SMART BUILDING POTENTIAL WITHIN HEAVILY UTILISED NETWORKS

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ABSTRACT

SP Energy Networks (SPEN) was involved in the research program Smart Building Potential within Heavily Utilised Networks to assess the role that Demand-Side Response (DSR) could play in providing the distribution network operators (DNO) with an economic and readily deployable means of enhancing the capability of their networks. DSR trials were carried out across 10 city centre buildings in Glasgow. The average level of demand reduction of controllable loads across the whole year was found to be around 20%, which equated to a 7% reduction overall. Comms issues were found in some buildings, which resulted in gaps in data.

Network models were developed that allowed the impact of DSR – taking the levels identified through live trials – to be modelled and a business case developed. The business case suggested that DSR is a cost-effective network support tool if low levels of load reduction are required. As the level of load reduction increases, traditional reinforcement is more cost effective.

INTRODUCTION

Networks within city centres are the most economically important to the country, the most heavily utilised and the most expensive to reinforce. To this extent these networks will be at the forefront of issues arising from the much anticipated low carbon technology loads and increased penetration of distributed generation (DG) [1].
There is an expectation that DNOs need to deliver the solutions to these problems not just through traditional means, but through the implementation of techniques such as DSR to reduce network peaks and, potentially, defer investment [2].
This paper focusses on the evaluation of DSR, implemented through the existing building management systems (BMS) of 10 city-centre buildings of varying archetypes across Glasgow.
The problem was broken down into 2 areas of investigation:

- physical implementation of DSR within 10 city-centre Glasgow City Council (GCC) buildings to understand the load reductions that can be achieved in real buildings at different periods of the year.
- modelling of each secondary substation in Glasgow city-centre network to understand likely load growth in the future; and

The modelling was carried out with the Energy Systems Research Unit (ESRU) at the University of Strathclyde and the physical DSR interventions designed and installed by Siemens Digital Grid Systems.
The results were brought together by modelling a virtual circuit that closely emulated the buildings in which DSR was implemented. A number of future load growth scenarios were applied to the virtual circuit and the impact of DSR – based on actual load reductions seen in trial buildings – assessed to overcome any peak loading conditions that arose.
Finally, the overall business case for DSR was assessed, using typical network upgrade costs and an average cost for implementing DSR in similar city-centre buildings.

PHYSICAL IMPLEMENTATION

Building Selection

Working in partnership with GCC stakeholders a list of buildings was produced for consideration. The list was created using a range of criteria including:

- Size of available load (kW);
- Level of building automation available;
- Location; and
- Strategic importance to GCC.

Each building identified by GCC was subject to an audit performed by Siemens, which baselined the existing in-building operations and quantified:

- the maximum demand of each building;
- the level to which that demand is currently controlled; and
- the possibility to add further control.

10 buildings were selected, listed in Table 1 below.
An unexpected learning from the audits was the fact that level of load under BMS control was significantly lower than first thought.

Building No.	Building Name	Max approved DSR demand (%)
B01	Exchange House (229)	14%
B02	Exchange House (231)	50%
B03	Hillhead Primary	17%
B04	Bardowie Care Home	34%
B05	City Chamber West	22%
B06	City Chamber East	14%
B07	Pirie Park	55%
B08	Gorbals Leisure Centre	48%
B09	Blackfriars Primary	20%
B10	Cook Freeze Unit	39%
	TOTAL	**32%**

Table 1: Buildings selected with DSR level approved

As the table shows, many buildings had less than 20% of the total building load under BMS control and the loads approved for use in the trial were sometimes under 15%. Some buildings were closer to the 50% mark, but as the testing showed, the true level of demand reduction fell short of this for a number of buildings. This is discussed later in the paper.

Nature of Building Loads included in DSR

The nature of the loads controlled by BMS were typically those pertaining to environmental comfort within the building: heating, ventilation and control (HVAC). Loads such as lighting and ICT were harder to include as it would be difficult to judge whether or not these loads can be turned off centrally without disturbing building occupants. The advantage of using HVAC loads for DSR is they generally have a level of hysteresis due to the thermal mass of buildings and the gradual manner in which temperature levels rise or fall.

