UK POWER NETWORKS PROVIDING POWER SERVICES FROM DISTRIBUTED ENERGY RESOURCES TO TRANSMISSION SYSTEM OPERATOR VIA A CENTRALISED DERMS PLATFORM

Ali R. AHMADI
UK Power Networks – U.K.
Alireza.Ahmadi@ukpowernetworks.co.uk

Inma MARTINEZ
National Grid ESO – U.K.
Inma.Martinez@nationalgrid.com

Biljana STOJKOVSKA
National Grid ESO – U.K.
Biljana.Stojkovska@nationalgrid.com

Rita SHAW
UK Power Networks – U.K.
Rita.Shaw@ukpowernetworks.co.uk

Tim MANANDHAR
UK Power Networks – U.K.
Tim.Manandhar@ukpowernetworks.co.uk

Sotiris GEORGIOPOULOS
UK Power Networks – U.K.
Sotiris.Georgiopoulos@ukpowernetworks.co.uk

ABSTRACT

The DERMS platform is a centralised control system that enables distributed energy resources (DER) connected to the distribution network to provide services to the transmission grid, in a coordinated and controlled manner. This paper presents the simulation results obtained from testing the functionality of the DERMS when providing real and reactive power services to the Electricity System Operator in UK, National Grid. The simulation results show that the DERMS effectively determines DER availability, capabilities and costs, and translate them into service availability and cost to National Grid at the interface GSPs, while optimising the DNO network. The DERMS real-time algorithm is shown to successfully provide coordinated services to National Grid from DER, in a pre-production simulation environment. This new control approach can create additional revenue streams for DER, hence facilitating DNO transition to the DSO business model.

INTRODUCTION

The Power Potential project is an innovation project funded by Ofgem between UK Power Networks and National Grid Electricity System Operator (ESO). The project looks to further utilise Distributed Energy Resources (DER) to provide active and reactive power services to the ESO at the interface Grid Supply Points (GSPs) between transmission and distribution in the South-East Coast of the UK [1].

The project is targeting four existing GSPs in this region; Bolney, Ninfield, Sellindge and Canterbury North in which the distribution network interfaces with the transmission grid.

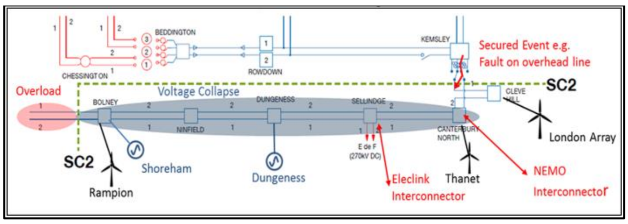

Figure 1 – UK South coast transmission constraints.

The transmission network and the areas within the distribution network at this location are at the limit of capacity for transferring generation away from the area. This means that, for particular faults and network conditions, voltage levels at certain points could reach values outside statutory voltage limits (see Figure 1). In order to prevent this, pre-fault flows across this South-East route are being constrained, preventing additional generation from connecting to the transmission or distribution networks in this area. To enable more generation to connect, large-scale network investment is traditionally required. The Power Potential project has designed an innovative solution to facilitate faster and cheaper alternative DER connection, which is expected to provide flexibility to the ESO, reducing operational costs.

The project aims to create a regional reactive power market for DERs to offer active and reactive power services to National Grid ESO via UK Power Network acting as a Distribution System Operator. This approach aims to defer network reinforcement needs in the transmission system. A technical and market platform known as Distributed Energy Resources Management System (DERMS) has been designed to support technical and commercial optimisation and dispatch. It includes gathering bids from DER and presenting an optimised view of the services to National Grid split by GSP. The DERMS is to be installed in the UK Power Networks' control room and is integrated with UK Power Networks' energy management system, PowerOn, that provides real-time SCADA network data to DERMS.

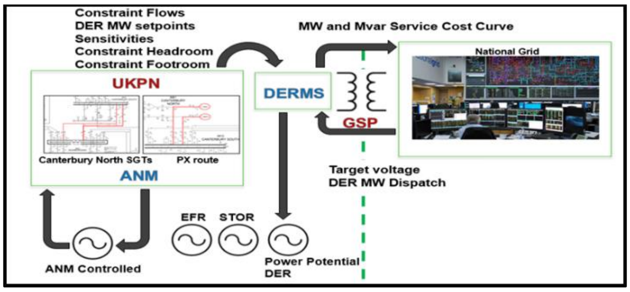

Figure 2 – Power Potential DERMS interface between National Grid and UK Power Networks.

