significant EV penetration and a peak period at 00:00-02:00, an additional 1,193 EVs could be accommodated on the Rise Carr network. If instead the significant penetration is ASHP, then the peak period becomes 07:00-09:00 and 11:00 – 13:00, and if DSR were called then, an additional 2,186 ASHP customers could be accommodated.

It was found that in the high EV penetration scenario compared to that of ASHPs, the peak demand due to EVs has a longer duration and is more flat. There are two high but short durations of peaks due to the use of ASHPs. In the enhancement study, I&C DSR service is called twice for these two peaks. As a result, the percentage uplift of ASHPs is higher than the corresponding figure of EVs.

Generalising these results to the UK as a whole, the 1,193 additional EVs represent around 12% of the Rise Carr customer base. This suggests that, in the event of rapid increase of EV take up, industrial and commercial DSR could facilitate the accommodation of an increase of 12% in the proportion of the population owning an EV before network constraints were reached and network reinforcement was required. In the same way, an increase of around 22% in the proportion of the population with ASHP could be accommodated before network constraints were reached. Although EV and ASHP were modelled separately, since their contribution to peak load occurs at very different times, it is likely that both increases could be accommodated simultaneously. It should be noted there was a limited number of trials carried out robust assertions about the reliability of the services could not be evaluated.

Previous work has indicated that electrical energy storage in collaboration with DSR offers synergistic benefits beyond the use of a single technique [2]. It can be seen that these benefits can equally be applied to powerflow management of infrastructural assets:

1. Results from the trials indicate that in some cases DSR response could be substantially slower than EES (up to 30 minutes). Therefore, for short duration excursions, due to the intermittency of renewables based generation and new LCT based load, the fast response of the EES coupled with DSR could reduce the number of calls and improve the response of the collaborative voltage control system.
2. The energy capacity of the EES required in a powerflow managaement scheme is reduced because the DSR system can remove or reduce the need for storage intervention. Given that EES technology is currently expensive and the cost of DSR is lower than the cost of EES, this is a valuable contribution.

2 Introduction

In this work, post-trial analysis of Industrial and commercial (I&C) DSR for power flow management (PFM) are carried out. This report starts with an introduction of the real time thermal rating (RTTR) profile, load profile of Rise Carr network, the I&C DSR profiles from the trials and low carbon technology (LCT) profiles. Detailed information about this I&C DSR can be found in [3]. In this work, LCT includes electric vehicle (EV) and air source heat pump (ASHP). The Validation, Extension, Extrapolation, Enhancement and Generalisation (VEEEG) methodology is adopted to analysis trial results. An introduction of VEEEG methodology can be found in chapter 4. In the next chapter, post-trial simulations results, including the validation, extension, extrapolation and enhancement studies are given. Finally conclusions are drawn.

3 Profiles

3.1 RTTR and load profile

3.1.1 RTTR and Current Profile

Figure 1 shows the load (current on the 6kV side of) and the real time thermal rating profiles of Rise Carr primary substation transformer T1.

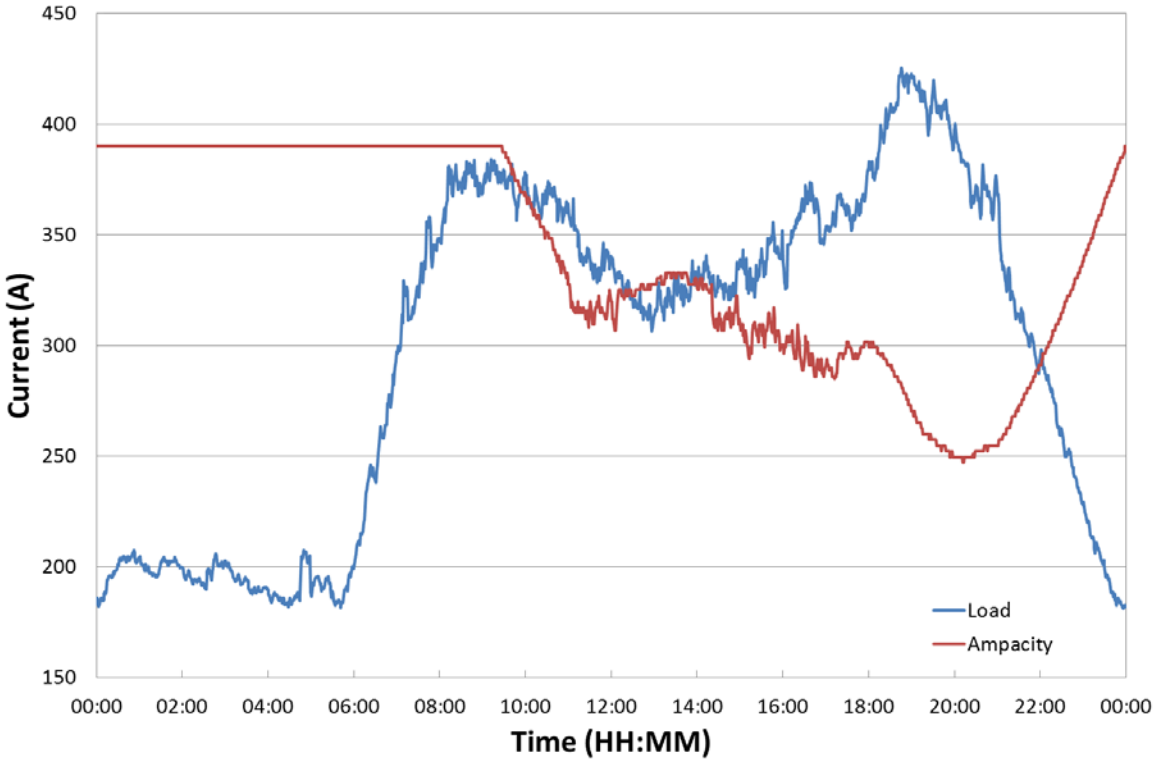


Figure 1 RTTR and Load Profile

The rating of T1 has been set to 260A. Maximum RTTR is assumed to be 150% of transformer rating. Thus, the maximum RTTR is 390A. RTTR reduces rapidly at around 10:00 and 18:00 due to the morning and dinner time peak load.

As can be observed, two overloads based on real time rating can be found in the morning and in the afternoon. I&C DSR can be a solution to solve the excursion. This work will focus on the power flow headroom I&C DSR can create and as a result, instead of using real time rating, only the static rating will use to calculate the headroom.

3.1.2 Rise Carr Load Profile

Rise Carr real and reactive demand is also available from FDWH. Peak load is 9.06MW at 18:46. This load profile is applied in IPSA model.

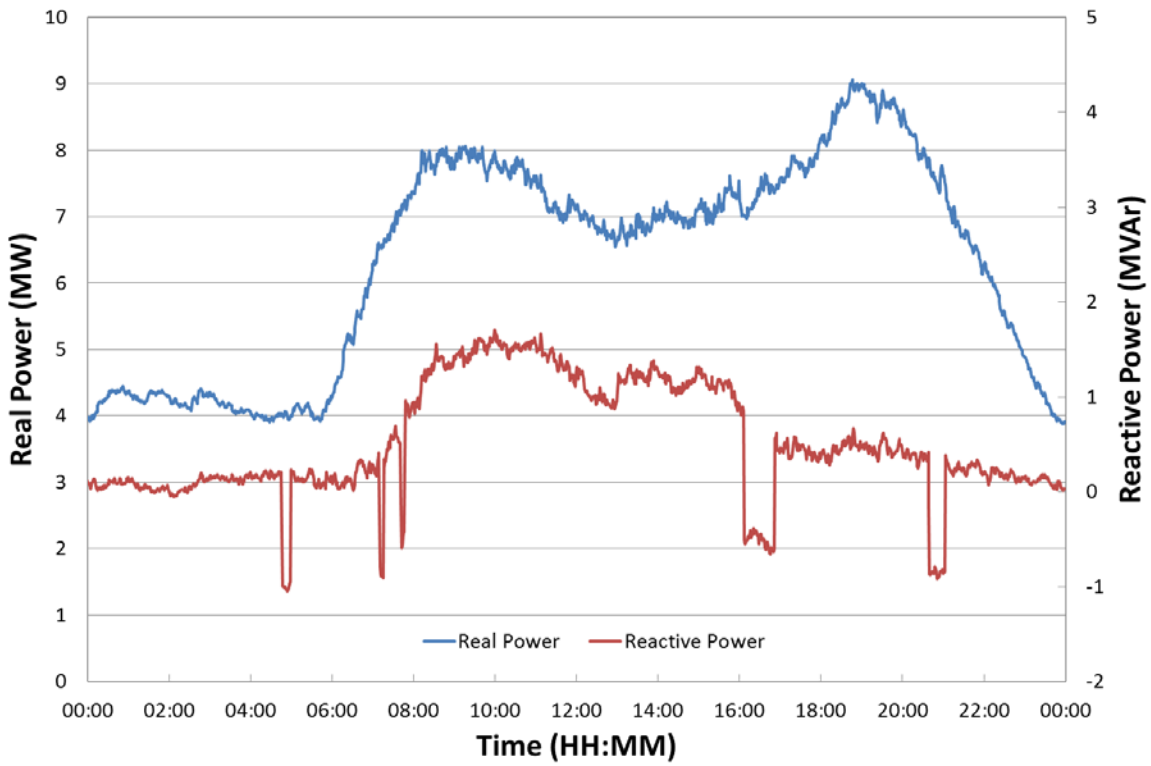


Figure 2 Rise Carr Load Profile

3.1.3 Rise Carr Voltage Profile

The voltage of the secondary side of the primary transformer T1 is available from FDWH. This voltage profile is used to calculate the current on the T1. If the apparent power on T1 is S_t at time t, the current I_t is given by

$$I_t = \frac{S_t}{\sqrt{3}V_t} \tag{3.1}$$

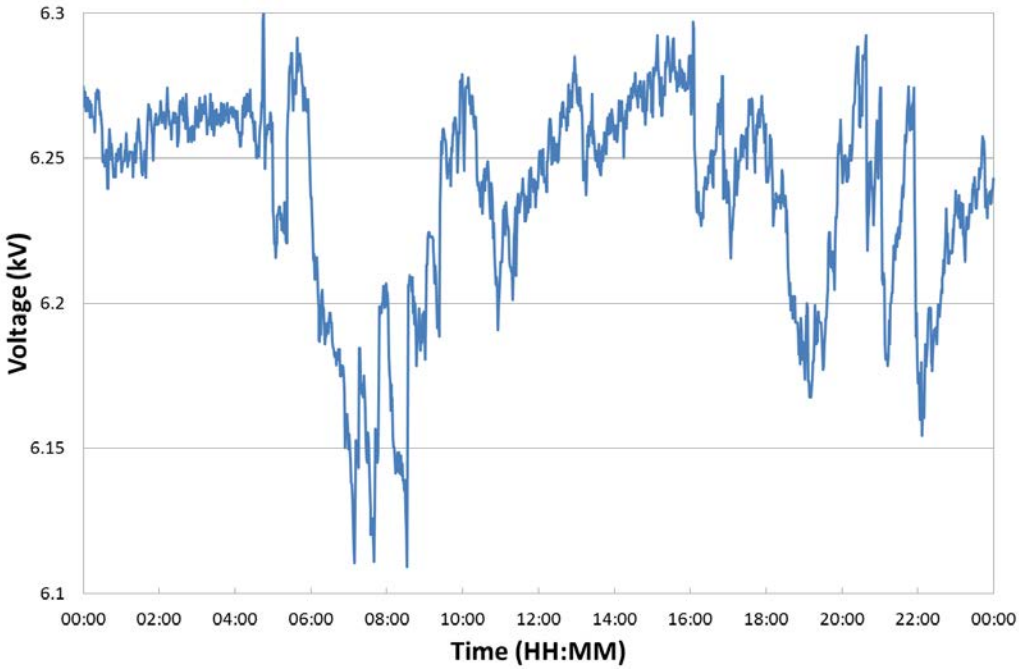


Figure 3 Rise Carr Voltage Profile

3.2 I&C DSR trial summary

3.2.1 DSR trial summary

In this trial, DSR services from 6 customers have been requested to solve thermal problems. The names, DSR types of these DSR customers are given in Table 1.