System Architecture

The system architecture implemented by Siemens is shown in the Figure 1 below.

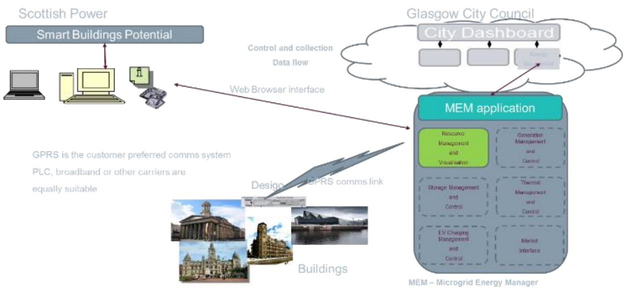

Figure 1: System Architecture

The BMS in each building was modified to reduce particular loads in response to DSR requests from the 'MEM' application. Access to the MEM, housed on a server is a Siemens facility, was via a secure web client.

DSR 'Event' Scheduling

The user interface (UI) that allowed test to be initiated was as shown in Figure 2 below.

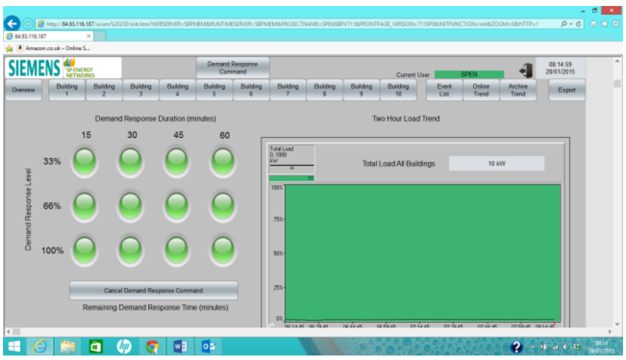

Figure 2: User Interface for scheduling DSR events

From this UI it was possible to initiate 12 different DSR events:

- 33% load reduction for 15/30/45/60 minutes
- 66% load reduction for 15/30/45/60 minutes
- 100% load reduction for 15/30/45/60 minutes

It was also possible to select buildings individually, such that one, many or all buildings were included in the DSR event, which would result in different levels of response. A scheduling facility was also available that allowed tests to be scheduled for a whole week without manual input.

Testing Methodology

For a typical Glasgow city-centre circuit (which typifies most city-centre circuits across the UK [3]), the peak demand is relatively flat and follows working hours (09:00-17:00) fairly closely, illustrated in Figure 3 below.

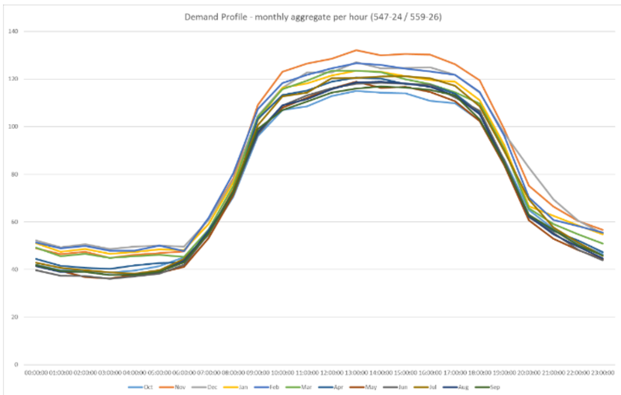

Figure 3: Typical city centre network profile

The testing, therefore, had to be consistent across the day and did not have to be focussed on any particular peaks at specific times of the day. Taking these aims and high-level constraints, a testing regime was developed.

Communications Issues

The data to and from each building was transmitted via a 4G comms link. Given the city centre nature of the buildings selected, 4G was thought to be the logical choice of comms carrier as it is available across the city. Significant issues were experienced throughout the project, however, which resulted in: a) some buildings being discounted from analysis altogether through missing data; and b) a change in the way the results were analysed, described below.

Analysis Methodology

It was originally envisaged that comparison of DSR and non-DSR loads would have been relatively straightforward process where the load profile for one week could be compared with (for example) adjacent weeks and the impact of DSR assessed.

However, the comms issues and the consequent difficulties in extracting and processing data meant that the nature of analysis had to change.