In parallel, an Active Network Management (ANM) system is being designed for the South Coast to manage distribution network constraints (see Figure 2). The ANM is designed to manage distribution constraints and to constantly communicate with DERMS by exchanging signals to avoid conflicts of services. This will result in DERMS accurately providing the visibility and availability of DER services to National Grid. Hence the direct dispatch of other DER services sitting behind ANM schemes would not be nullified by ANM operation.

This paper presents desktop simulation results demonstrating the operation of major components from the DERMS Power Potential control system between National Grid, UK Power Networks and DER, as shown in Figure 3. Note that National Grid service instructions to DERMS are via the Platform for Ancillary Services (PAS) interface and that DER control system is interfaced with DERMS through an RTU (Remote Terminal Unit) via PowerOn.

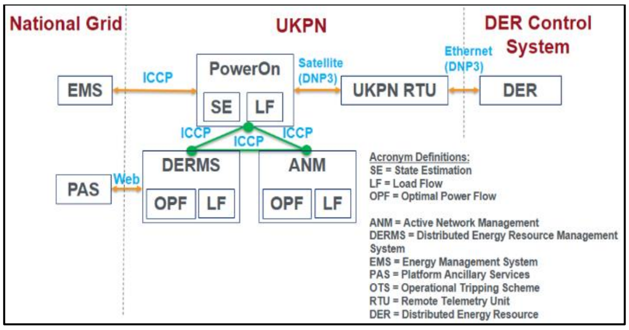

Figure 3 – Power Potential main communication paths between National Grid, UK Power Networks and DER through DERMS.

In particular, simulation results will be presented to capture DER operation during the provision of active and reactive power services in real-time operation. The efficiency of the DER controller under DERMS in supporting the transmission network by offering dynamic voltage control in the reactive power service is validated with these results. The total aggregated response from DER can be considered as an equivalent virtual power plant (or SVC) at the transmission-distribution interface GSPs in the South Coast. In addition, the operation of the DERs in providing active power services to manage a transmission thermal constraint is also presented in this paper. The results demonstrate the transition path of UK Power Networks into UK's first DSO, by providing support through coordinated TSO/DSO action.

ENHANCED TRANSMISSION/DISTRIBUTION SYSTEM COORDINATION AND CONTROL

The Power Potential project, is looking at the technical and commercial aspects of procuring and absorbing active and reactive power from DERs connected to the distribution network to help manage voltage and thermal constraints on the transmission network.

Power Potential will procure the following services:

1. **Reactive Power - Q service:** Dynamic voltage support (Mvar).
2. **Active Power - P service:** Active power support (MW) for constraint management and system balancing.

The project is developing an innovative market based arrangements for the provision of reactive power from DER. This will facilitate connection of new generation by freeing up the available network capacity which would otherwise be offset to allow for variations in DER [3].

National Grid will define the real and reactive power services instruction at the interface 400kV level (GSP) in the form of:

- P service: target set-point ($\Delta P^{400\,kV}_{set}$).
- Q service: target set-point (V^{400kV}_{set}), droop and dead-band.

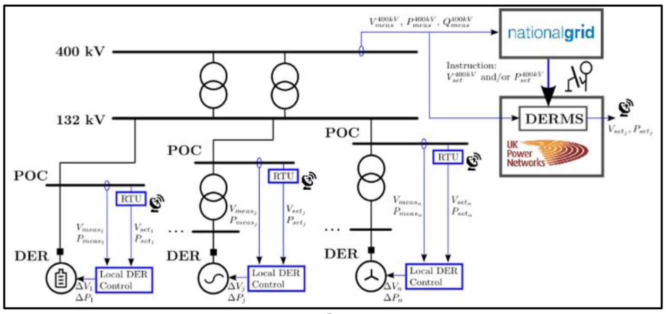

Figure 4 – DERMS network integration overview.

DERMS receives the instructions from National Grid and optimises the operation of the distribution network to deliver the required services at the GSP, as shown in Figure 4. It coordinates the operation and control of Distributed Energy Resources (DERs) as a Virtual Power Plant (VPP). This concept is illustrated in Figure 5.