Table 1 DSR Customer Type and data available

Customer	DSR type	Data Available
DSR Customer A	Load	5-minute resolution power consumption, half-hourly energy consumption
DSR Customer B	Generation	less than 1-minute resolution power consumption, half-hourly energy consumption
DSR Customer C	Generation	less than 1-minute resolution generator power, half-hourly energy consumption
DSR Customer D	Generation	Half-hourly energy consumption
DSR Customer E	Load	Half-hourly energy consumption
DSR Customer F	Generation	Half-hourly energy consumption

During the trials, 31 DSR events happened in 13 days. The dates and time of the events are summarised in Table 2. Most trials happened on 24/03/2014. This day is chosen for post-trial study.

Table 2 DSR Events Summary

Customer	DSR Customer A	DSR Customer B	DSR Customer C	DSR Customer D	DSR Customer E	DSR Customer F
13/03/2014					15:28:24	16:44:18
14/03/2014					17:52:05	
18/03/2014		15:27:57	15:27:57	15:27:56	15:26:06	
19/03/2014	18:40:38	15:06:11	17:55:14	15:06:10	15:06:09	
20/03/2014				15:01:42	15:15:16	15:01:41
21/03/2014		15:59:51		15:20:50	15:16:42	15:17:18
24/03/2014		15:40:27	18:39:15	15:40:26	15:40:25	15:01:37
25/03/2014						
26/03/2014		16:14:15			17:40:31	16:14:16
27/03/2014				16:11:12		
28/03/2014		16:34:46				
24/04/2014	15:57:30					
25/04/2014	15:18:01					

3.2.2 DSR Customer A

DSR customer A is a compressed gas supply company. As illustrated in Figure 4, its main demand is a motor which has a peak demand of 10MW approximately. The motor operates at an interval of 2 to 3 days. A mismatch between overall consumption and motor consumption is marked in red.

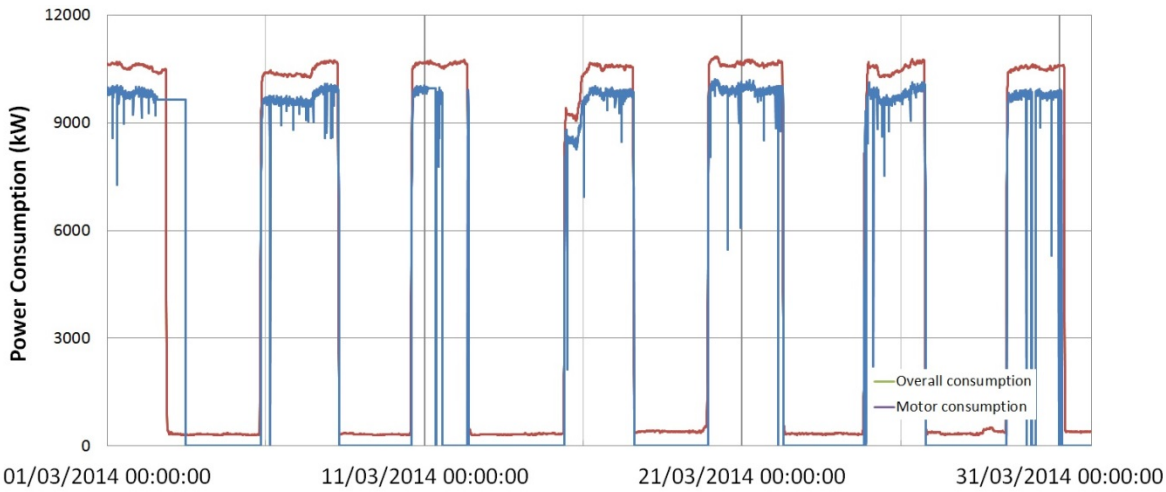


Figure 4 Power Consumption of DSR Customer A in March

On 24/03/2014, the chosen day for post-trial study, DSR service from DSR customer A was not called. The demand of DSR customer A was low during the day and increased after the end of the trial. As a result DSR customer A is not considered in this study.

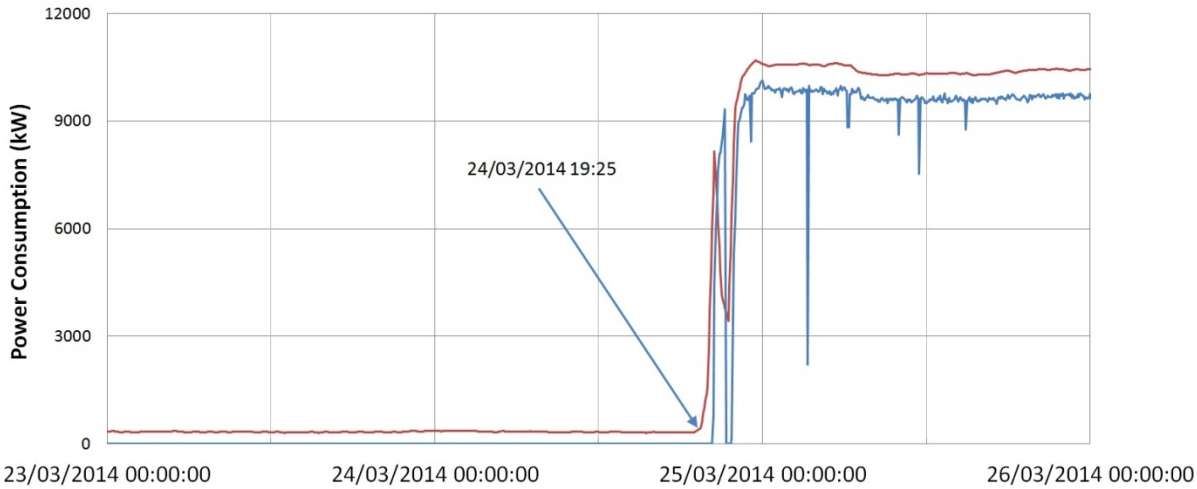


Figure 5 Power Consumption of DSR Customer A from 23/03/2014 to 16/03/2014

3.2.3 DSR Customer B

DSR customer B is generation type of DSR. The consumption reduces to 0 during DSR events. The load profile of DSR customer B is plotted in Figure 6. For DSR customer B, upon receiving the DSR service request, there is a 2 to 3 minutes delay before the consumption starts to decrease and it takes about 30 seconds for the consumption to reduce to 0.

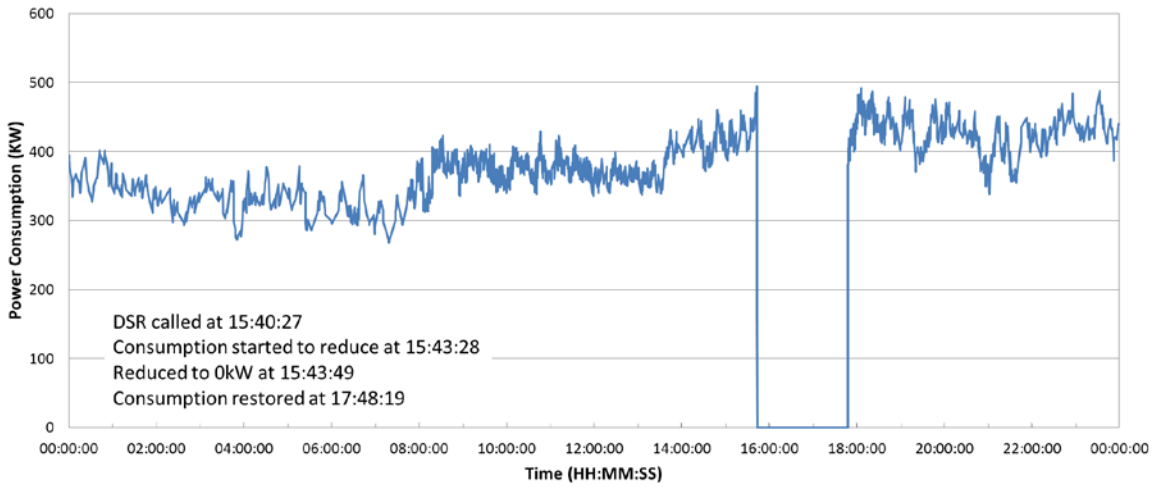


Figure 6 DSR Customer B Power Consumption during the DSR Event

The half-hourly energy consumption of DSR customer B is available for the whole of March 2014. Based on this mean half-hourly consumption data for the days of the month with no DSR events, an average non-DSR event profile for DSR customer B can be derived for the month. The demand reduction of customer B during DSR events is defined as the difference between the average power consumption (the red trace in Figure 7) and its real consumption (the blue trace in Figure 7, 0kW during DSR events).