Rather than comparing demand one week to another, it was decided that the results had to be compared over longer periods of time – typically a season - to ensure data was available across the entire working day for both DSR and non-DSR event periods. Each day was split into 15 minute slots and the load values for each slot extracted and added to the cumulative load value for each respective slot. The value used in the final analysis was an average of all available values in each time slot, which was calculated using Power Pivot tables in Excel.

Figure 4 below illustrates the typical output for a building over a prolonged period of time (winter in this case).

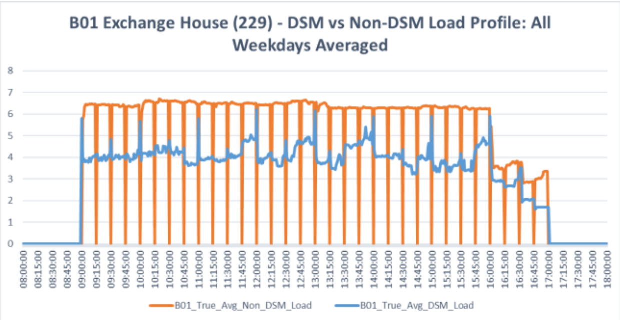

Figure 4: Typical DSR vs Non-DSR output

The orange line represents the non-DSR load seen in a particular timeslot and the blue line represents the load seen when DSR is initiated.

Physical Implementation Summary

As a result of the comms issues, the results from several buildings had to be discounted as the gaps in data were too great to derive meaningful results. Consequently, the buildings analysed were Buildings: 1, 2, 5, 7, 9 & 10. The results are as follows.

DSR Response Over Whole Year

- The variability of demand response between buildings was considerable: some displaying apparently no demand-response and others displaying significant reductions in demand over the period of the day.
- The average level of demand reduction of controllable loads across the whole year is around 20%, which equates to a 7% reduction overall (explained later). Demand reduction appears greater in the morning (24% on average) versus the afternoon (13% on average).
- The magnitude of available load for reduction reduces as the day goes on, which limits the level of demand response possible.

Seasonal Variations to DSR Response

- The level of demand reduction possible across the period of the day appears to be more consistent during Winter, followed by the Transition periods. In summer, the level of demand reduction is less consistent.
- The magnitude of demand reduction possible appears to be more during the Transition periods, follow by Winter. In summer, the magnitude of demand reduction appears to be less.

Please note: Winter = Dec-Feb, Summer = Jun-Aug, Transition = Mar-May & Sep-Nov combined.

Daily Variations to DSR Response

- Minimum demand reduction is achieved at start of the week (Monday)
- Maximum demand reduction is achieved at end of the week (Friday)
- Level of demand reduction gradually increases as week goes on, from an average of 15% up to around 30%

Varying Delay Before DSR Event Scheduled

Demand reduction is affected by period of delay allowed prior to a test being scheduled:

- A delay greater than 30 minutes will result a level of response similar to that seen when significantly longer delay allowed
- Scheduling tests less than 30 minutes apart will result in lower demand reductions.

Overall DSR Response Trends

From the physical DSR implementations, the following overall observations were made:

- the level of load under BMS control varies considerably across building archetypes, affecting the load available for DSR;
- the average load reduction possible varies according to factors such as building type, season, time of day and time of week; and
- the average load reduction possible was around 20% of the total BMS-controlled load, illustrated in Figure 5.

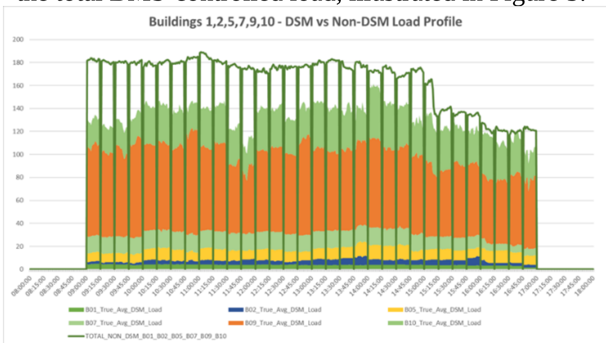

Figure 5: Load reduction seen in trial buildings

Note that the maximum building demand was calculated to be 893kW (for Buildings 1,2,5,7,9,10) and the total load available for demand reduction was 280kW, which equates to a theoretical maximum reduction of 31%. Therefore, the average demand reduction of 20% of load controlled by the BMS across the period of a year seen in live trials, equates to about a 7% reduction overall.

