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Power Potential project

Validation of the Power Potential Commercial Trials

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Project Team

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Executive Summary

At the heart of the Power Potential project is the Distributed Energy Resources Management System (DERMS). DERMS computes the available aggregated DER capacity for active and reactive power (PQ curve) that can be used by the ESO at the grid supply point (GSP), taking into consideration distribution network local network constraints, which is the fundamental concept of Virtual Power Plant (VPP). The distribution network constraints will need to be secured first before the remaining available DER capacity can be offered to ESO as transmission services. Using this bottom-up incremental approach, ESO's use of DER via DERMS will not violate distribution constraints in the Power Potential area.

In order to validate DERMS calculation and identify potential improvements, the work described in this report aims to:

- Review the cost curve construction logic for the day-ahead time frame based on the planned system conditions and predicted demand and DER availability. It means checking that the DER ranking is correct and that the minimum cost solution is offered while respecting the various constraints (including the network, processing environment and time available). The nomination decision (which available band is selected) is an internal process that not expected to be reviewed.
- Investigate the impact of network losses on the VPP PQ operating curve
- Analyse the impact of different network and operating conditions affect the cost curve construction (day-ahead snapshot)

Based on the results of a spectrum of studies performed and the analyses, it can be concluded that the VPP reactive power capability calculated by DERMS is aligned with the results of the ICL model. The studies demonstrate the following:

- DERMS calculation captures the asymmetrical reactive power capability from Power potential DERs.
- Reactive power capability varies depending on DER's active power production following the PQ operating characteristic.
- The impact of reactive power services from DERs on distribution network losses is included in DERMS calculation, and it tends to expand the range of reactive power that can be modulated at the GSP.
- The range of reactive power services varies slightly depending on the network loading condition as the impact on losses changes.
- Network thermal limit is not considered in DERMS reactive power calculation, and therefore, it requires an offline assessment from UKPN's planning team to artificially modify DER's reactive capability behind the constraint to ensure the thermal limit is not violated. It is recommended that DERMS formulation should be improved in future, especially if the DER participation in reactive power services increases.
- DERMS allocates the reactive power resources optimally according to the bids from DERs.

Chapter 1. Introduction

1.1 Background

The Power Potential project is the world-first trial to harness active participation from medium-scale distributed generation and storage connected at distribution systems to provide reactive power support to the National Grid ESO (NGESO) as the GB transmission system operator (TSO)[1]. The project coordinated by UK Power Networks aims to create a new local reactive power market for distributed energy resources (DERs), providing the TSO with more reactive power sources to maintain voltage and system stability in the South-East part of the GB transmission system. The increased number of providers will reduce market power as there is an increased requirement of reactive power capability in this area driven by increased connection capacity of distributed generation and interconnections. On the other hand, the cost of engaging traditional providers such as large-scale thermal power generators is relatively high.

The project market trials in Wave 2 aim to establish the proposed commercial framework's viability and allow price discovery through DER competition. DER bidding for the reactive power service is introduced, with the volumes accepted by NGESO in line with actual system requirements[2]. DERs will compete among themselves in day-ahead auctions, and the number of market hours is currently fixed to 1800h.

At the heart of the trial is the Distributed Energy Resources Management System (DERMS). DERMS computes the available aggregated DER capacity for active and reactive power (PQ curve) that can be used by the ESO at the grid supply point, taking into consideration distribution network local constraints, which is the fundamental concept of Virtual Power Plant (VPP). Distribution network constraints will need to be secured first by the DSO before the remaining available DER capacity can be offered to ESO as transmission services. Using this bottom-up incremental approach, ESO's use of DER via DERMS should not violate distribution constraints in the Power Potential area.

DERMS also compute the cost curve of the VPP. Cost curves are the combination of the individual DER bids (availability and utilisation price), reflect DER's effectiveness[3], expected reactive range and forecast utilisation while considering distribution network constraints. Effectively, DERMS provides information for ten bands (or VPPs) at each GSP, not providing individual DER information. The stack order of DERs used to construct the day-ahead cost curves is based on a deterministic algebraic process that considers each DER's availability cost, utilisation cost and MVar size. The approach ensures that processing time scales linearly with the number of DERs.

As shown in Figure 1, the concepts of the expected range of Q available and maximum reactive range are the basis for the cost curve construction.

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[1] Source: National Grid ESO, link: www.nationalgrideso.com/future-energy/projects/power-potential

[2] These volumes will not be used to secure the system.

[3] The effectiveness is measured by the contribution of the DER to reactive power injection/absorption at the respective grid supply point.

