ASSESSING THE CONTRIBUTION OF DEMAND SIDE RESPONSE TO NETWORK SECURITY

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ABSTRACT

Electricity distribution companies in Great Britain have a licence obligation to plan and develop their networks in accordance with a standard agreed by the regulator for gas and electricity markets. The security of supply standard covering the planning and design of distribution networks is Engineering Recommendation P2/6. This standard provides guidance as to the network capacity required to securely serve electricity demand and specifies the network security contribution that could be credited to different forms of distributed generation connected within a group of demand through the Engineering Technical Report 130. Demand Side Response (DSR) has been recognised by distribution network operators as a potentially cost-effective solution for the planning and development of the low carbon networks of the future. Currently, ER P2/6 and ETR130 do not provide clear guidance on the network security contribution that can be relied upon from DSR. This paper presents a new methodology to evaluate the capacity contribution of DSR to distribution network security whilst maintaining the philosophy of the current distribution network planning and design standards. The methodology constitutes an improvement to the current distribution network planning and design standards enabling network operators to quantify the capacity contribution of DSR to network security and attain compliance with regulatory obligations.

INTRODUCTION

The UK's commitments towards the decarbonisation of the energy sector has led Distribution Network Operators (DNOs) to explore smarter means of accommodating distributed energy resources combined with smarter management and control of electricity demand. In particular, Demand Side Response (DSR) has been recognised by DNOs as a smart solution for the planning and development of the low carbon networks of the future [1] and has been trialled on research projects, for example, as part of the Low Carbon London project delivered by UK Power Networks (UKPN) [2]. The deployment and application of DSR within a DNO's licence area must be compliant with the security of supply standard ER P2/6 [3] and ETR130 [4] as part of the DNO's licence conditions. To this end, the GB Distribution Code Review Panel sought views from industry, through formal consultation [5], on the modification of ETR 130 to ensure that ER P2/6 is interpreted in an appropriate manner when considering DSR and its contribution to system loading levels and the consequential assessment of system security. The proposed amendment to ETR130 to account for DSR acknowledges that an appropriate allowance should be made for the successful delivery of contracted or expected DSR and that it is for each individual DNO to decide whether a DSR allowance is considered either as a reduction in demand or as an increase in available system capacity. The proposed amendment suggests that: "in order to determine the effective security contribution from DSR, an assessment is needed of the magnitude and longevity of the demand reduction which is likely to be delivered by the DSR arrangements in place at the time when the intervention would be needed to meet the security requirements of ER P2/6".

In this respect, the current standards and the proposed amendment look to DNOs to provide the methodology and respective guidance on how to quantify and assess the network security contribution that can be relied upon from DSR. Other work undertaken by the C_2C project [6] should also be noted. This work devised a set of proposed changes to the existing distribution network security standard to accommodate DSR.

The appropriate treatment of DSR within the security of supply standard is critically important for the future implementation of DSR. Under estimating the contribution of DSR to security of supply may prevent realising its full technical benefits and economic potential. Conversely, over estimation may result in costumers facing an increased risk of security of supply.

This paper presents a methodology to evaluate the capacity contribution of DSR to distribution network security whilst maintaining the philosophy of the current distribution network planning and design standards utilising the trial data collected as part of the Low Carbon London project delivered by UK Power Networks (UKPN) [2].

Retaining consistency with the principles and concepts of the present security of supply standard enables DSR to develop and provides distribution network planners with a methodology that is easily understood and applicable when calculating ER P2/6 compliance in distribution systems with DSR.

METHODOLOGY

The methodology is based on a hybrid approach that combines simulation techniques for the selection of the DSR facility with analytical techniques to calculate the reliability of DSR. The methodology uses real-world data collected from field trials conducted in the Low Carbon London project [2] to characterise the operational behaviour of different types of DSR.

Following a circuit outage, the distribution network security standard specifies the approach to assess the expected capacity that the remaining network circuits and distributed generation (DG) provide. This paper expands this approach to include the expected contribution of DSR to network capacity within a group of demand as depicted in Figure 1.

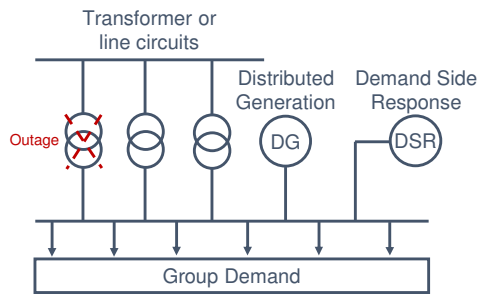

Figure 1: Example of a distribution system structure

In order to achieve consistency with the principles and concepts of the present network security standard, the proposed methodology assesses DSR contribution by comparing reliability with the capacity of a perfect circuit, and uses Expected Energy Not Supplied (EENS) as the reliability criterion. Thus, the effective capacity contribution (or capability) of DSR corresponds to the capacity of a perfect distribution circuit which, when substituted by DSR, results in the same level of reliability of supply [7]. Figure 2 illustrates this principle that underpins the assessment of the contribution of DSR to security of supply. Assuming the perfect circuit is fully reliable, the comparison between DSR and circuit capacity is performed by adjusting the circuit capacity until the same level of EENS is attained. Under this condition, the perfect circuit capacity will be lower than the peak demand.