NETWORK MODELLING

In order to understand the role that demand-side management could have in the future, it is important to understand what the likely load growth is on the network. A bespoke model was created by ESRU that would allow the project to understand what the likely load growth is on each individual circuit in the centre of Glasgow. A detailed explanation of the model and the methods it uses to describe and predict electricity load profiles for city centre circuits is beyond the scope of this paper: only the results can be discussed.

Comparing modelled and real demand profiles

To have confidence in the modelled results, a correlation exercise was carried out using: measured load data from each building, merged into a single profile; and the load predicted by the tool, based on the floor area and archetype of each building.

Figure 6 below show the modelled weekly winter profile for the representative circuit from the ESRU Tool (the light blue line is the total peak load). Figure 7 shows the actual demand for the same winter period for each of the buildings, merged together as if they are on the same circuit.

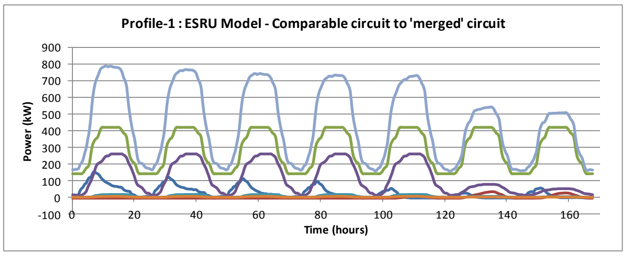

Figure 6: Modelled weekly winter profile

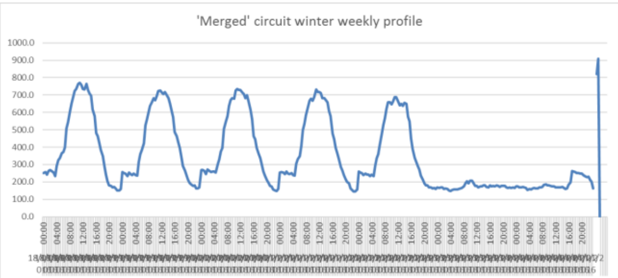

Figure 7: Weekly winter profile of 'merged' circuit

Immediately apparent from both curves is the agreement in 2 ways:

- the magnitude of demand seen on the network is almost identical (791kW modelled versus 770kW real); and
- the load decreasing as the week goes on, with the highest peak demand seen on Monday.

Remarkably, the modelled and actual max demand for weekdays are within 3 percent of each other. This degree of correlation was not anticipated, but it demonstrates that the model can be considered representative.

Note that this is only applicable to weekday profiles, but as these were the only periods of the week of interest to the project, no efforts were made to find correlation at weekend periods also.

Summary Network Modelling

A number of different scenarios were modelled, which looked at possible load growth outcomes for the network from increased deployment of a range of technologies. The following observations were made:

- The impact of a number of low-carbon technologies on the network load profile varied considerably with some (heat pumps) reducing network peaks in the short-to-medium term and others (Electric Vehicles) significantly increasing peak loads anticipated;
- The impact of increased cooling load in the future is likely to present the greatest challenge to city-centre networks; and
- Increased penetration of heat pumps is unlikely to adversely affect network until penetration > 60%.

Whilst the impact of cooling should be closely monitored, if we look at the annual load profile of an existing city centre feeder – illustrated in Figure 8 below – the winter load is still the most critical. Therefore, until such time as cooling presents a significant load to the network, winter – January in particular – will continue to be the peak loading period for a city centre network.