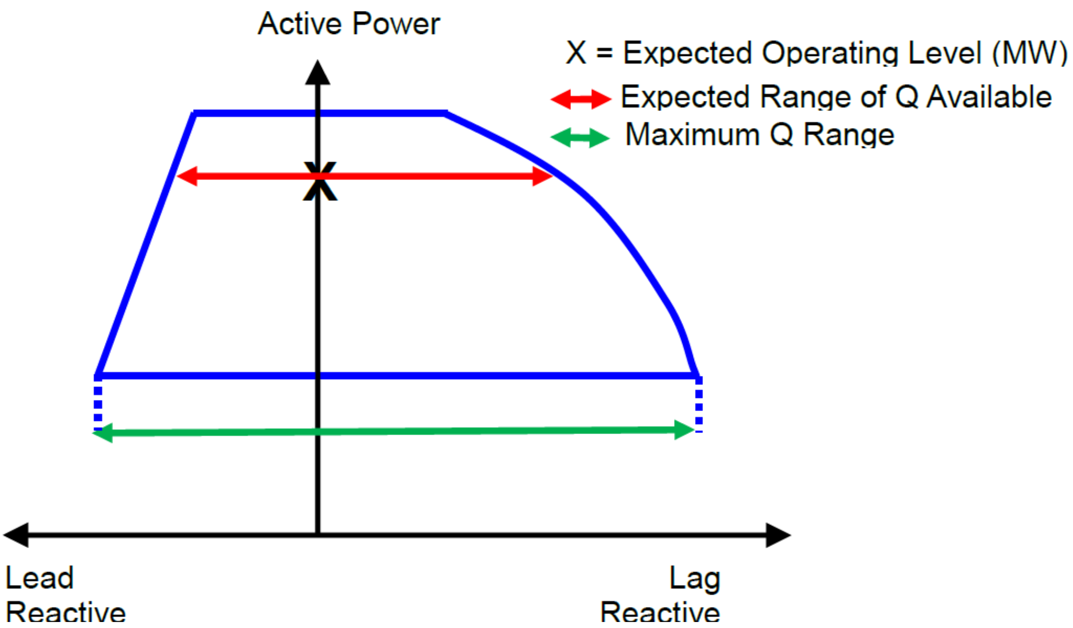

Figure 1 Illustration of the VPP PQ operating curve computed by DERMS

Following the work we carried out in Phase I[4] and Phase II[5] , Phase III will compare the academic VPP model developed at Imperial and the VPP model computed by DERMS. In this context, this report describes a range of case studies performed and analysed to validate the functionalities of DERMs.

1.2 Objective and scope of the work

The following summarises the objective and scope of the work in Phase III:

- Review the cost curve construction logic for the day-ahead time frame based on the planned system conditions and predicted demand and DER availability. It means checking that the DER ranking is correct and that the minimum cost solution is offered while respecting the various constraints (including the network, processing environment and time available). The nomination decision (which available band is selected) is an internal process that not expected to be reviewed.
- Investigate the impact of network losses on the VPP PQ operating curve;

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[4] Phase I was about the development of the commercial framework and the conceptual approach to determine the optimal portfolio of commercial contracts for voltage control and reactive power services provided by Distributed Energy Resources (DER). The details of the methodology and its findings can be read in the report: "Market Framework for Distributed Energy Resources-based Network Services". This report is available at: https://www.nationalgrideso.com/document/118251/download

[5] The study in Phase II focused on the conflict and synergy between DSO and ESO-based DER services investigated using Power Potential's incremental approach and whole-system approach.It also looked at the importance of DSO led smart control in distribution to maximise access for DER and the implications of preventive or corrective control modes on the DSO-ESO coordination, and the benefits of Power Potential in reducing market power in the provision of reactive power services. The details of the methodology and its findings can be read in the report: "Evaluating Synergies and Conflicts of DER services for Distribution and Transmission Systems and Market Power Assessment".

- Analyse the impact of different network and operating conditions affect the cost curve construction (day-ahead snapshot).

The case studies focus on the PP trial GSP, where three DERs participate in the Power Potential trials. The case studies also focus on the reactive power services from DERs, assuming that the active power dispatch will be fixed.

1.3 Input data requirement

For this analysis, all data used to compare and analyse the results between DERMS and the Imperial model must be consistent.

In general, the input data required by the Imperial model consist of:

- Network data including the topology, parameters (R, X, B)[6], thermal rating (MVA), control settings for transformers, reactive compensators. The study used the network model for the PP trial GSP with the highest Power Potential DER capacity. There are 3 DERs to be used in these studies.
- Operating limits
- Active and reactive power demand
- DER operating limits
- DER bids (availability and utilisation for reactive power services)
- DER availability
- Planned outage (maintenance)
- Critical single contingencies or a set of contingency list considered by DERM

The analysis will also require the output of DERMS[7]:

- PQ curve
- Cost curve presented as a range of VPP bands.

In principle, the studies will try to validate DERMS calculation for all possible operating conditions but focusing more on the extreme conditions.

1.4 Approach

Using the same case-study scenarios (as described in Chapter 2), the DERMS and Imperial model results are compared. DERMS output is produced in JSON format, while the Imperial model output is in Excel. The JSON format is converted into Excel using JSON converter software, allowing the outputs to be compared and analysed further. The process is illustrated in Figure 2.

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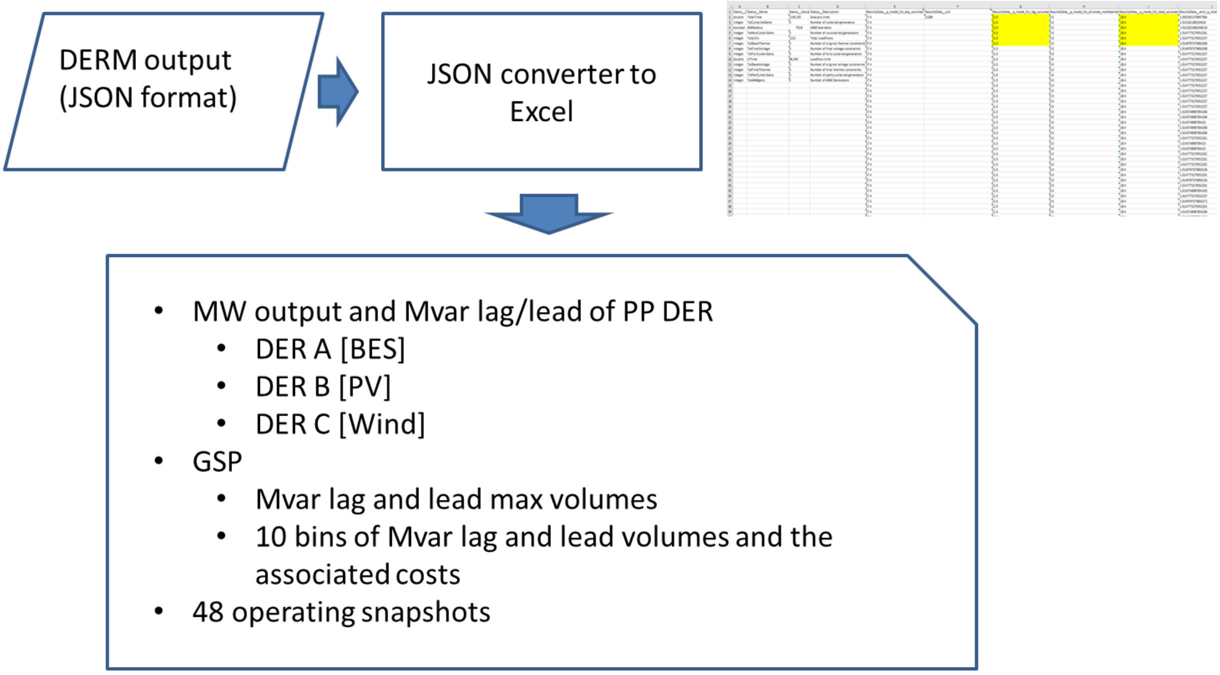
[6] In 100 MVAbase