Figure 2: Comparison of DSR with a circuit capacity

Figure 3 shows under the load duration curve (LDC), the magnitude of perfect circuit capacity and therefore the DSR capability that attains the same level of EENS for the period of analysis.

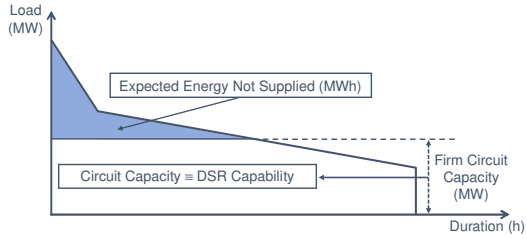

Figure 3: Evaluation of firm circuit capacity for a specific level of EENS

The capability of DSR to meet demand is equivalent to the quantified firm circuit capacity and it can be translated into an F-factor corresponding to the ratio between the effective capacity of DSR and the contracted capacity of DSR.

DSR representation

The representation of the operating regime of DSR is based on data collected from real-world customer field trials conducted in the Low Carbon London project with Industrial & Commercial (I&C) electricity customers [2]. The trials included 37 DSR facilities with a total of 185 DSR events. Demand reduction has been achieved by end-users turning down one or more high power devices such as comfort chillers or by end-users dispatching generation to displace their site load such as the use of diesel back-up generators and combined heat and power units. Figure 4 details the operational behaviour of two distinct events of demand reduction based DSR.

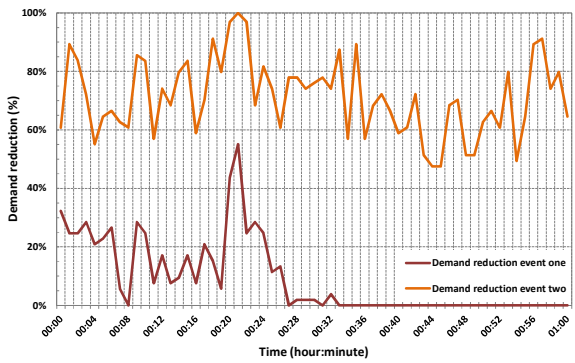

Figure 4: Operational behaviour of demand reduction based DSR

This demand reduction site is characterised by a contracted DSR capacity of 200kW (i.e. 100% in the y-axis of Figure 4) and it is remotely controlled to enable the DNO to request a reduction in load. It can be seen in Figure 4 that both demand reduction events present relatively significant variability that is consistent to that of the non-diversified network load profile that the DNO is trying to manage by reducing the individual demand of this DSR site.

In order to characterise and represent the operating regime of DSR, the time series response of all the possible demand reduction events observed for this site are statistically assessed through probability distribution as displayed in Figure 5.

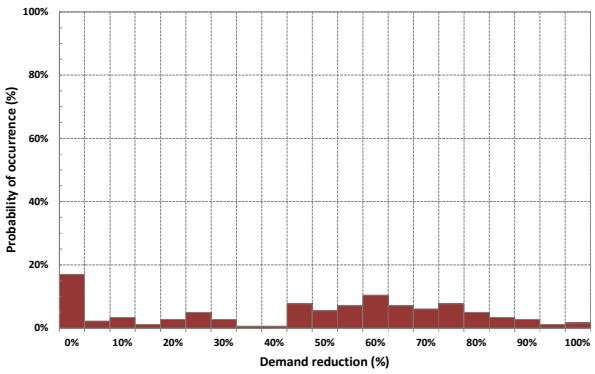

Figure 5: Statistical representation of demand reduction based DSR

It can be observed in Figure 5 that the operational performance of the demand reduction based DSR displays a relatively even dispersion of the magnitudes of the demand reduction attained. This behaviour is a consequence of the demand reduction variability registered across all DSR events of the site. Figure 5 indicates that the likelihood of the site being unavailable to reduce demand when called upon is approximately 17%. Furthermore, there is around a 57% chance of the magnitude of demand reduction ranging from 50% to 100% of the contracted capacity of DSR from the site.

The probability distribution of demand reduction can be expressed in the form of a Capacity and Probability Table (CPT) [8] that is consistent with that used in the present network security standard to characterise the magnitude and probability of outage states of DG.