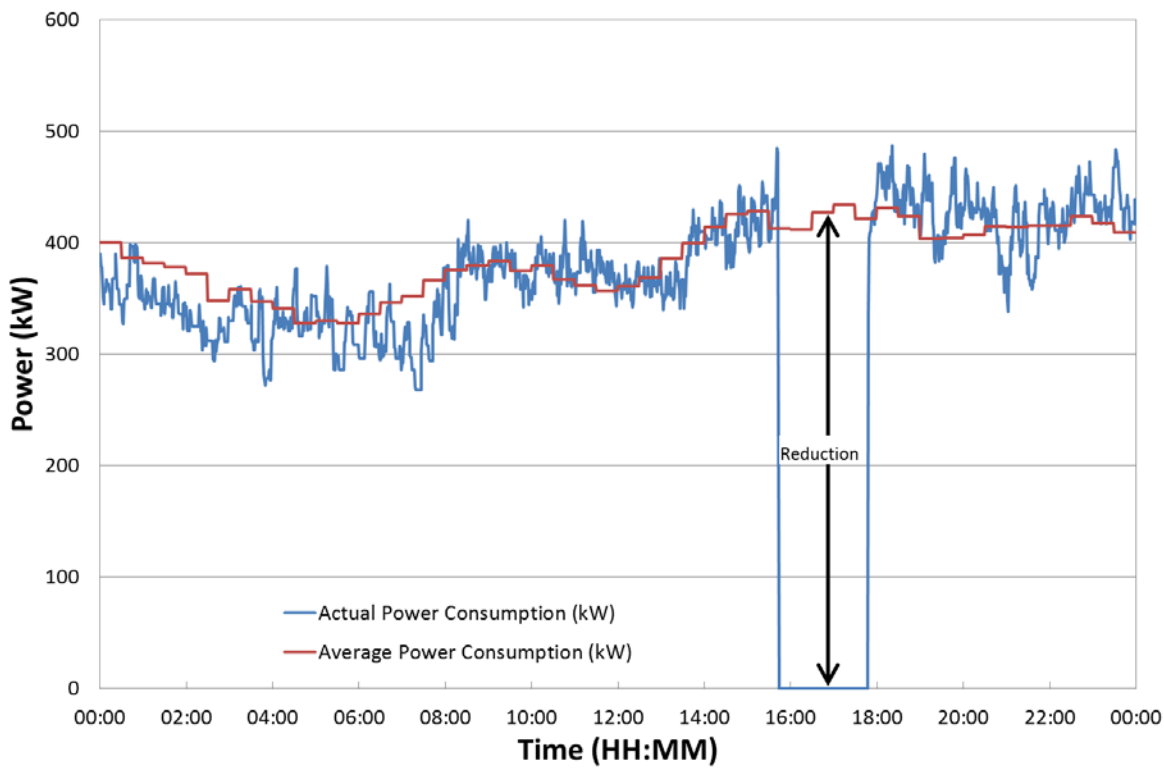


Figure 7 DSR Customer B Actual Power Consumption and Average Power Consumption

3.2.4 DSR Customer C

DSR customer C uses three generators to supply its demand during DSR events. Generators start 1 minute after DSR requests and it takes another 1 minute for the generators to reach full power output. The generation profile during DSR trial is plotted in Figure 8.

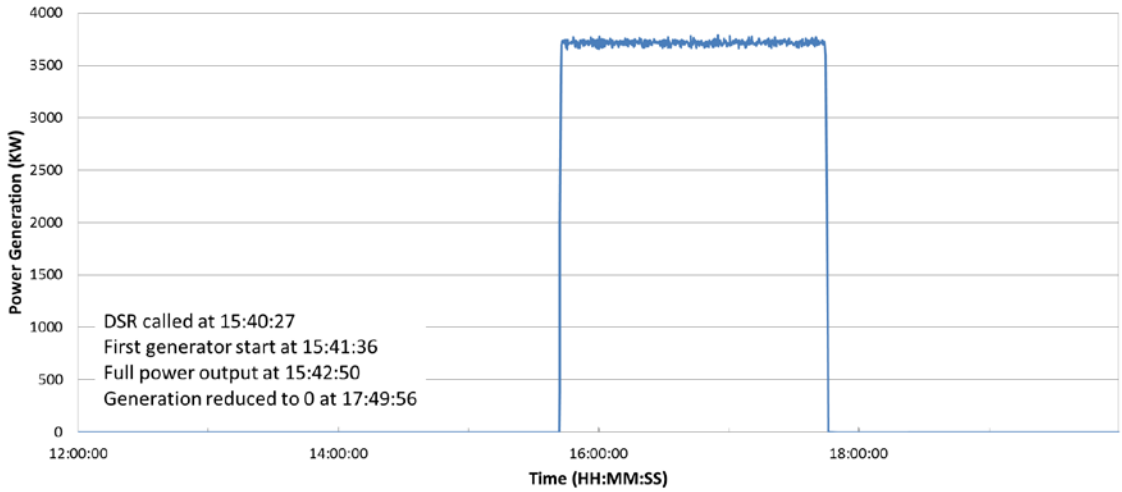


Figure 8 DSR Customer C Generation Profile during DSR Event

Figure 9 depicts the average power consumption of DSR customer C based on its March half-hourly energy consumption and generation profile.

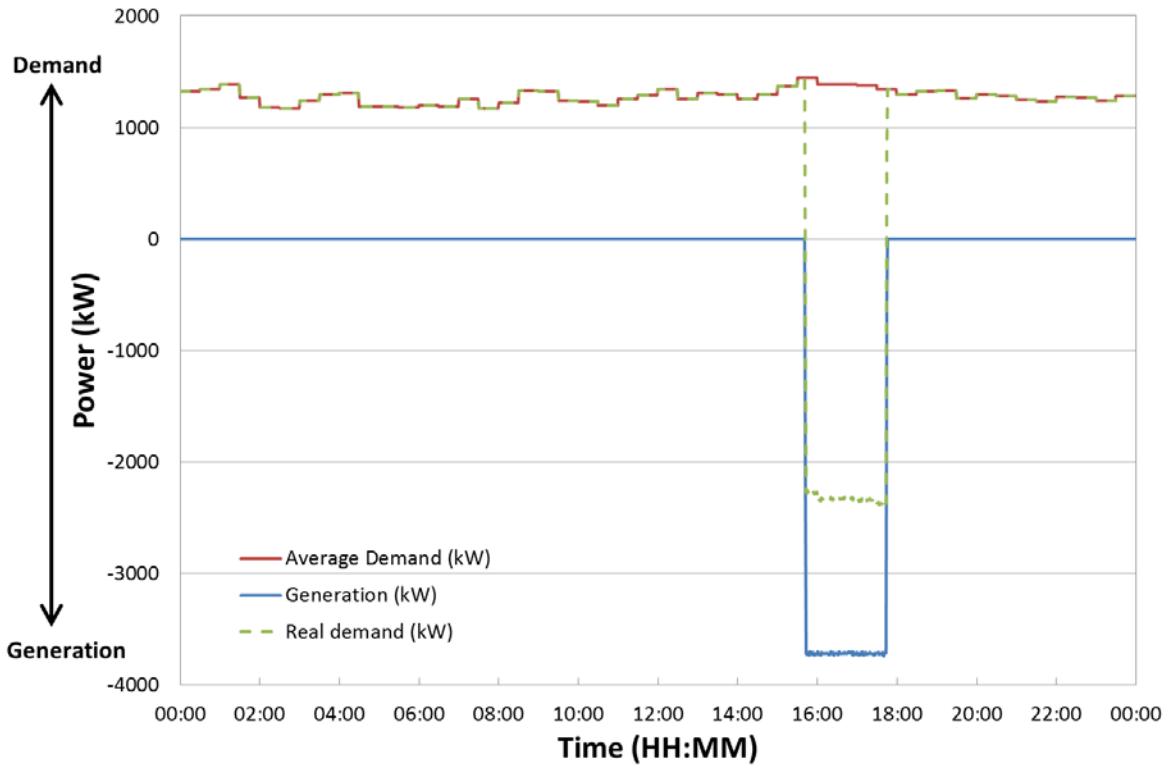


Figure 9 DSR Customer C Average Power Consumption and Generation Profile during DSR Event

3.2.5 DSR customer D

DSR customer D provides a generation type of DSR. In Figure 10, an average power profile derived from one months half-hourly energy consumption, for the days without the DSR trials, is presented.

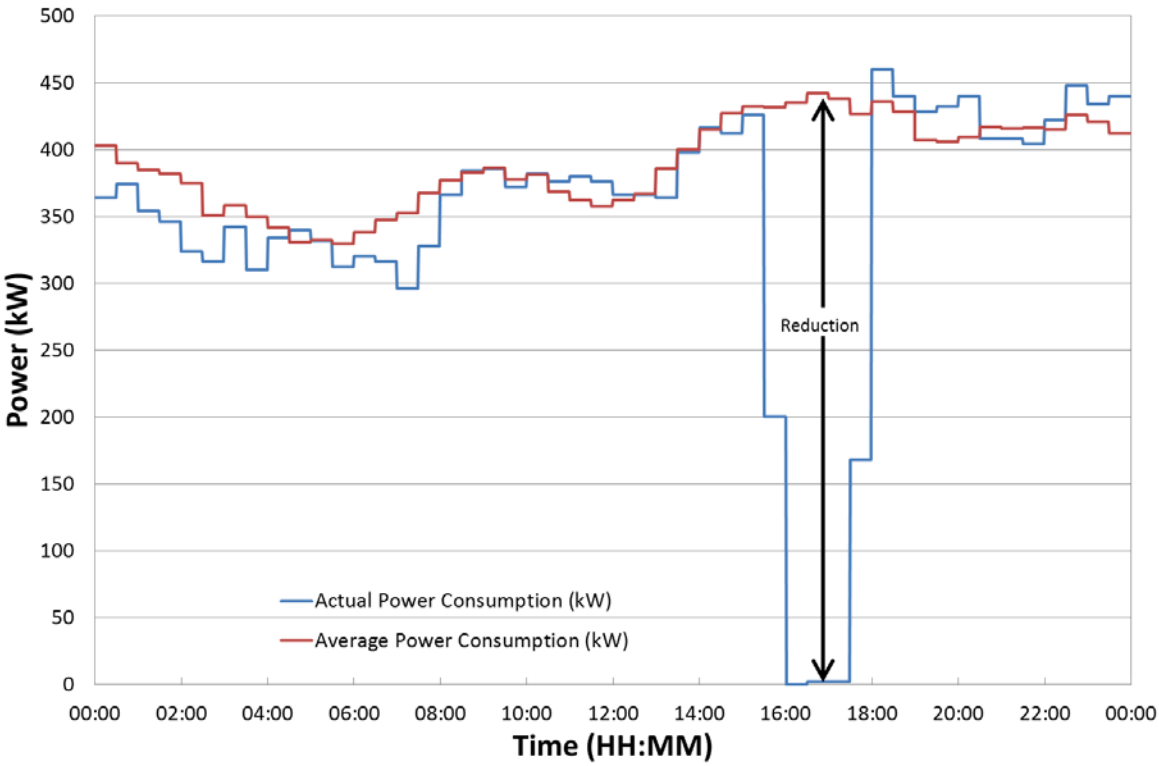


Figure 10 DSR Customer D Average Power Consumption and Power Consumption during DSR Event

3.2.6 DSR Customer E

DSR customer E is a load type DSR. However, as illustrated in Figure 11, unlike DSR customer B, C and D, the daily demand of customer E varies from day to day and thus it is not useful to derive an average demand for this customer.