[7] As results of the DERM simulation



- MW output and Mvar lag/lead of PP DER
  - DER A [BES]
  - DER B [PV]
  - DER C [Wind]
- GSP
  - Mvar lag and lead max volumes
  - 10 bins of Mvar lag and lead volumes and the associated costs
- 48 operating snapshots

Figure 2 Illustration of the VPP PQ operating curve computed by DERMS

Chapter 2. Validation analysis of DERMS computation

2.1 Assumptions on DERs' settings

The study assumes the following settings:

- DER A's MW output is fixed to 27.4 MW. DER A's PQ chart in Figure 3 shows that the reactive power output range from DER A is between -28.4 Mvar (lead) and 21 Mvar (lag).

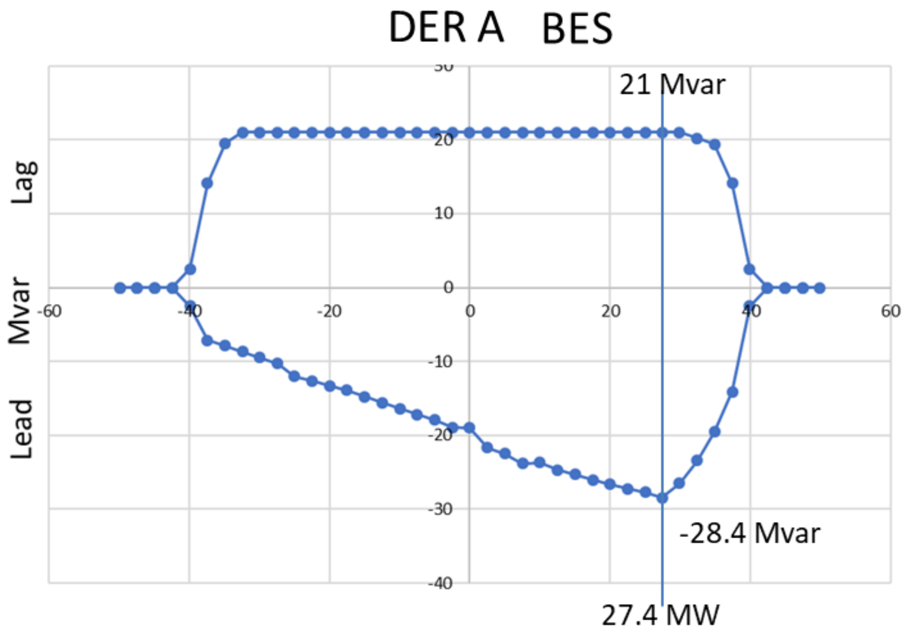


Figure 3 PQ operating curve of DER A

- DER B's MW output is fixed to 0 MW. DER B's PQ chart in Figure 4 shows that DER B's reactive power output range is between -1 Mvar (lead) and 1 Mvar (lag).

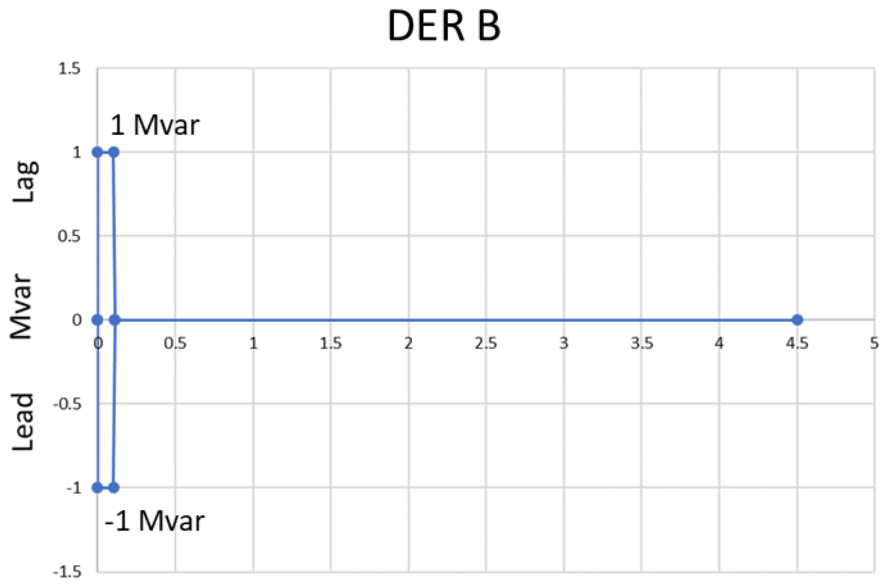


Figure 4 PQ operating curve of DER B

- DER C's MW output is fixed to 20 MW. DER B's PQ chart in Figure 4 shows that DER B's reactive power output range is between -19.6 Mvar (lead) and 19.8 Mvar (lag).