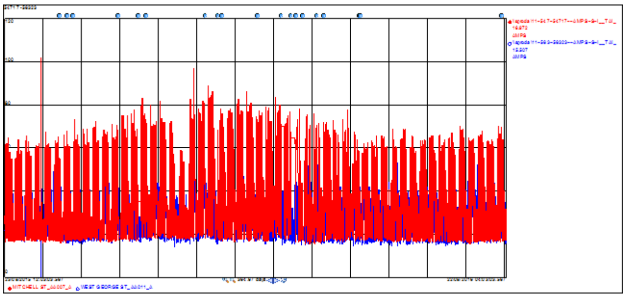

Figure 8: Annual load profile of city centre feeder

DSR BUSINESS CASE

Given the scale of development in Glasgow in recent years [4], particularly in the city centre, it is possible that new buildings will be added to existing circuits. As discussed above, the winter peak is still the most important on the network, therefore, the impact of additional buildings on the winter peak was assessed. To model this, the area of connected buildings is simply increased in the ESRU model and the revised load profile produced.

As expected (and by design) the winter peak is breached and the circuit would have to be upgraded. However, what could be done to reduce the overall peak through DSR and what is the cost of doing this versus traditional network reinforcement: essentially, what is the business case for DSR to support the network? This is now discussed.

Cost Assumptions

SPEN Infrastructure

The following costs are considered representative for conventional reinforcement of the network [5].

- Primary Substation: 11kV Reinforcement - £225/kVA
- Secondary Substation: LV Reinforcement - £150/kVA

DSR Costs

To allow the cost of DSR to support the network to be assessed against the cost of conventional reinforcement of the network, a range of costs (per building) have been modelled. This allows a breakeven cost for DSR to be identified.

DSR Revenues

In order to allow revenues to be built into the Cost-Benefit Analysis it has been assumed that the 'Network Support' revenues would be similar to current average Short-Term Operating Reserve (STOR) rates [6], as the manner in which these are scheduled would be similar to 'Network Support' events.

Estimation of the number of DSR events

The typical network profile, found in Figure 8 above, was taken and it was assumed that it represented a circuit at maximum load. The profile was then increased by 7% - the notional maximum demand reduction achievable through DSR (based on trial results) – and it was found the network limit would be breached 4 times per year.

Considering the length of DSR event, it has been assumed that the average length will be 4 hours.

Summary Business Case

From the business case, the following observations were made:

- DSR is unlikely to be cost-effective as a standalone implementation that supports the network only – it must be done in conjunction with other, established load control mechanisms (STOR, etc) and tariff benefits.
- As the level of DSR required increases, the cost of installing the equipment approaches that of traditional network reinforcement
- Increasing the amount of load controlled by the BMS will improve the cost-effectiveness of DSR
- As the price of DSR equipment drops, the business case to install it become more compelling with paybacks of less than 5 years achievable in some circumstances
- If DSR is procured by the DNO as a service, with the cost of DSR implementation borne by the building operator or an aggregator, it becomes considerably more cost-effective and could rival the cost of traditional reinforcement.
- DSR could play a significant role for a future Distribution System Operator (DSO), allowing localised control of loads
- If incentives are targeted correctly, business case of STOR can be improved which in turn will encourage more building owners to install DSR capability within their buildings.

CONCLUSIONS

DSR was implemented in 10 buildings and found to be successful in 6. Poor comms (4G) resulted in issues being masked and data being lost. For the buildings that DSR was successfully implemented, grid-relevant load reductions (20% of controllable load) were seen.

Cost benefit analysis, which merged network modelling of typical city centre circuits with the DSR trial results, demonstrated that DSR as a standalone network intervention was cost effective if a small load reduction is needed to avoid network peaks, but as the level of reduction increases, traditional network reinforcement is the most cost effective.

The procurement of DSR as a service, with the cost of DSR implementation borne by the building operator or an aggregator, considerably improves its cost-effectiveness and could rival the cost of traditional reinforcement. There is likely to be a limit – both financial and technical – beyond which DSR will not be effective and traditional reinforcement must be implemented. DSR, however, could defer that investment for many years.

As more buildings have controllable BMS installed, the cost of DSR as a network support tool should decrease.

Combining STOR-type mechanism for supply constraints with network-related incentives to keep load within agreed parameters, could be model for DSO: DSR could play a significant role, allowing localised control of loads.

ACKNOWLEDGEMENTS

SPEN would like to thank Glasgow City Council (GCC) for providing their buildings to have DSR equipment installed and DSR trials ran, and for the continued support of the Carbon Management Team and GCC Building Managers throughout the duration of the project.

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