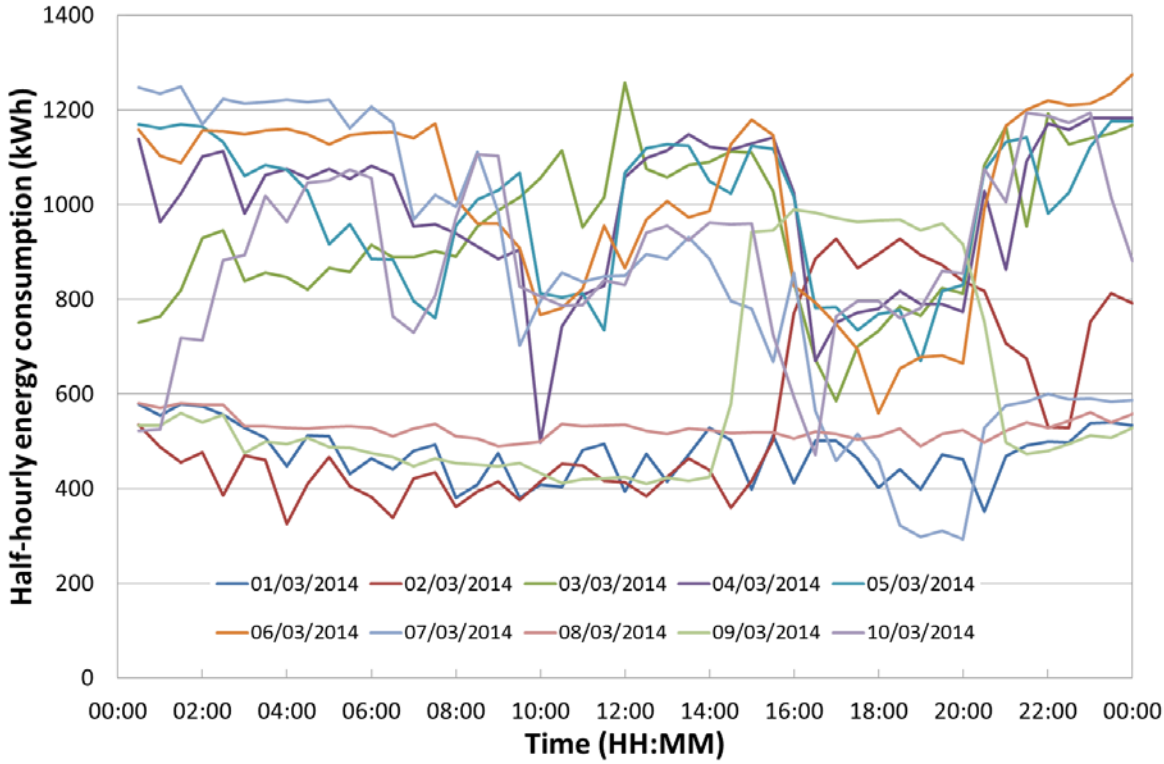


Figure 11 DSR Customer E Half-hourly Energy Consumption for 10 Days without DSR

The demand reduction from DSR customer E during a DSR event is therefore defined as

$$\Delta P_t = P_{t0} - P_t$$

In which, ΔP_t is the reduction, P_{t0} is the power consumption when DSR starts and P_t is the power consumption during a DSR event at time t. This is illustrated in Figure 12.

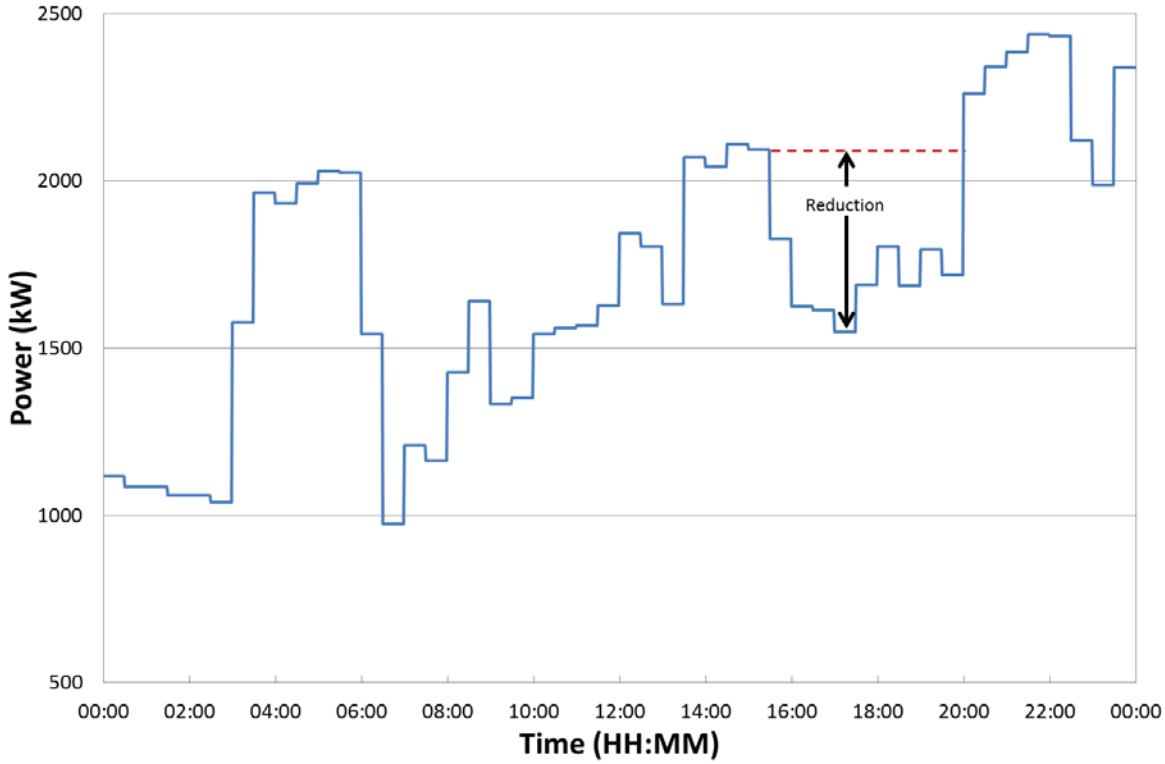


Figure 12 DSR Customer E Power Consumption Based on Half-hourly Energy Consumption and Demand Reduction

3.2.7 DSR Customer F

The consumption of DSR customer F is relatively constant. Customer F is a generation type of DSR and its consumption reduces to 0 during DSR events.

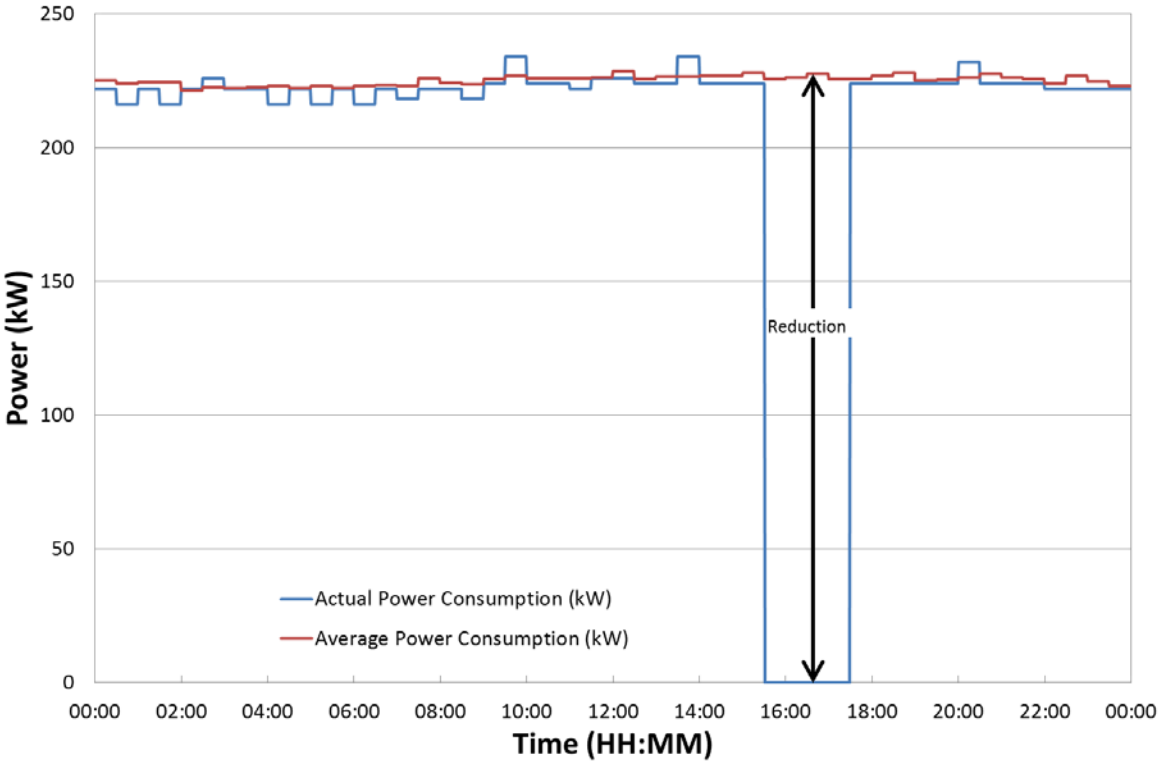


Figure 13 DSR Customer F Average Power Consumption and Power Consumption during DSR event

3.3 LCT profiles

Average EV and ASHP load profiles are plotted in Figure 14.

The EV consumer model used in this work is 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.

An ASHP load model suitable for this analysis is derived from data from the CLNR project programme. 277 households with operational ASHPs units have been equipped with disaggregated monitoring equipment that monitors household load and ASHP load at a 1-minute time resolution. This profile is the mean consumption of 277 customers on the peak day.

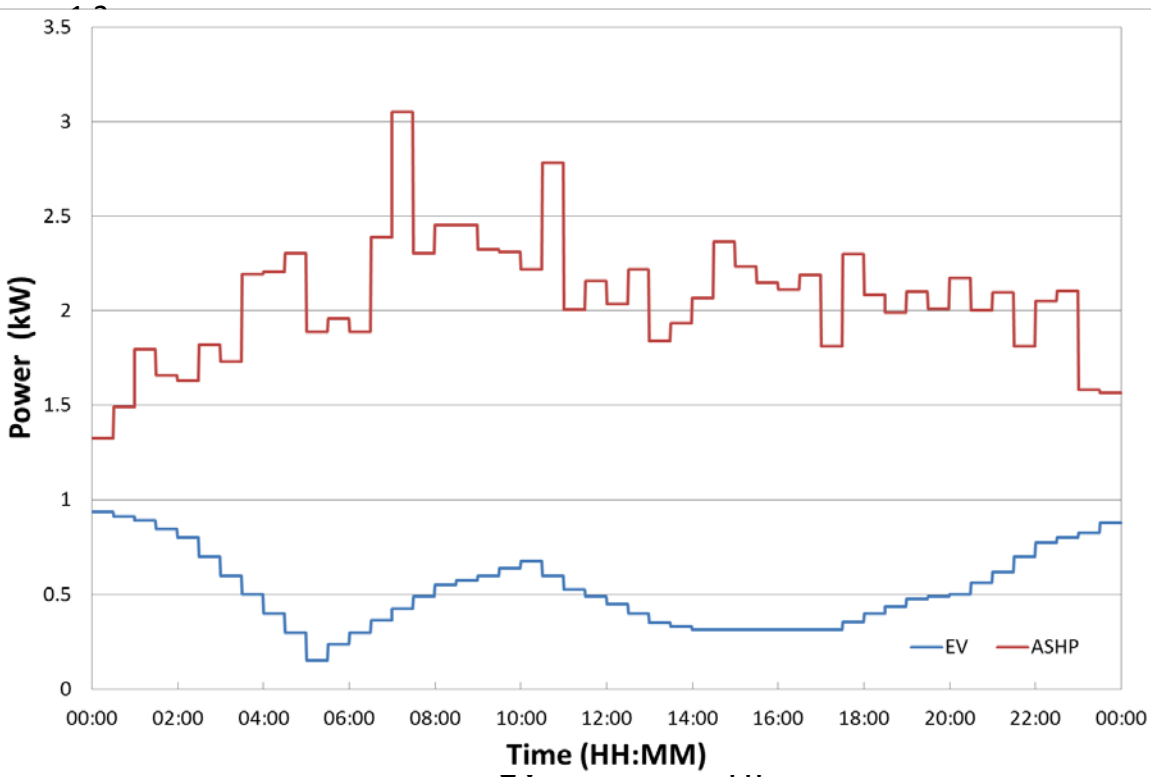


Figure 14 EV and ASHP profiles

4 VEEEG Methodology

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. This approach is derived from previous experience of trials 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 [5]. 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 proposed systematic approach consists of five steps: -

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

This methodology is designated as VEEEG (Validation, Extension, Extrapolation, Enhancement, and Generalisation) and is illustrated diagrammatically in Figure 15.