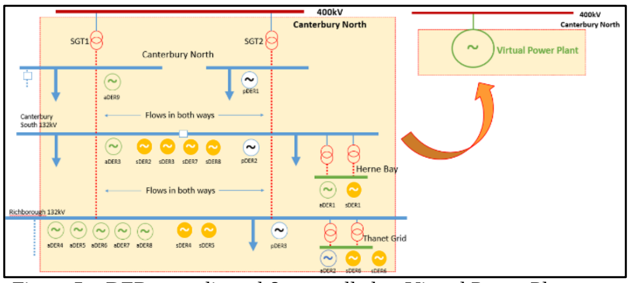

Figure 5 – DERs coordinated & controlled as Virtual Power Plant at a GSP.

For the reactive power service, DER are expected to operate under a local voltage droop control scheme whose set-point V_{DER}^{set} can be adjusted by DERMS. This occurs after receiving a voltage set-point instruction V_{400kV}^{set} from National Grid or after a large transmission voltage change V_{400kV}^{meas}, which allow DER to provide dynamic voltage support. Full description of local DER and supervisory controllers to operate under DERMS are presented in [2].

POWER POTENTIAL SOLUTION

This section describes the DERMS processes during real-time for the dispatch and use of the Power Potential services during the service delivery day. Procurement of Power Potential power services will take place at the day-ahead stage and specific details on the commercial framework associated to these can be found in [3].

Active Power Services

The following describes the proposed calculation, presentation and instruction of active power services via Power Potential during real-time.

Ahead of real-time, the DERs would have input their P bids with a utilization price (£/MWh) for each commercial interval of the delivery period by 14:00 on the day ahead using a web interface with DERMS. This tendering process is presented below (see [3] for details):

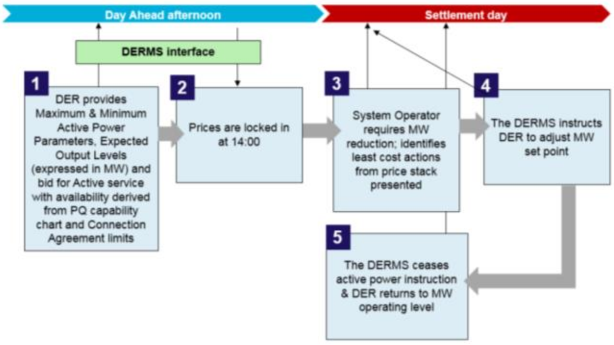

Figure 6 – Active power service commercial process.

Using the DER commercial information, real-time demand, generation and network running arrangement, the DERMS loadflow engine calculates the available dispatchable active power (ΔP) volume at each GSP. The DERMS does not make dispatching decisions itself for active power; however, it can receive an instruction from National Grid to dispatch active power.

The dispatchable active power (ΔP) is presented to National Grid in the form of delta volume at each GSP. In other words, granular view of every DER (Distributed Energy Resources) is not presented to National Grid in real-time. For each GSP (400kV delivery point), National Grid can provide DERMS a target set-point MW service instruction.

Reactive Power Services

This section describes the proposed calculation, presentation and dispatch of reactive power services via Power Potential during real-time.

Ahead of real-time, during the auction process (before gate close) each DER provides a declared availability; in absolute terms; and an availability price (£/Mvar/h) and utilisation price (£/Mvarh) for each commercial interval of the delivery period using a web interface with DERMS. At the close of the commercial auction, selected DERS are contracted to be available to provide Mvar support for each commercial interval during the delivery period.

The diagram below illustrates how the auction will look like for participating in reactive power market (see [3] for details):

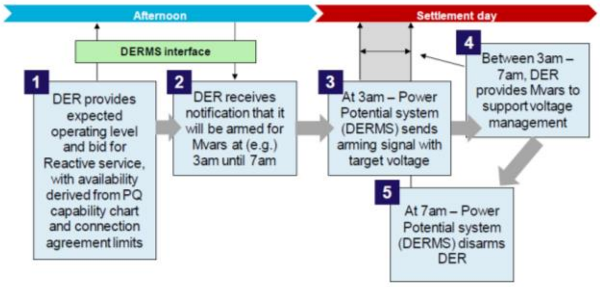

Figure 7 – Reactive power services commercial process.

Using the DER commercial information, real-time demand, generation and network running arrangement, the DERMS loadflow engine calculates the available dispatchable reactive power (ΔQ) volume at each GSP, both lag (injecting) and lead (absorbing). It would also send an arming instruction for the reactive power service at the start of the instruction period (to change the DER operating model voltage droop control and provide dynamic voltage support). For each GSP (400kV delivery point), National Grid can provide DERMS a target voltage set-point kV service instruction, to be delivered with a droop characteristic within a certain dead-band, to get Mvar support from DER.