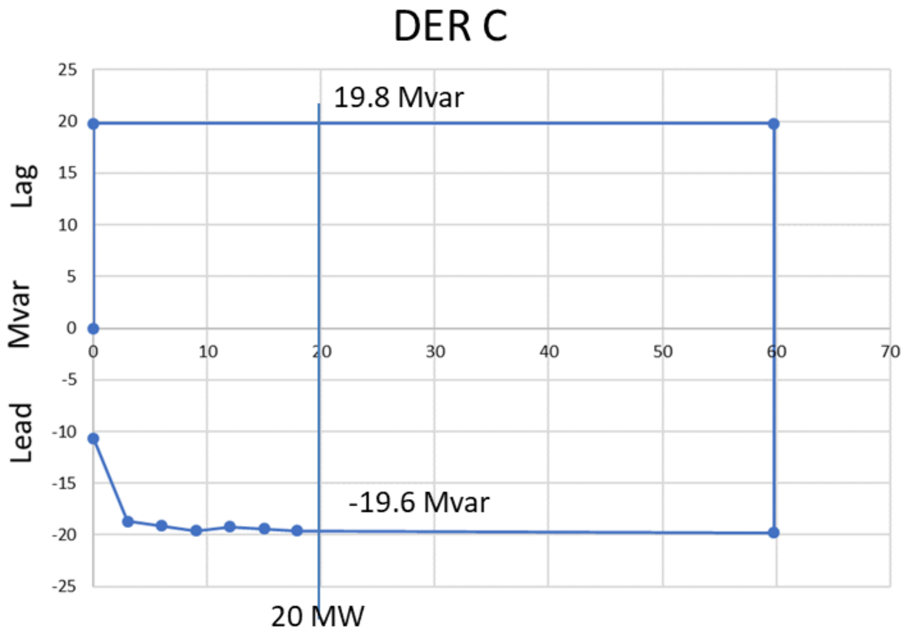


Figure 5 PQ operating curve of DER C

The sum of reactive capability from all three DERs is -49 Mvar (lead) and 41.8 Mvar (lag).

2.2 Comparison between reactive power capability computed by DERMS and ICL model

DERMS calculates the aggregated capability of reactive services from the three DERs at the GSP point for 48 operating snapshots (considering the load variation across a day) based on the settings described previously. The results are shown in Figure 6.

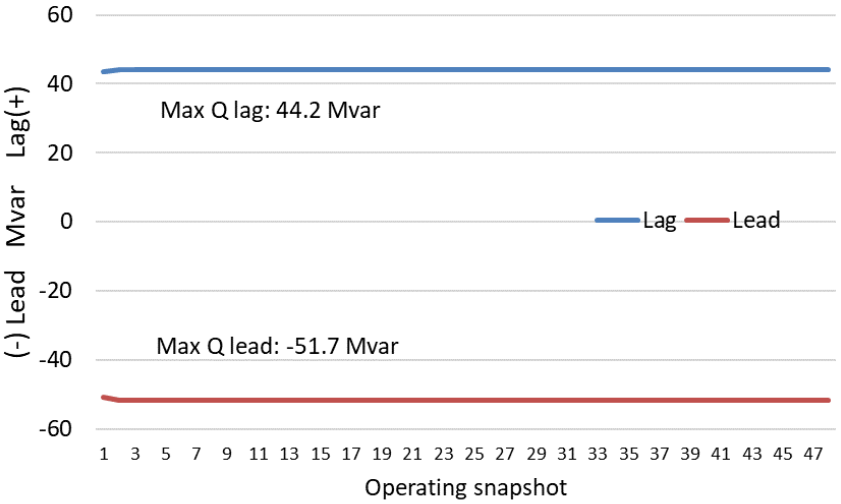


Figure 6 Range of GSP's reactive services calculated by DERMS

For most operating snapshots, the reactive power range computed by DERMS is between -51.7 (lead) and 44.2 (lag) Mvar.

The range of reactive power services at the GSP point computed by DERMS and ICL model are compared in Figure 7.

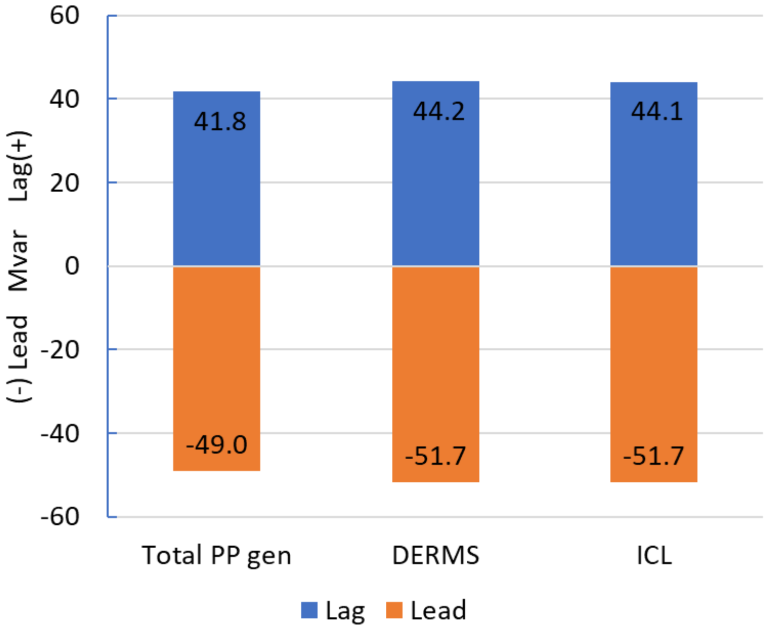


Figure 7 Range of VPP reactive power capability computed using DERMS and ICL model

The first bar in Figure 7 shows the total range of reactive power services from the Power Potential's DERs, i.e. between -49 (lead) and 41.8 (lag) Mvar. The aggregated capability from the DERs considers the PQ characteristic of each DER, as discussed in the previous section.

The second bar shows the results of the DERMS computation. DERMS calculates the impact of reactive power from Power Potential's DERs on the reactive power changes at the GSP point. The third bar shows the results of the ICL model. The results are practically the same as the results of DERMS.

The results demonstrate:

- DERMS calculation captures the asymmetrical reactive power capability provided by the DERs. DERMS also models the impact on losses which extends the range of reactive power services between -51.7 (lead) and 44.2 (lag) Mvar. When the DERs inject 41.8 Mvar, reactive losses decrease by (net) 2.4 Mvar and therefore, from the GSP point of view, the net change in reactive demand from the distribution networks is 44.2 Mvar. On the other hand, when the DERs absorb 49 Mvar, reactive power losses increase by 2.7 Mvar, and therefore, the transmission will see reactive power demand from the distribution network increasing by 51.7 Mvar. The impact of losses is slightly higher when DERs absorb reactive power, as expected. The impact is asymmetrical since the distribution assets tend to incur reactive power losses. Only during low-loading conditions, reactive power generated by the lines/cables may be higher than the losses.

2.3 Impact of MW output on the VPP reactive capability

Using the same DER settings as the previous case except for DER A, it is operated at -20MW output. The reactive capability of DER A decreases to -13.3 Mvar (lead) – 21 Mvar (lag), as shown in Figure 8. The sum of reactive power from all three Power Potential DER is -33.9 Mvar (lead) – 41.8 Mvar (lag).