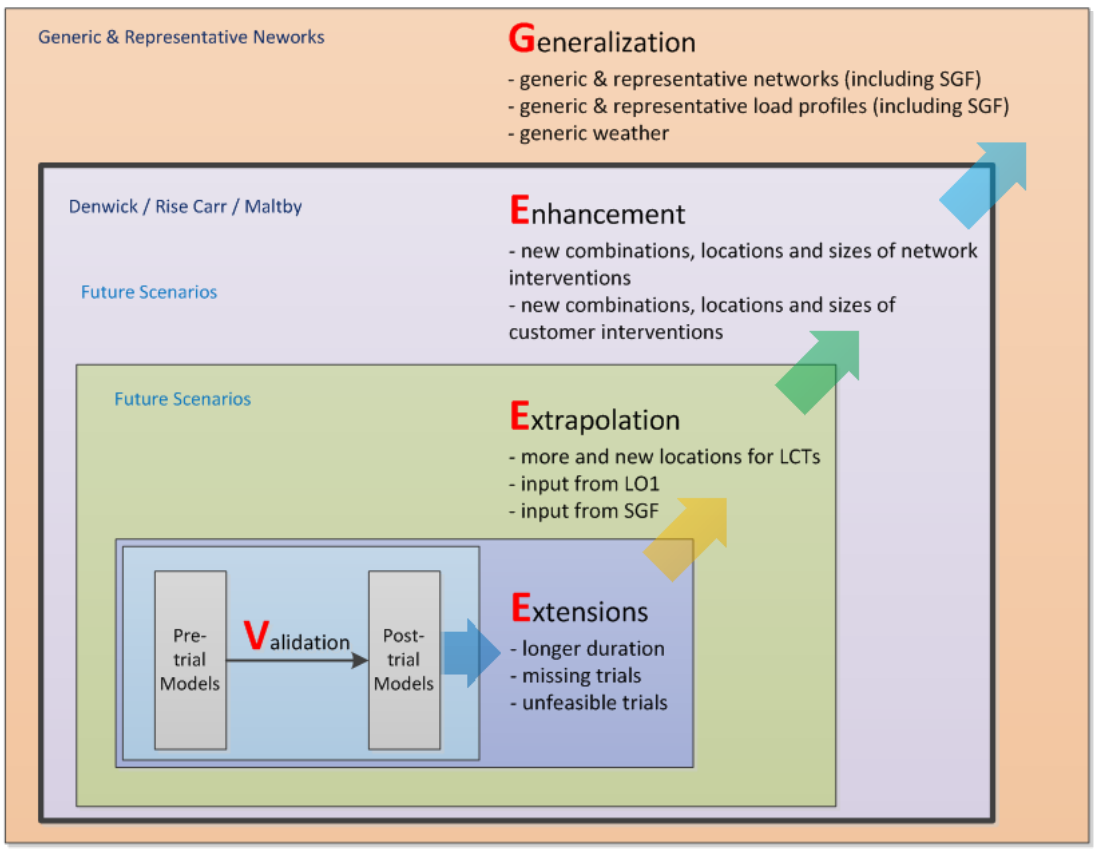


Figure 15 Post-trial methodology VEEEG

5 Post-Trial Simulation Results

5.1 Validation

The network model of Rise Carr is validated by running 24 hours load flow at 1 minute resolution. The real and reactive power profile of Rise Carr network is introduced in section 3.1.2. Load flow result (power flow on Transformer T1) is used to derive the current on transformer T1 based on equation (3.1). The derived current is then compared with current measurement from FDWH. Current measurement from FDWH is introduced in 3.1.1. Simulation result and measurement is compared in Figure 16.

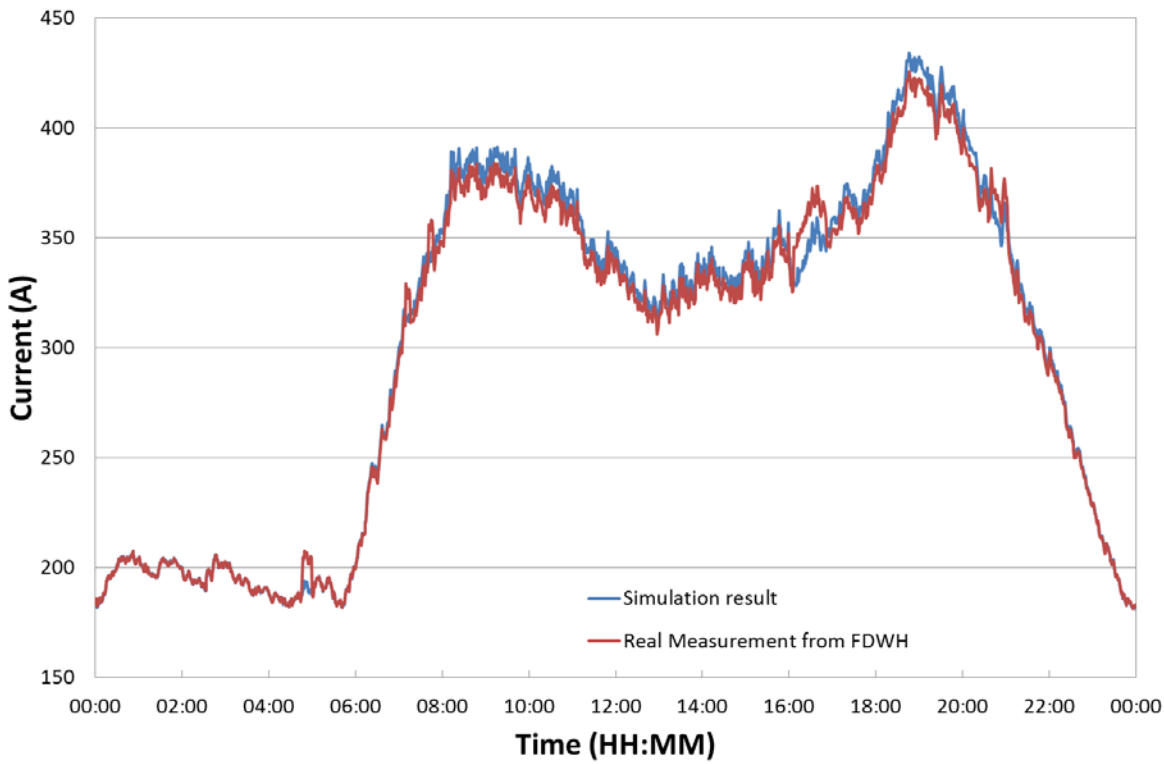


Figure 16 Transformer T1 Measured Current and Simulation result

It can be seen that the simulation result and the real measurement agree with each other. Statistically analysis results shows that two curves have a high correlation coefficient of 99.81% and a small mean average percentage error (MAPE) of 2.3%.

Correlation coefficient is a measurement of the relationship between two sets of data. The correlation coefficient of data X and Y is given as

$$r = \frac{n(\sum x \cdot y) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad \textbf{(5.1)}$$

MAPE can be calculated as

$$M = \frac{100}{n}\sum_{t=1}^{n}\frac{|x_t - y_t|}{y_t} \quad \textbf{(5.2)}$$

In which n is the total number of the data.

In conclusion, validation results show that the IPSA model used in this work is accurate.

5.2 Extension

In reality, none of the DSR customers are connected to the Rise Carr network. In this post-trial simulation, in IPSAl, all DSR customers are connected to the Rise Carr green and red busbar. Simulation result is given in Figure 17. It can be seen that, with I&C DSR customers connected, the current on transformer T1 can be reduced by 300A, approximately. However, since the DSR service was not called during peak demand hours, the peak demand is only reduced by a limited amount. The reduction provided by I&C DSR is 300kW approximately from 18:00 to 20:00.

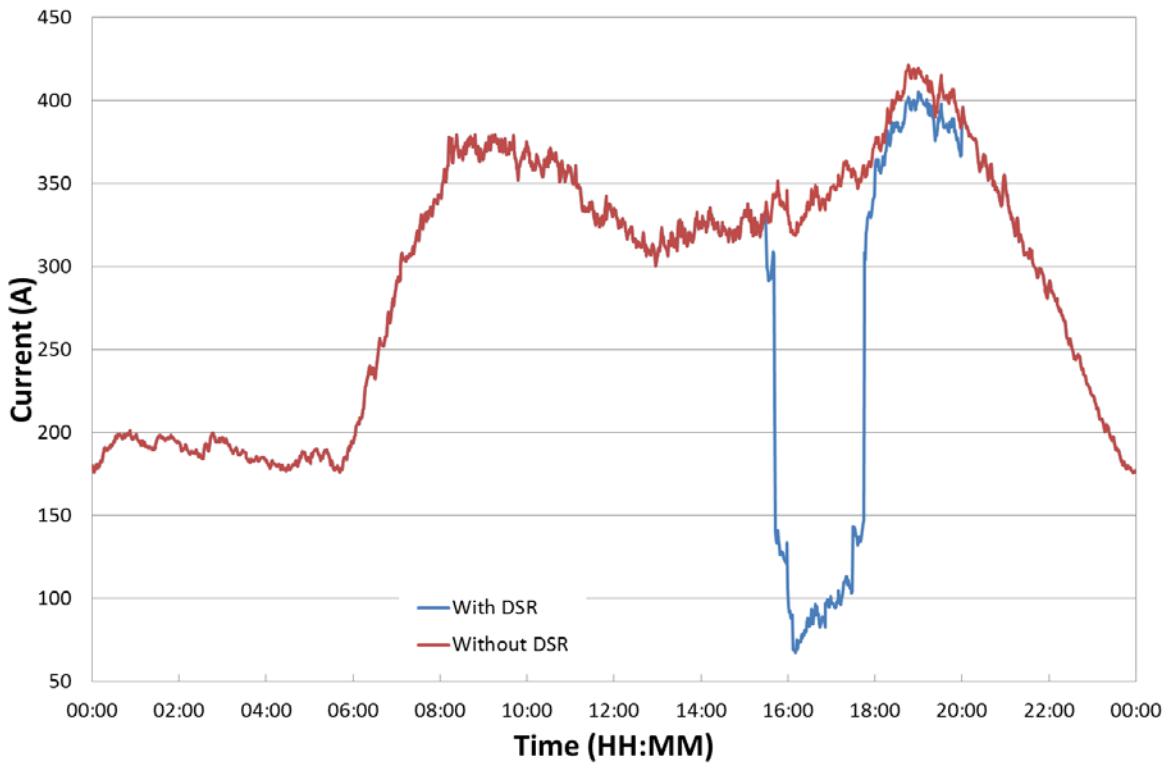


Figure 17 Post-trial Simulation - Transformer T1 Current with and without DSR

5.3 Extrapolation

In this section, the head room created by using I&C DSR is gauged by the numbers of EV and ASHP that can be accommodated on the Rise Carr network. PV is not considered in this study because I&C DSR cannot be applied to solve reverse overload due to distributed generation. It is assumed that the network is under n-1 condition and the static rating of transformer T1 (23MVA) applies. Other criteria such as feeder end voltage limits and feeder rating limits are not considered.