The high level operation of the Power Potential services during real-time can be then summarised as follows:

- DERMS receives service requests from National Grid per 400KV delivery point
- Based on these service instructions the DERMS builds a production schedule for DER to be delivered in each operating interval over the remainder of the current commercial operating period. (max 24hrs)
- For each operating interval, DERMS has a number of DERs that are contracted to provide power services for a specific price.
- At the start of each commercial interval the DERMS instructs each DER to enable their set-points and confirms that this has been done.

DERMS SIMULATION RESULTS

This section presents the simulation results obtained from testing the functionality of the DERMS when providing real and reactive power services to National Grid during real-time operation. The tests were conducted with DERMS real-time algorithm running on a Microsoft Azure pre-production simulation environment.

The desktop test arrangements are presented in Figure 8:

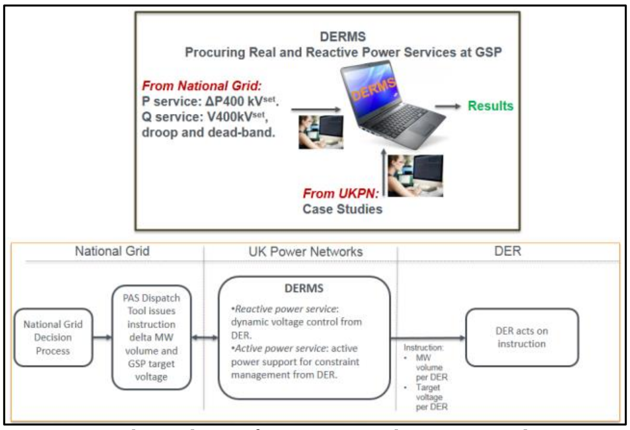

Figure 8 – High Level setup for DERMS Desktop Functionality Test in simulation environment.

The DERMS end-to-end simulation based functional testing included two different instructions:

1. P service: target ΔP (MW) at 400 kV GSP.
2. Q service: target V^{set} voltage (kV) at 400 kV GSP, droop percentage and dead-band in kV.

The simulation was tested on a 100 bus bar distribution network connected to transmission network at 400kV Canterbury North GSP via two supergrid transformers (SGT1, SGT2). The distribution network contained 5 DERs which can provide Power Potential active and reactive power services:

- Maidstone and Canterbury DERs at 132kV.
- ALL, Barming and Sheepway DERs at 33kV.

A reduced schematic of the distribution network connected to Canterbury North GSP and location of the 5 DERs are shown in Figure 9:

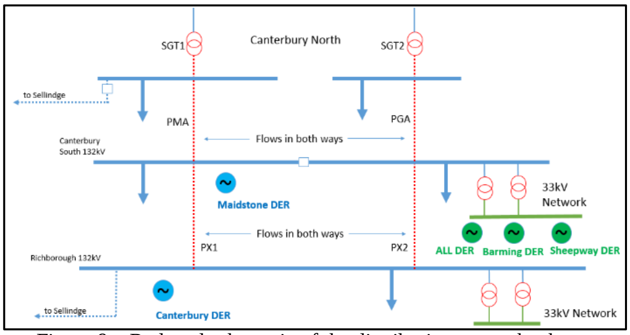

Figure 9 – Reduced schematic of the distribution network where DERMS where tested in simulation environment.

Active Power Services Results

The initial DER condition presented in Table 1 illustrates the technical real/reactive power capability of each DER and its associated bids.

Table 1 – Simulation initial condition.

	DER Commercial/Technical Data				
DER No.	**1**	**2**	**3**	**4**	**5**
	Maidstone	**Canterbury**	**ALL**	**Barming**	**Sheepway**
£/MW[1]	2	1	3	4	5
£/Mvar[2]	2	1	3	4	5
Max MW	100	200	30	20	20
+ve Mvar	50	50	10	10	10
-ve Mvar	-50	-50	-10	-10	-10
	DER Initial Setpoint				
DER P set (MW)	100	200	30	20	20
DER Q set (Mvar)	0	-48	-10	-10	-10

As shown in Table 1, all DERs are operating at their maximum real power export setpoint (i.e. base case study with initial setpoints). The first study in Table 2 with 0MW instruction at GSP level, illustrates the DER's initial condition.