Table 1 details the CPT for demand reduction based DSR. The capacity (in kW) of a state represents the specific level of demand reduction observed from the trial data. Thus, the CPT describes the magnitude and respective likelihood associated with a specific demand reduction state. For the site under analysis, a demand reduction of 120kW is estimated to have 10.38% chance of occurrence.

An identical framework has been applied to represent the operational behaviour of generation-led DSR (diesel and CHP). It is noted that the overall availability of these three different types of DSR is implicitly considered in the time series of the various DSR events observed in the trials. Broadly, the overall availability includes attributes related to: (i) technical availability which reflects whether the facility is in a working state; (ii) energy availability which reflects whether energy is available to drive the diesel and CHP units; and (iii) commercial availability which reflects whether it is commercially available.

In addition to the different availability characteristics of the DSR sites, there are other important drivers that may impact the capacity contribution of DSR to network security such as, the number of generating units, the capacity of the units, the technology of units and the location of units. These parameters need to be considered when assessing the security contribution of DSR.

Table 1: Capacity and probability table for demand reduction based DSR

State	Capacity (kW)	Probability (%)	Cumulative probability (%)
1	0	16.94	16.94
2	10	2.19	19.13
3	20	3.28	22.40
4	30	1.09	23.50
5	40	2.73	26.23
6	50	4.92	31.15
7	60	2.73	33.88
8	70	0.55	34.43
9	80	0.55	34.97
10	90	7.65	42.62
11	100	5.46	48.09
12	110	7.10	55.19
13	120	10.38	65.57
14	130	7.10	72.68
15	140	6.01	78.69
16	150	7.65	86.34
17	160	4.92	91.26
18	170	3.28	94.54
19	180	2.73	97.27
20	190	1.09	98.36
21	200	1.64	100

Network load representation

The network security standard considers specific load groups and aggregates all the loads supplied by that group to form a 'group demand'. Group demands are represented by LDCs derived from five historical winters for the eight different primary substations of the UKPN licence area under consideration during the Low Carbon London project trials.

Contribution of DSR to network security

To quantify the contribution of DSR to network security, the capacity and probability of the operational performance of DSR and the LDC at a primary substation are required [9]. Firstly, the reliability level of the system is evaluated through EENS as follows:

- create the CPT for DSR;
- each state of the CPT is superimposed on the LDC individually as shown for one state i in Figure 6;
- the energy not supplied E_i whilst in this capacity state is determined as the area below the LDC and above the capacity of the state under consideration;
- this value of energy is weighted by the probability of being in this capacity state; and
- the weighted values of energy are summated over all capacity states resulting in EENS.

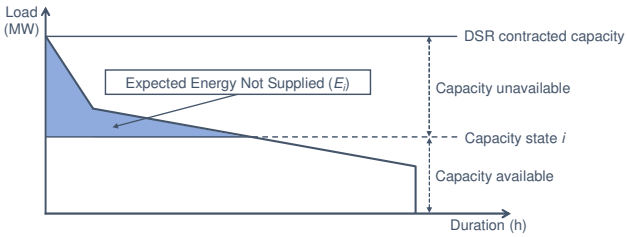

Figure 6: Evaluation of EENS for DSR

Secondly, the capacity of the perfect circuit is calculated assuming that this capacity is constant, exists continuously and creates the same EENS as calculated for DSR when this capacity level is imposed on the LDC. This capacity is defined as the capability of DSR to meet demand. Finally, the capability of DSR is expressed through an F-factor corresponding to the ratio of the capability of DSR to the rated capacity of DSR.

Modelling framework to assess the contribution of DSR to network security

As previously stated the modelling framework is based on a hybrid approach that combines simulation techniques for the selection of the DSR facility with analytical techniques to calculate the reliability of DSR. Real-world field trial data from the Low Carbon London trials has been used to characterise the operational behaviour of different types of DSR and historical electricity load profiles to represent the LDC for a particular primary substation. The method randomly generates a sample of the number of DSR facilities to be analysed and selects their respective operational behaviour from the trial data. The time series describing the performance of each of the selected DSR facilities is statistically assessed from the development of its probability distribution. Subsequently, these probability distributions are statistically combined through convolution to compute a single probability distribution that is statistically representative of the operational performance of the selected sample of DSR facilities.

The probability distribution of DSR is superimposed on to the LDC of a primary substation to determine the level of EENS. The capacity contribution of DSR to network security is then quantified by finding the capacity of a perfect circuit that, when substituted by DSR, attains the same level of EENS.

Uncertainty associated with the probability distributions of DSR due to the finiteness of the samples of historical data, is estimated through a bootstrap method. This technique samples with replacement from within the dataset to produce bootstrap samples that are then used to re-estimate the capacity contribution of DSR to network security and respective confidence intervals. The flow chart of the modelling framework for the assessment of the contribution of DSR to network security is presented in Figure 7.