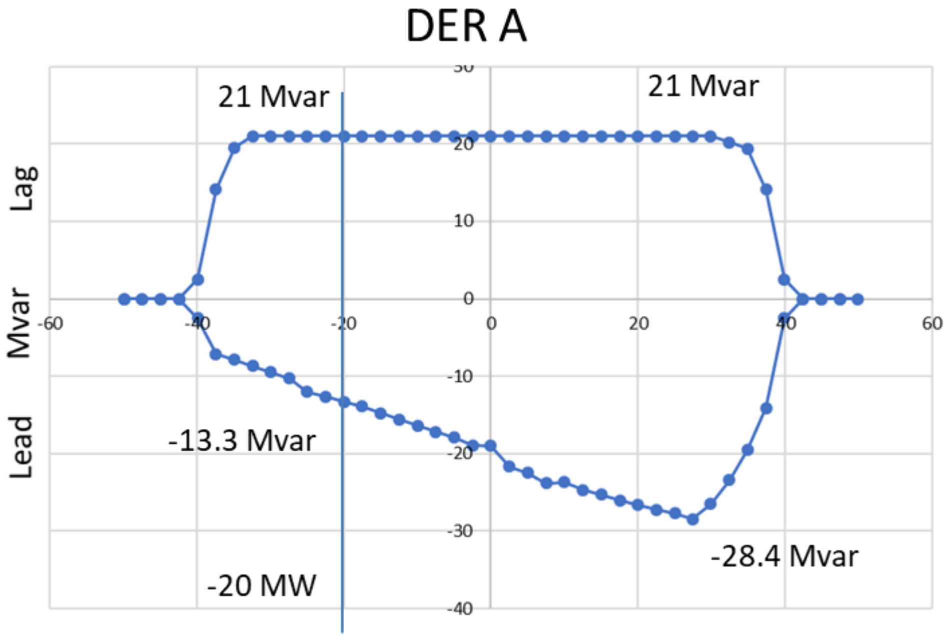


Figure 8 Reactive capability of DER A (a battery energy storage system) operated at -20MW output

The reactive range computed by the ICL model for the updated DER A setting is between -35.4 Mvar (lead) and 44.2 Mvar (lag), as shown in Figure 9.

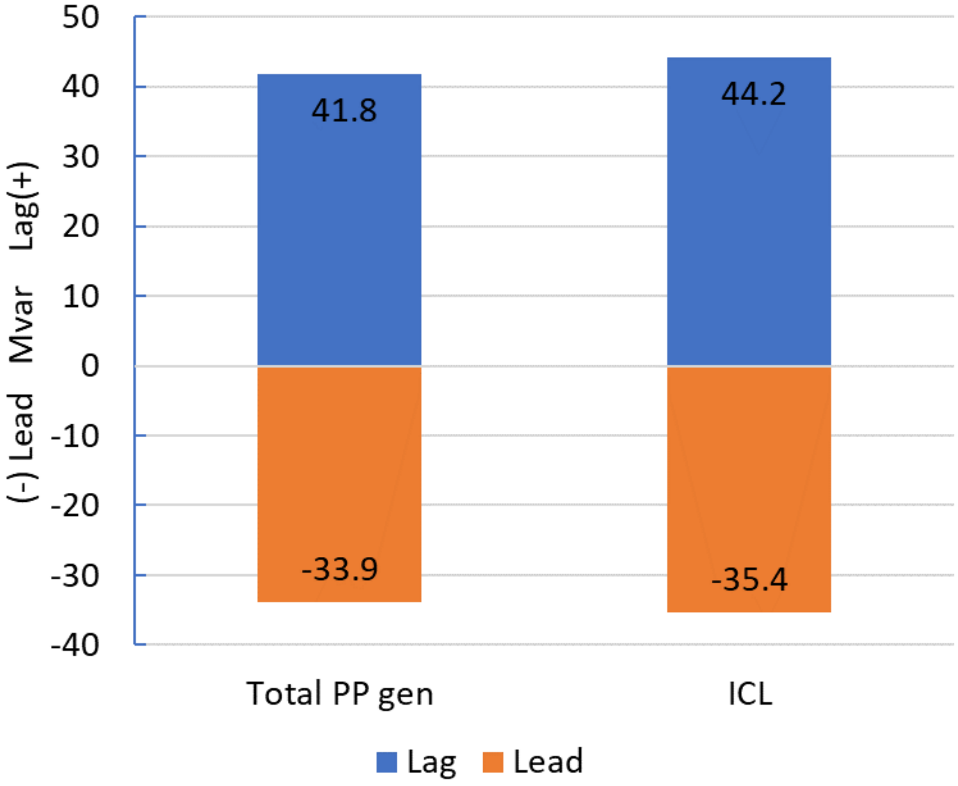


Figure 9 Impact of different DER A setting on the VPP reactive range

Like the previous case, the impact of reactive services from the DERs on distribution reactive losses enhances the range of reactive capability at the GSP point. Injecting 41.8 Mvar reduces 2.4 Mvar reactive losses by 2.4 Mvar while absorbing 33.9 Mvar increases reactive losses by 1.5 Mvar. The later has a lower impact due to the smaller volume of reactive services used.

2.4 Impact of energy demand on VPP reactive capability

In order to identify the impact of network loading conditions, two additional cases were developed using 75% and 125% of the central load (as used in the previous case) for the low and high loading scenarios. The impact of different loading conditions on the VPP reactive capability is relatively small but visible, as shown in Figure 6. The results from the ICL model are compared to the DERMS results. The latter does not vary because the extent of load variation used in the DERMS study may be relatively small. The results are expected since the network is relatively strong, and the volume of DERs is still limited, and therefore, it will not substantially affect the range of VPP reactive power capability. The range of reactive capability tends to increase when the system loading is higher as DER reactive services' impact on distribution reactive losses is intensified. This is shown in Figure 10.