5.3.1 Electric Vehicle

Without DSR, the maximum number of EV that can be connected is 19,775. Load profiles with and without EV are depicted in Figure 18. It can be observed that, the peak demand has been shifted to night time between 20:00 to 04:00 and to morning time between 08:00 to 12:00 due to EV charging.

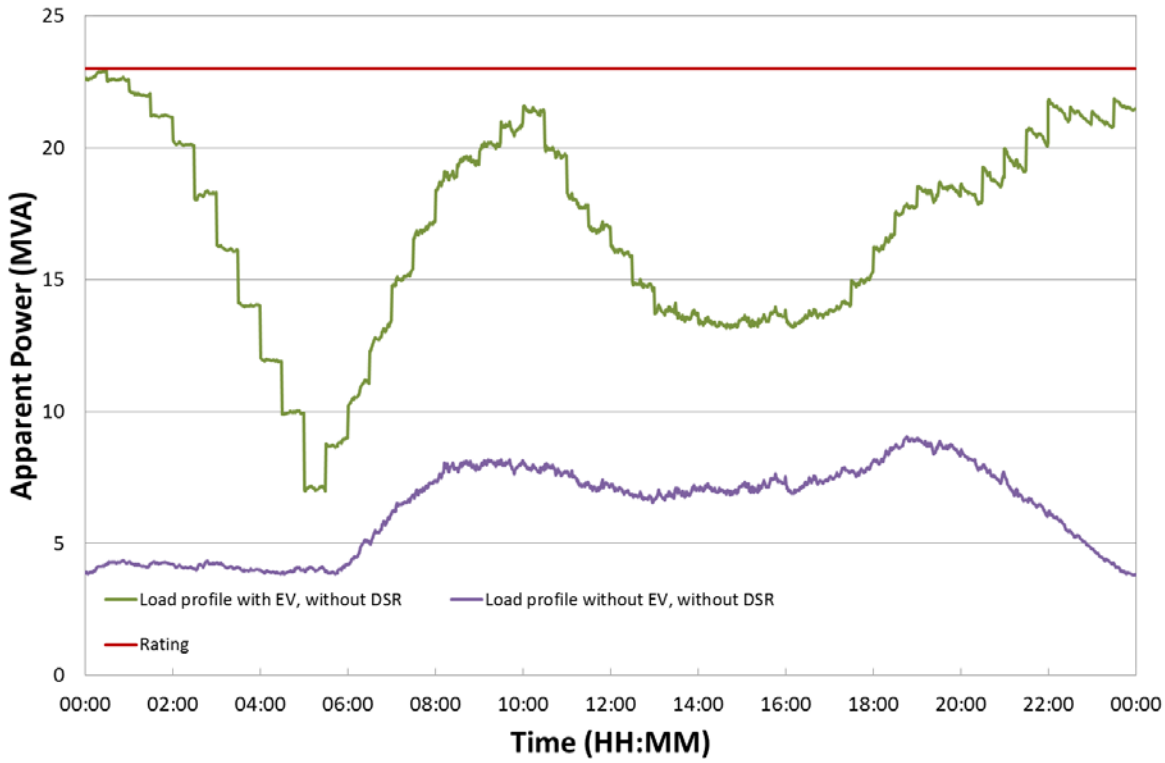


Figure 18 Load Profiles of Rise Carr Network with and without EV

When DSR is applied between 16:00 and 18:00, the number of EVs that can be accommodated does not increase. As illustrated in Figure 19, DSR is able to reduce the demand however, it is not able to reduce the peak demand. As a result, the use of DSR between 16:00 and 18:00 is not able to create headroom for EV charging on the Rise Carr network.

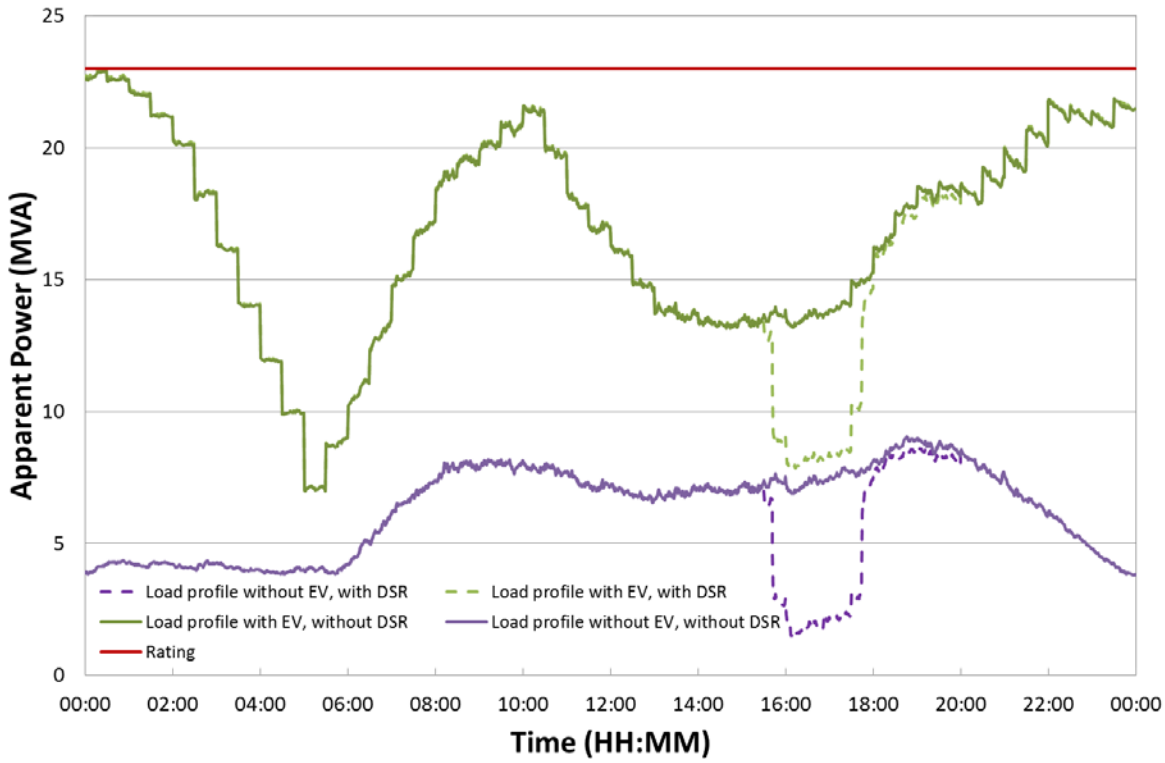


Figure 19 Load Profiles of Rise Carr Network with and without EV and DSR

5.3.2 Air Source Heat Pump

Similarly, the use of DSR between 16:00 and 18:00 is not able to increase the maximum number of ASHPs connected to the Rise Carr network. The number of ASHP that can be accommodated is 5,168. As illustrated in Figure 20, the new peak time occurs from 06:00 to 12:00 and as a result, the use of DSR between 16:00 and 18:00 is not able to reduce the peak demand.

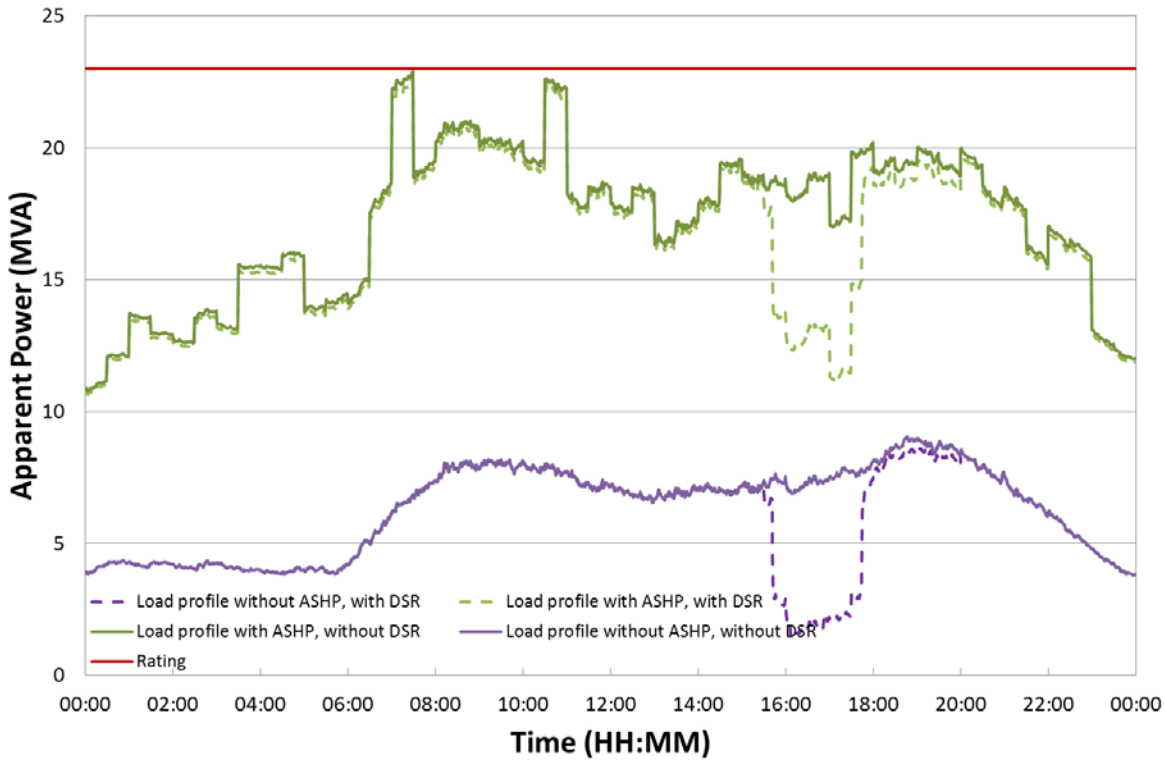


Figure 20 Load Profiles of Rise Carr Network with and without ASHP and DSR

5.4 Enhancement

5.4.1 Electric Vehicle

As can be observed in Figure 18, the first peak demand due to EV charging occurs between 00:00 and 02:00. In this enhancement study, it is assumed DSR can be called at any time of day. Table 2 summarised the DSR request time of each trial. On 24/03/2014, the day this case study is using, all DSR requests are sent between 15:00 to 16:00. However, as illustrated in Figure 21, if a DSR requests are sent at 23:00, with the same response profile, the number of EVs that can be accommodated increases from 19,775 to 20,968.