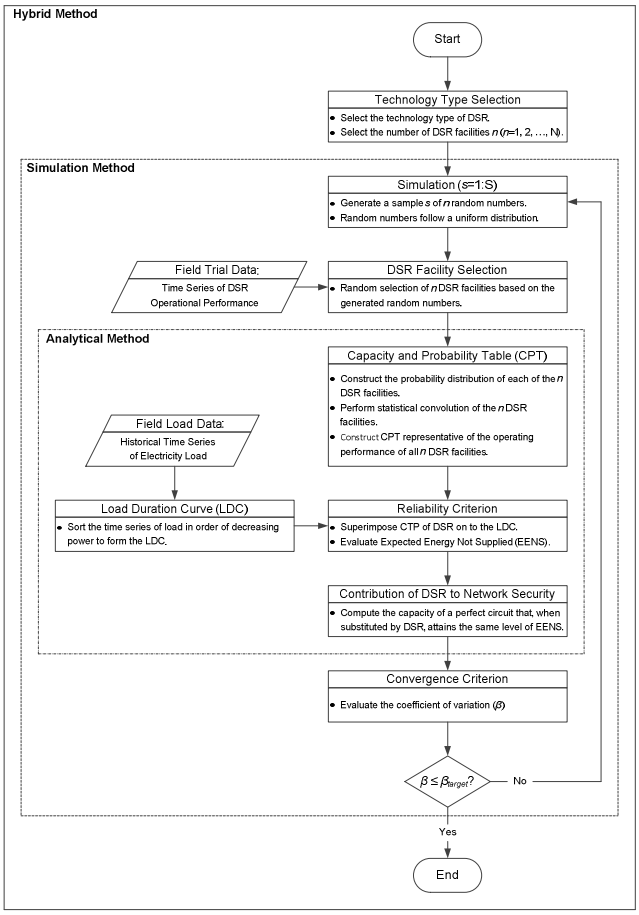

Figure 7: Flow chart of the modelling framework

CASE STUDY

The proposed modelling framework has been applied to the London Power Networks licence area to evaluate the contribution of DSR to network security. The operating regime of DSR is derived from the real-world customer field trials conducted in the UKPN's Low Carbon London project [2]. The LDCs are derived from five historical winters for eight different primary substations of the licence area under consideration. The capability of DSR to meet demand is expressed through the F-factor that corresponds to the ratio of the effective capacity of DSR to the rated capacity of DSR.

F-factors for DSR

The contribution of DSR to network security can be generalised through the use of look up tables and/or graphs that can be readily used by distribution network planners. In this respect, based on the operational behaviour of the different technology types of DSR observed in the customer field trials and considering the eight individual LDCs, Table 2 presents a look up table containing the F-factors for the specific types of DSR and for different numbers of DSR facilities present in the distribution system.

Table 2: Contribution of DSR to distribution network security

	DSR technology type		
Number of DSR facilities	Demand Reduction	Diesel	Combined Heat and Power
1	52%	60%	68%
2	68%	65%	70%
3	69%	66%	72%
4	70%	68%	73%
5	70%	69%	73%
6	70%	69%	73%
7	70%	69%	73%
8	71%	70%	74%
9	71%	70%	74%
10	71%	70%	74%

It can be inferred from Table 2 that a demand reduction based DSR facility of 1MW contracted rated capacity, could usually be expected to support a maximum demand of 0.52MW. It can be seen in Table 2 that for a low number of facilities, the contribution of DSR to system security is relatively significant across all technology types. For instance, one demand reduction based DSR facility is characterised by an F-factor of 52%. As the number of facilities increases, the contribution of DSR to system security heads towards saturation as the marginal contribution declines. This look up table provides a simple framework for network planners to estimate the contribution of DSR to system security and consequently the capability of a network to meet group demand.

CONCLUSIONS

This paper presents a methodology to quantify and assess the capacity contribution of DSR to distribution network security. The methodology is based on a hybrid approach that combines simulation techniques for the random selection of the operational regime of a DSR facility with analytical techniques for the evaluation of reliability metrics and capacity value of DSR. The methodology uses real-world data collected from customer field trials conducted in the Low Carbon London project and associated network measurements to characterise the operational behaviour of different technology types of DSR.

The methodology is consistent with the principles and concepts of the present security of supply standards, which enables DSR to develop by providing distribution network planners with a methodology that is easily understood and applicable when calculating ER P2/6 compliance in distribution systems with DSR. Hence, the methodology constitutes an improvement of the current distribution network planning and design standards enabling DNOs to quantify the capacity contribution of DSR to network security and attain compliance with regulatory obligations. It also enables electricity distribution companies to identify how much DSR capacity will need to be procured to maintain network security which is an essential part of assessing the Cost Benefit Analysis (CBA) of potential DSR schemes. The methodology is currently being put into business as usual practice by UK Power Networks.

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