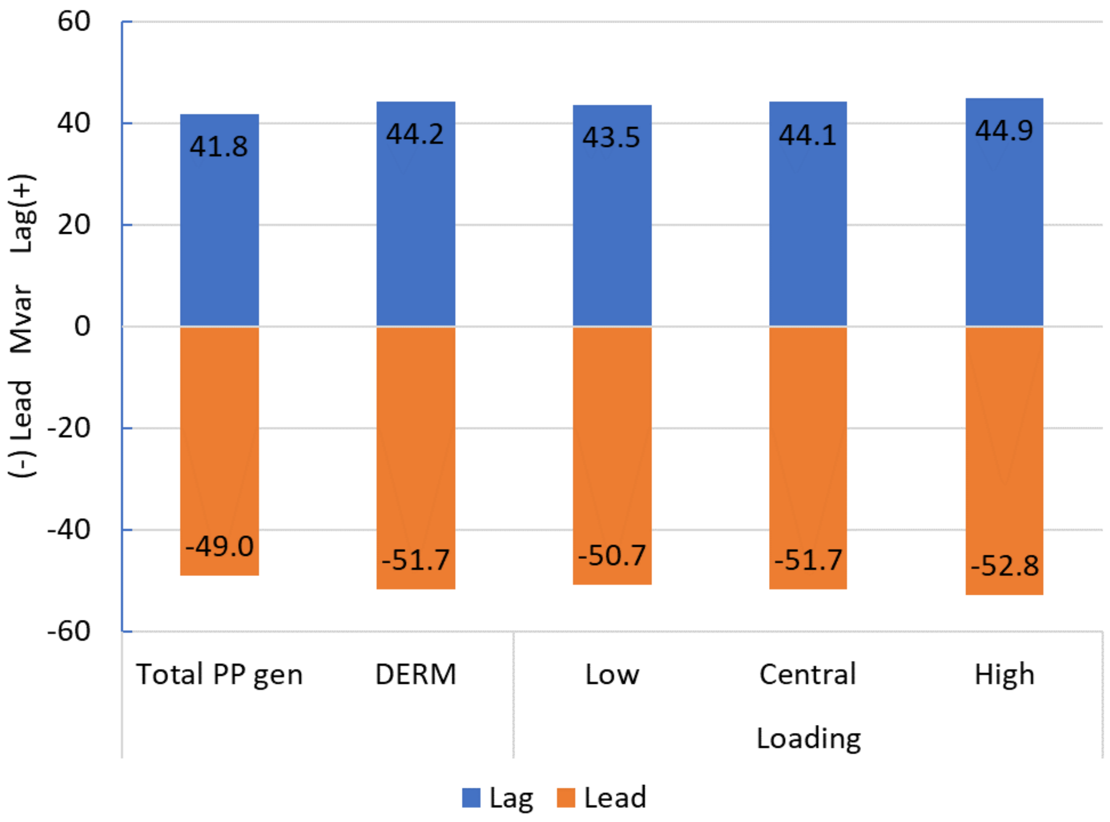


Figure 10 Impact of different energy demand on VPP reactive capability

2.5 Impact of network thermal constraint on the VPP's reactive capability

The distribution system around PP trial GSP is relatively strong and has sufficient spare capacity to operate under N-1 condition for the three DERs under the study. A hypothetical test case was developed to investigate if the network thermal constraint is considered in the DERMS reactive range computation. In this case, one of the two circuits (C1) connecting DER A into the Hasting substation is out-of-service, and the other circuit capacity is derated to 30 MVA (original capacity is 105 MVA). This case study is illustrated in Figure 11.

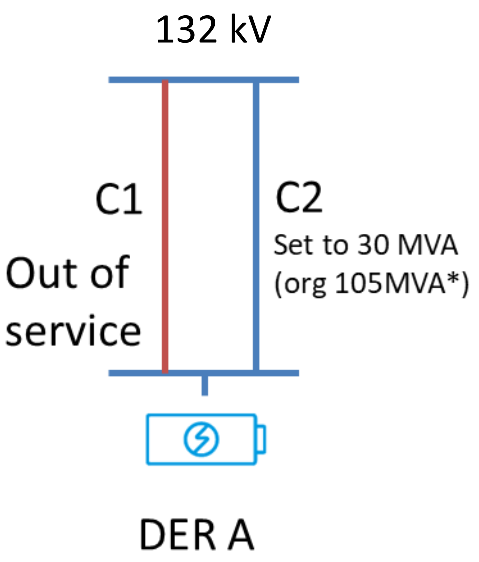


Figure 11 Network constraint for DER A

While operating at 27.4 MW output, the circuit outage will reduce DER A's capability to provide reactive service up to 12.2 Mvar (lead or lag). Above that range, it will violate the circuit's 30 MVA thermal capacity. The impact of network constraint on the PQ curve capability of DER A is illustrated in Figure 12.

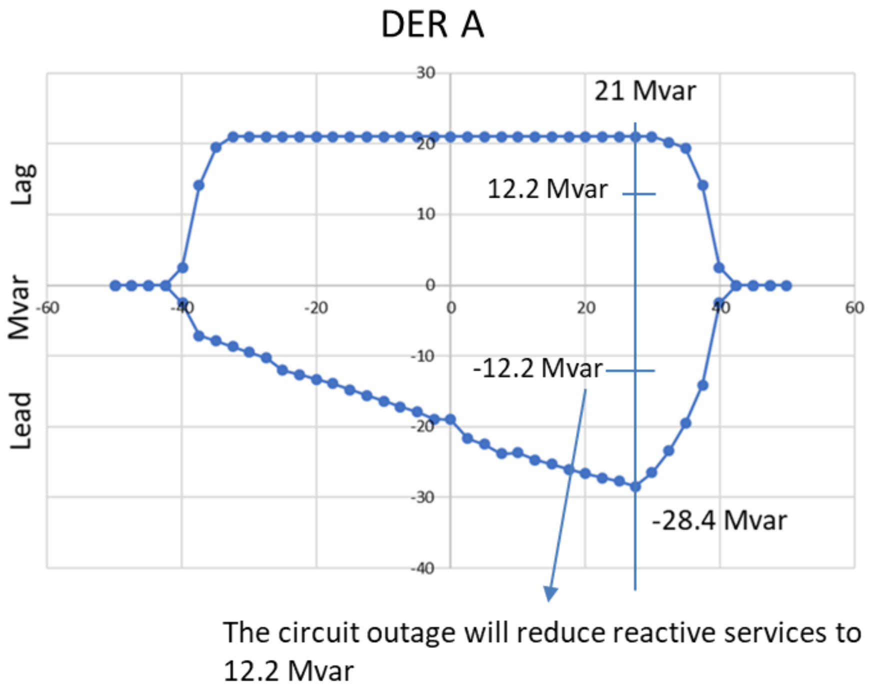


Figure 12 Impact of network constraint on DER A reactive capacity that can be offered to the grid

The impact of the network constraint on the DERMS and ICL model calculation is shown in Figure 13.