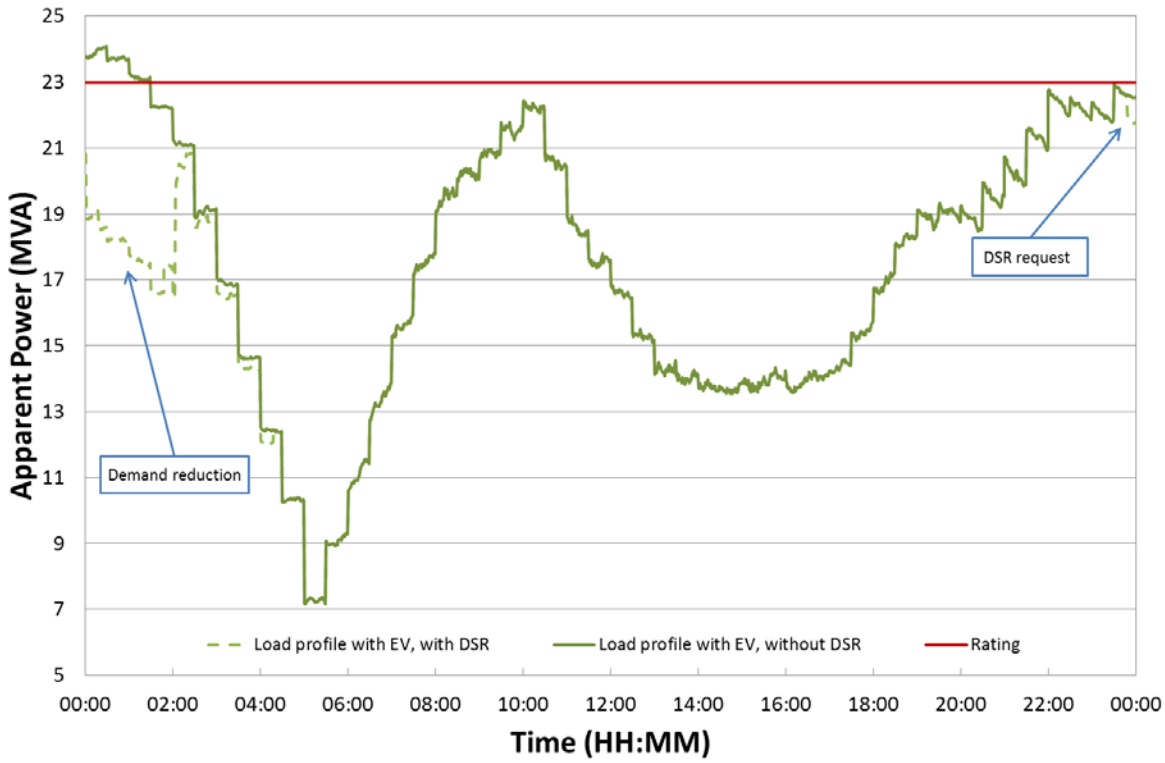


Figure 21 Load Profiles of Rise Carr Network with and without EV and DSR – Enhancement Study

5.4.2 Air Source Heat Pump

As can be observed in Figure 20, the first peak demand due to ASHPs occurs between 07:30 and 08:00 and the second peak occurs between 10:00 and 11:00. In this enhancement study, it is assumed DSR can be called at any time of day and can be called more than once. As can be seen in Figure 22, two DSR requests have been sent. With the same DSR profile, the number of ASHPs that can be connected to the network increases from 5,168 to 6,261.

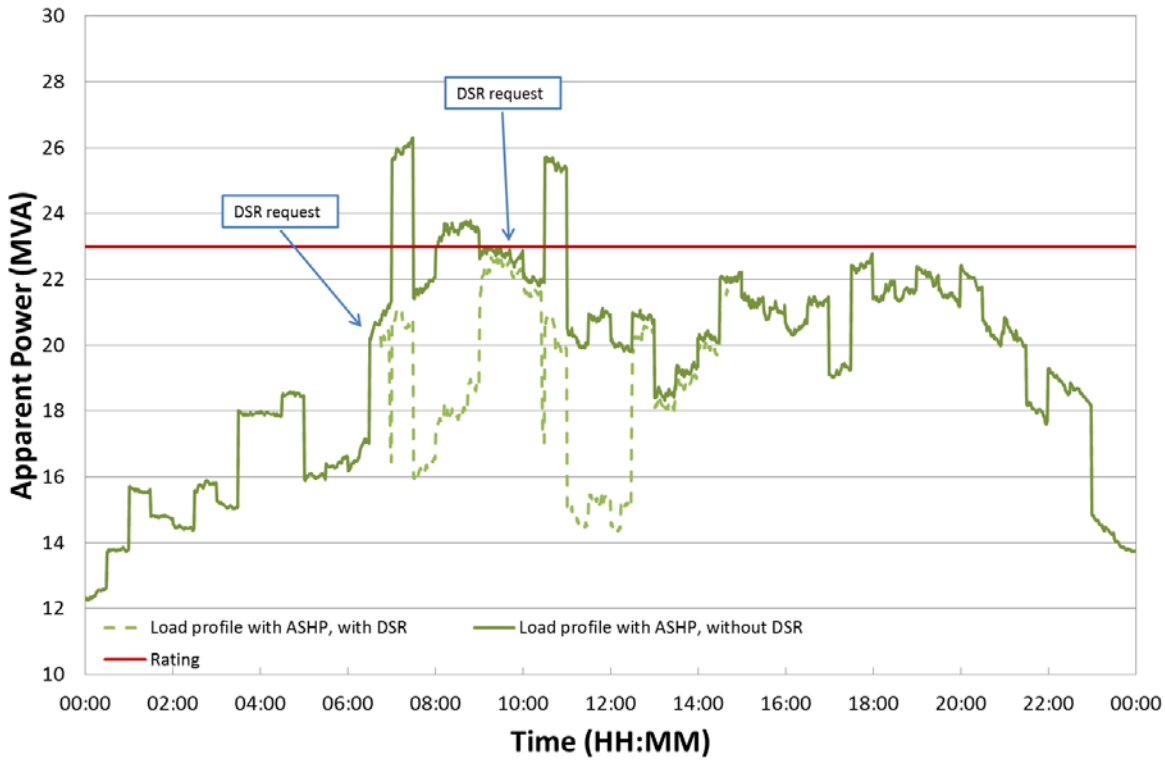


Figure 22 Load Profiles of Rise Carr Network with and without ASHP and DSR – Enhancement Study

5.5 LCT profiles update

Test cell 3 (ASHP) and test cell 6 (EV) results were not fully available when this report was initially prepared. As a result, the research conducted in this report used the output from Smart Grid Forum (SGF) for EV study. In this section, the EV profile has been replaced with TC6 results from the CLNR project and the 95 percentile heat pump profile has been replaced with mean profile. Figure 23 compares the SGF profile to the test cell 6 profile data [6].

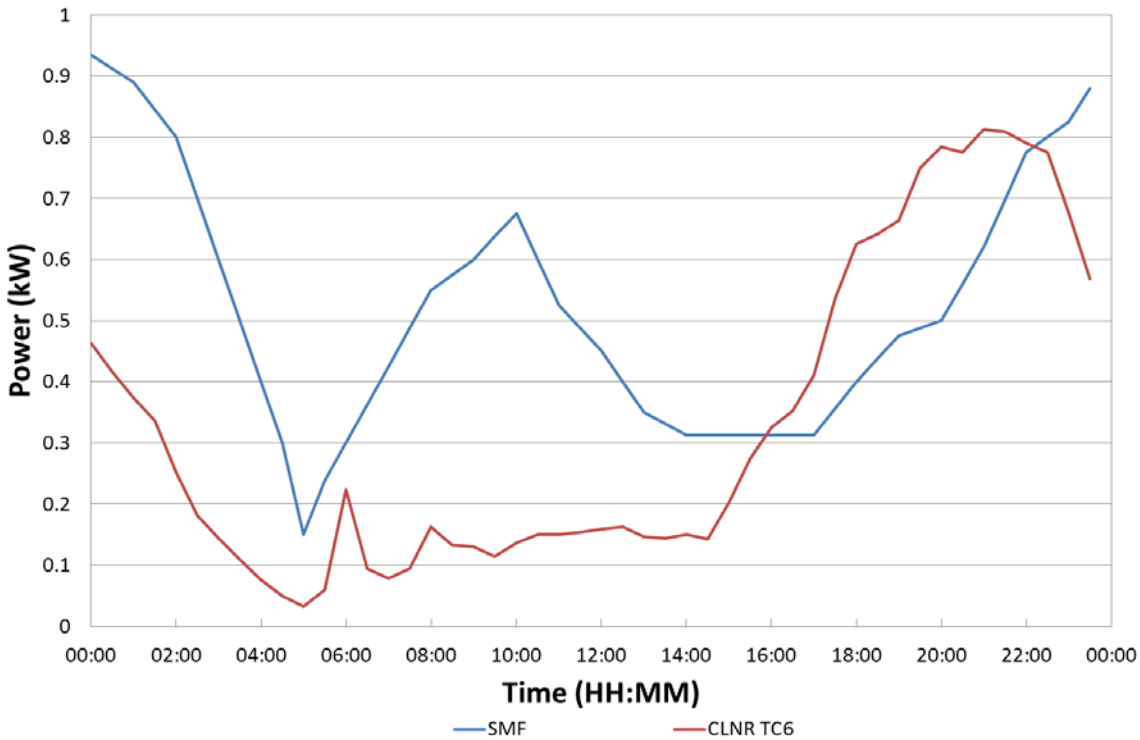


Figure 23 EV profiles comparison

Baseline and enhancement study is carried out with the revised EV profile. With the revised EV profile, in the baseline study, the number of EVs can be accomadated is 18,532. In enhancement study, DSR is called during peak time, and the number of EVs that can be accomadated increases to 20,575.