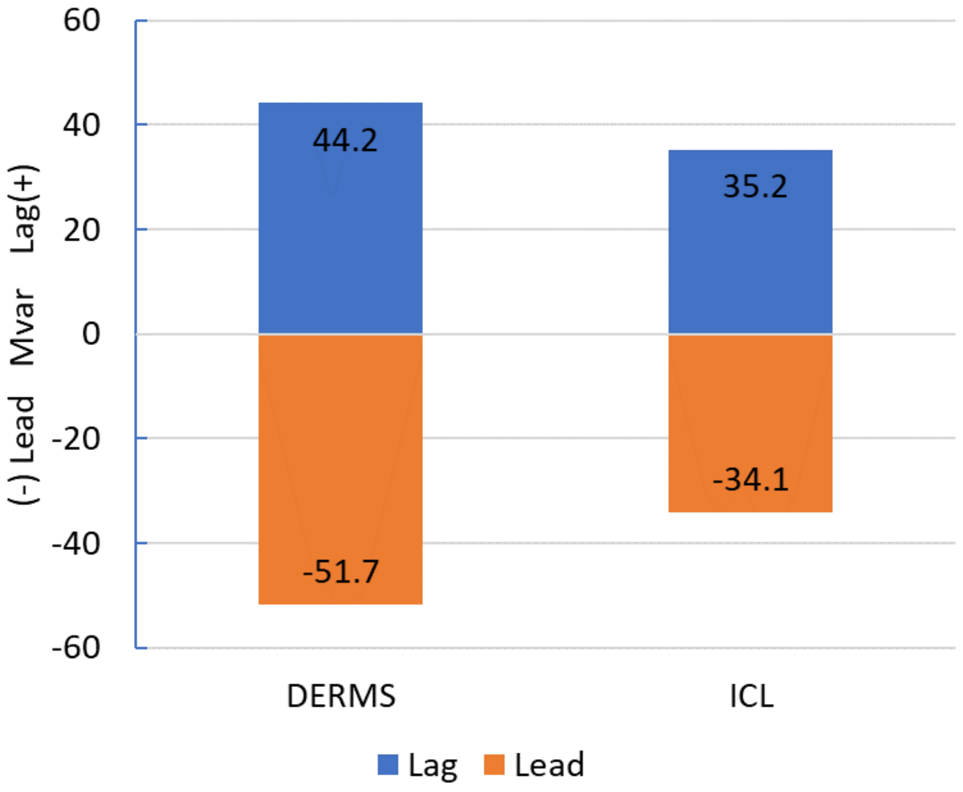


Figure 13 VPP reactive power range based on DERMS and ICL model

DERMS calculation does not consider the MVA thermal limit to constrain Mvar flows. Thus, the 30 MVA thermal constraint does not affect its calculation since the MW limit is met. On the other hand, the ICL model results show the impact on the VPP reactive capability. It reduces the range to -34.1 Mvar (lead) – 35.2 Mvar (lag).

Since the real system has sufficient thermal capacity, the study results do not trigger any concern but point out that the future DERMS formulation may need to be enhanced to respect thermal constraints for the reactive power capability computation. Alternatively, it requires an offline assessment from UKPN's planning team to artificially modify DER's reactive capability behind the constraint to ensure the thermal limit is not violated. This assessment has been carried out during the trial period to ensure the safe operation of the distribution network.

2.6 Validation on the merit order of DER reactive dispatch

It is essential that when allocating reactive power services, DERMS always uses the most economical sources to minimise the respective system operating cost. Three cases with different DER reactive power utilisation cost were developed to test this allocation process. The Mvar utilisation cost assumptions are shown in Table 2-1. The availability cost of all DERs is set to be zero.

Table 2-1 Reactive power utilisation cost (£/Mvarh) scenarios

Case	DER A	DER B	DER C
1	3	1	2
2	2	3	1
3	1	2	3

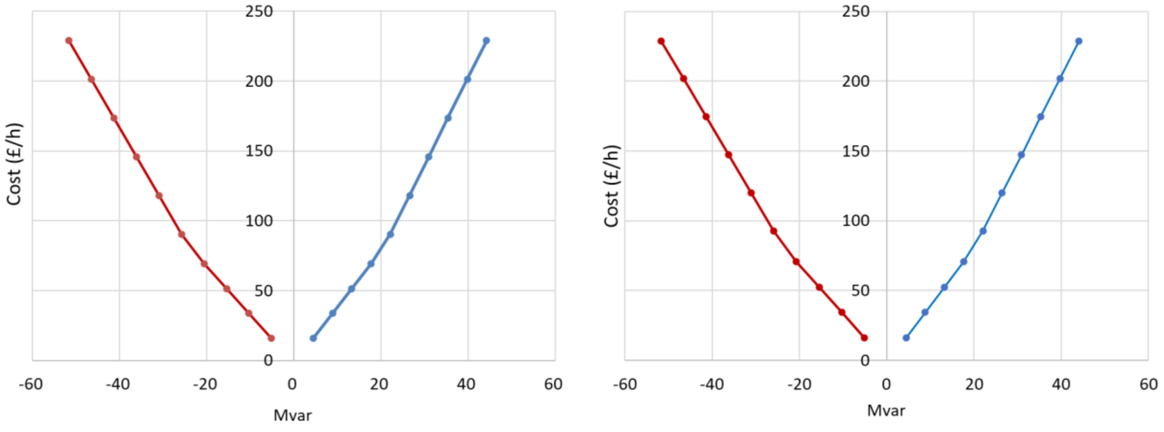
DERMS approach to calculate the cost function of the reactive power services from the Power Potential DERs is replicated in the ICL model. The cost curve is divided into ten bands with a uniform interval determined by dividing the maximum range of Mvar lead and lag by ten separately. Based on the range obtained by DERMS, i.e. -51.7 Mvar (lead) to 44.2 Mvar (lag). The interval for Mvar lead is -5.17 Mvar and for Mvar lag is 44.2 Mvar.

Table 2-2 VPP reactive power bands

	MVAR	
BAND	Lead	Lag
1	- 5.2	4.4
2	- 10.3	8.8
3	- 15.5	13.2
4	- 20.7	17.6
5	- 25.9	22.1
6	- 31.0	26.5
7	- 36.2	30.9
8	- 41.4	35.3
9	- 46.5	39.7
10	- 51.7	44.2

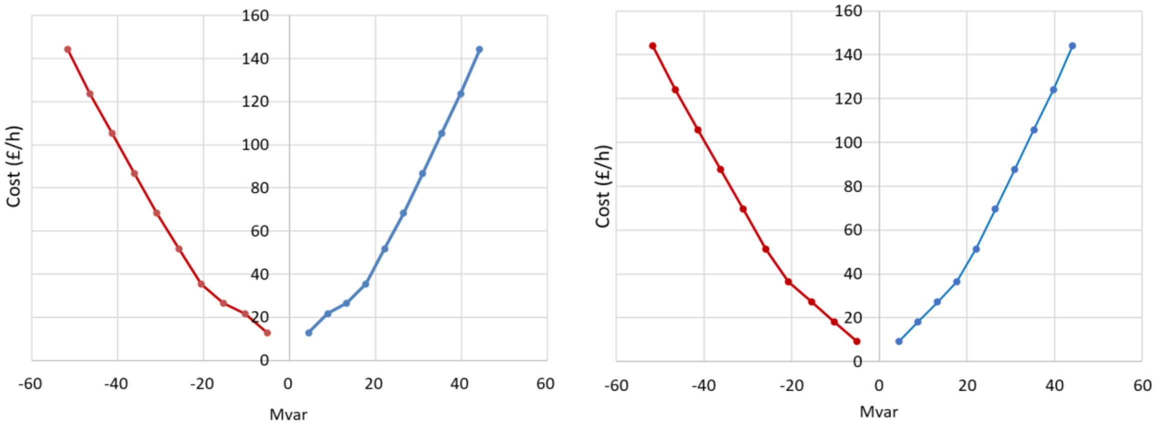
For each band, the minimum cost is calculated by selecting the most economic portfolio. The portfolio will be different in each case following the merit order shown in Table 2-1. The approach is based on the pay-as-bid service. It is worth noting that when ESO selects a band, it will be applied to both Mvar lag and lead automatically. For example, if band 5 is selected, DERMS will allocate -25.9 Mvar (lead) and 22.1 Mvar (lag) capability.

The results from DERMS and ICL model for every case are compared in Figure 14 (Case 1), Figure 15 (Case 2), and Figure 16 (Case 3). The three figures demonstrate that the results from both models are practically the same. The results suggest that DERMS allocates the DERs correctly according to their merit order.



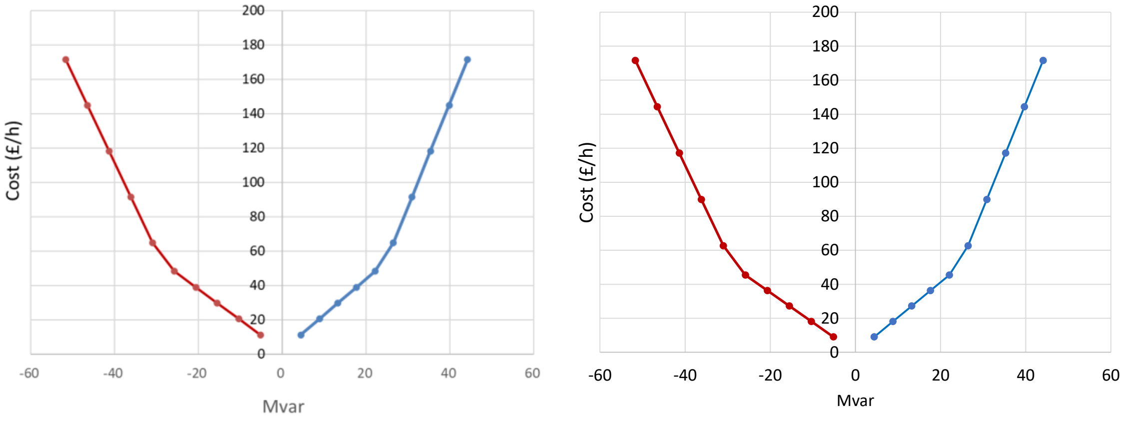
(a) DERMS solution (b) ICL model solution

Figure 14 Case 1 reactive power unit cost function from DERMS and ICL model



(a) DERMS solution (b) ICL model solution

Figure 15 Case 2 reactive power unit cost function from DERMS and ICL model



(a) DERMS solution (b) ICL model solution

Figure 16 Case 3 reactive power unit cost function from DERMS and ICL model

Chapter 3. Conclusions

Based on the results of a spectrum of studies performed and the analyses, it can be concluded that the VPP reactive power capability calculated by DERMS is aligned with the results of the ICL model. The studies demonstrate the following:

- DERMS calculation captures the asymmetrical reactive power capability from Power potential DERs.
- Reactive power capability varies depending on DER's active power production following the PQ operating characteristic.
- The impact of reactive power services from DERs on distribution network losses is included in DERMS calculation, and it tends to expand the range of reactive power that can be modulated at the GSP.
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- Network thermal limit is not considered in DERMS reactive power calculation, and therefore, it requires an offline assessment from UKPN's planning team to artificially modify DER's reactive capability behind the constraint to ensure the thermal limit is not violated. It is recommended that DERMS formulation should be improved in future, especially if the DER participation in reactive power services increases.
- DERMS allocates the reactive power resources optimally according to the bids from DERs.