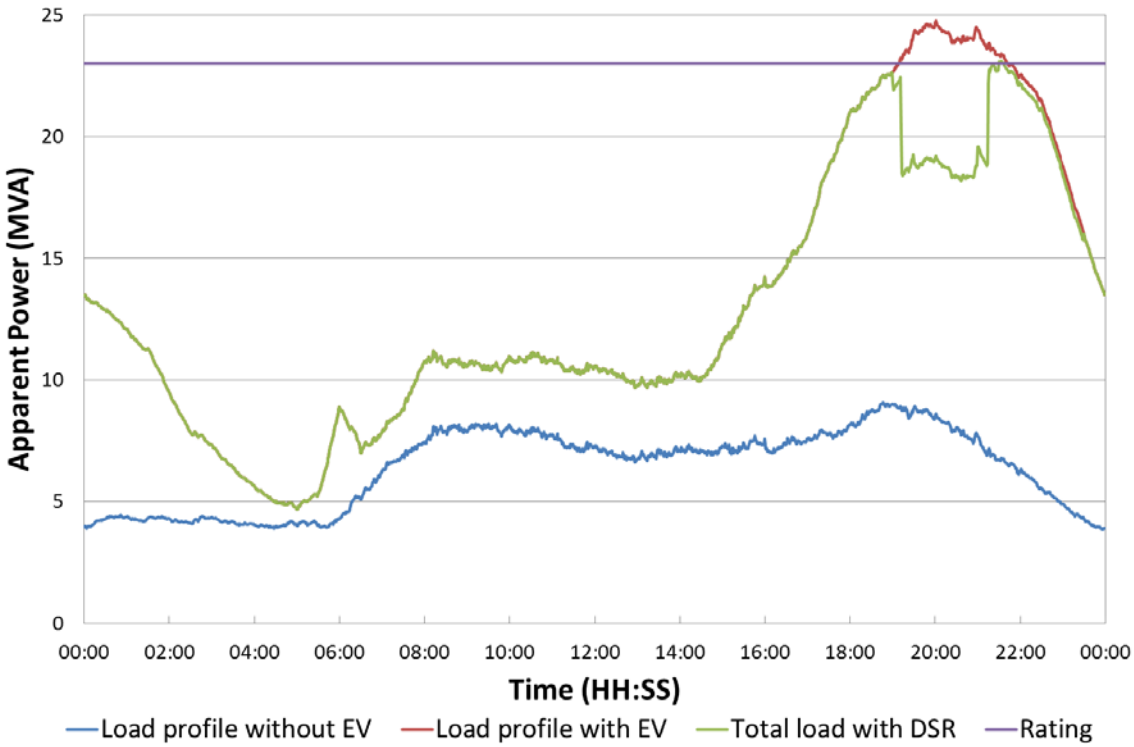


Figure 24 Enhancement study with revised EV profile

Mean and 95 percentile ASHP profiles from the CLNR project TC3 are compared in Figure 25.

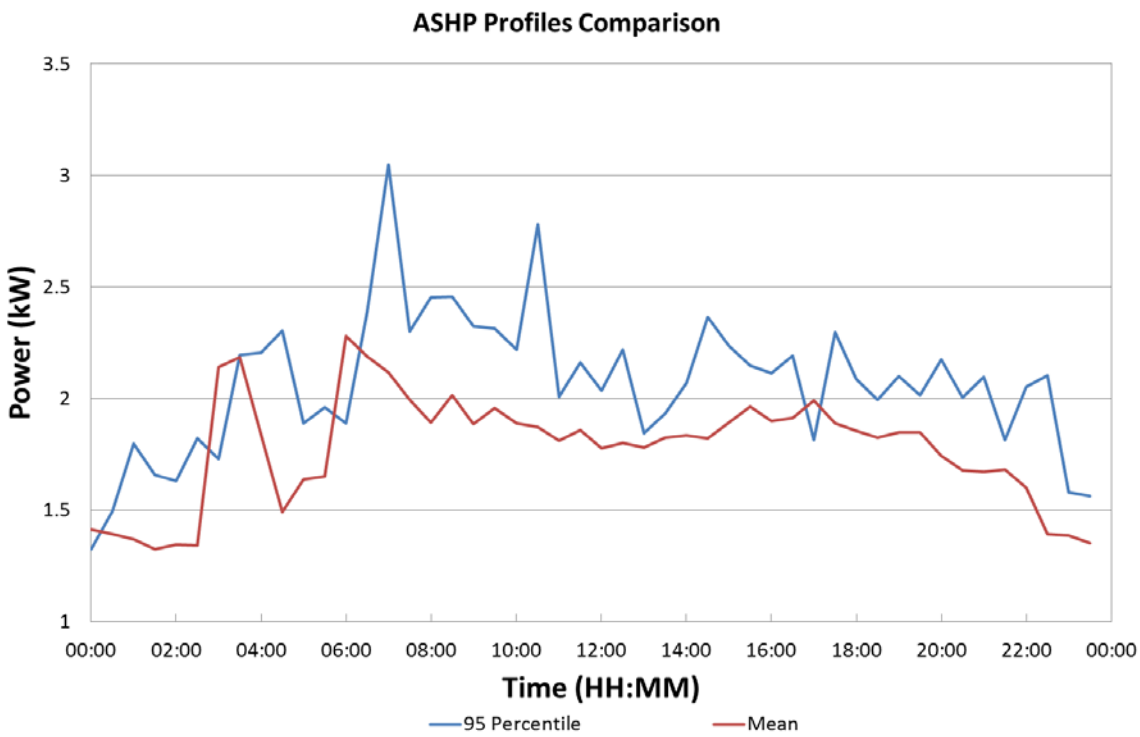
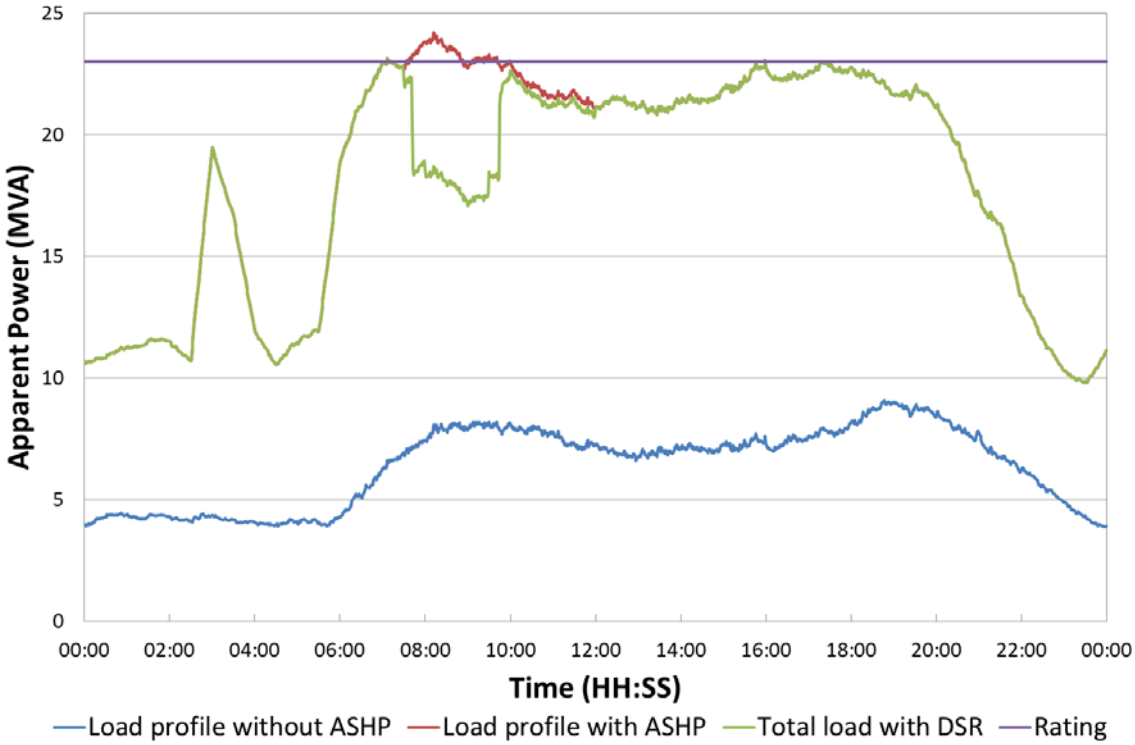


Figure 25 ASHP profiles comparison

With the revised ASHP profile, in the baseline study, the number of ASHPs can be accomadated is 14,773. In the enhancement study, DSR is called during peak time, and the number of ASHPs that can be accomadated increases to 15,712.



5.6 Generalisation

No generalisation work was required in this report as the load profiles, LCT profiles and network scenario were deemed to be representative of the future scenarios in the UK. Repeating the study for another area of network would not add any additional meaning to the results presented here.

6 Conclusions and Learning

In this report, DSR responses were called, from a number of service providers, to mitigate thermal overloads that the GUS control system observed. As the distribution networks where the GUS Control System has been deployed have been selected to be robust, thermal overloads are highly unlikely to occur during the trial. As per the trial design methodology developed as part of CLNR the thermal limits on the item of infrastructure under investigation are reduced in order to stimulate a response from the GUS control systems [7]. In addition, real-time thermal ratings are used instead of conventional static ratings as part of the trials. The trials therefore demonstrate how DSR can be fully integrated with a distribution network management system which utilises transformer RTTR to evaluate its control actions. The theory and validation of this RTTR algorithm will be included in a future report.

The EHV/HV transformer RTTR profile together with load profile of Rise Carr network, the I&C DSR responses, and LCT (EV and ASHP) profiles are presented. An overview of the VEEEG post-trial analysis methodology is given. Post-trial analysis of I&C DSR for power flow management trials are detailed. Post-trial simulations results, including validation, extension, extrapolation and enhancement, are given in in chapter 5.

The validation process uses real and reactive power measurement as an input to IPSA model. Current result derived from load flow results is compared to real current measurement. A high correlation coefficient of 99.81% and a small MAPE value of 2.3% prove that the model is accurate.

The extrapolation study demonstrates that due to the LCT load profiles, the time the peak demand occurs on the network will change and, that DSR utilised between 16:00 and 18:00 will not able to create any additional headroom for LCT load.

The enhancement study illustrates that if it is assumed that DSR can be called at any time of day and more than once then additional headroom for LCT load can be created. This modified DSR enables, in conjunction with the powerflow management system, additional EVs and ASHPs to be connected to the network. The post-trial analysis results are summarised below in Table 3.

Table 3 Maximum Numbers of EV and ASHP Connected in Different Studies

	Extension	Extrapolation	Enhancement	Percentage increased due to enhancement
Number of EV	19,775	19,775	20,968	6.0%
Number of ASHP	5,168	5,168	6,261	21.1%

Comparing Figure 21 and Figure 22, it can be observed that, compared to that of ASHPs, the peak demand due to EVs has a longer duration and is more flat. There are two high but short durations of peaks due to the use of ASHPs. In the enhancement study, theDSR is called twice for these two peaks. As a result, the percentage uplift of ASHPs is higher than the corresponding figure of EVs.

Some conclusions can be drawn from this study:

1. The delay time of DSR depends on how DSR is provided. DSR provided through load shifting or shedding tends to have longer delays. DSR provided through the use of generation tends to have a shorter delay time;
2. The connection of large quantities of LCT will change the load profile on the network and the peak demand time will be shifted;
3. The timing of the DSR request is critical to the headroom created;
4. The number of times DSR can be requested is critical to the headroom created.

Previous work has indicated that electrical energy storage in collaboration with DSR offers synergistic benefits beyond the use of a single technique [2]. It can be seen that these benefits can equally be applied to powerflow management of infrastructural assets:

1. Results from the trials indicate that in some cases DSR response could be substantially slower than EES (up to 30 minutes). Therefore, for short duration excursions, due to the intermittency of renewables based generation and new LCT based load, the fast response of the EES coupled with DSR could reduce the number of calls and improve the response of the collaborative voltage control system.
2. The energy capacity of the EES required in a powerflow managaement scheme is reduced because the DSR system can remove or reduce the need for storage intervention. Given that EES technology is currently expensive and the cost of DSR is lower than the cost of EES, this is a valuable contribution.

7 Reference

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