Table 2 – Active Power Services Instruction Results per DER.

	DER No.					Transformer flows			ΔP at GSP
DER output	**1**	**2**	**3**	**4**	**5**	**SGT1**	**SGT2**	**Total Flow**	**P Instruction**
P (MW)	100	200	30	20	20	-171.28	-169.12	-340.4	**1st Study: 0 MWs**
Q (Mvar)	0	-48	-10	-10	-10	73.75	72.25	146	
P (MW)	100	200	30	20	20	-171.28	-169.12	-340.4	**2nd Study: 50 MW**
Q (Mvar)	0	-48	-10	-10	-10	73.75	72.25	146	
P (MW)	100	126	30	20	20	-132.99	-131.32	-264.3	**3rd Study: -74MW**
Q (Mvar)	0	-50	-10	-10	-10	74.84	71.83	146.7	
P (MW)	100	200	30	20	20	-171.28	-169.12	-340.4	**4th Study: 0MW**
Q (Mvar)	0	-48	-10	-10	-10	73.75	72.25	146	
P (MW)	0	0	0	0	0	11.41	11.25	22.66	**5th Study: -370MW**
Q (Mvar)	0	0	0	0	0	-3.97	-4.59	-8.56	

The second study in Table 2 demonstrates that the instruction of extra 50MW export at GSP level is not possible because the DERs were already operating at their maximum export capacity, hence the DER outputs and SGT flows do not change. The third study, shows the instruction of 74MW reduction at GSP level. The DERMS algorithm instructs the cheapest DER, which is DER 2 (Canterbury DER), at a cost of £1/MW, to reduce from 200MW to 126MW. The fourth study shows the return to the initial conditions by instruction a delta P of 0MW at GSP level. The fifth study, demonstrates the instruction of

[1]Instantaneous active power utilisation price.
[2]Instantaneous reactive power utilization price. Reactive power availability price not reflected in table as DER will have been already procured.

370MW reduction at GSP level. In order to achieve the instruction, DERMS has instructed all DERs to operate at 0MW in order of cheapest cost first. Hence the net export across both SGTs have reduced from -340.4MW to a net import of 22.66MW, whilst keeping all distribution network constraints within limits.

These studies show effective optimisation of DER real power services by DERMS as a VPP, in order to achieve National Grid's instructions at the GSP whilst keeping all distribution network constraints within limits.

Reactive Power Services Results

The DER commercial and technical data and initial set-points are the same as Table 1. However, the initial GSP voltage setings are as shown below in Table 3:

Table 3 – GSP initial voltage and reactive power settings.

	Reactive Power Initail Setpoints
GSP Deadband (kV)	1
GSP Droop (%)	4
GSP Target Voltage (kV)	400
Slack Bus bar Voltage (kV)	404

This initial condition is demonstrated by the sixth study in Table 4, with National Grid request of a target voltage of 400kV, the cheapest and most effective DERs are instructed by DERMS to operate at their leading reactive power, absorbing vars.

Table 4 – Active Power Services Instruction Results per DER.

	DER No. (P in MW and Q in Mvar)					Trans. flows	Slack Volt. (kV)	GSP Target Voltage (kV)
DER output	1	2	3	4	5	Total Flow	Voltage Achieved	Q Instruction
P	100	200	30	20	20	-340.4	404.00	6th Study: 400kV
Q	0	-48	-10	-10	-10	146		
P	100	200	30	20	20	-341.22	404.35	7th Study: 404.97kV
Q	0	0	0	0	0	59.67		
P	100	200	30	20	20	-341.41	405.49	8th Study: 415kV
Q	50	50	10	10	10	-114.88		
P	100	200	30	20	20	-338.4	403.48	9th Study: 395kV
Q	-50	-50	-10	-10	-10	206.52		

The seventh study shows the change in GSP target voltage set-point to 404.97kV, the slack bus is operating at 404kV, hence the DERMS instructs DERs to operate at a zero reactive power as the target voltage and slack bus bar voltage is within the deadband.

The eighth study shows a GSP target voltage increrase to 415kV. Hence instructing the cheapest and most effcetive DERs first, DERMS requests all DERs to operate at their maximum lagging reactive power limit, injecting vars.

The nineth study shows the GSP target voltage reduced to 395kV. Hence instructing the cheapest and most effcetive DERs first, DERMS requests all DERs to operate at their maximum leading reactive power limit, absorbing vars.

The Canterbury North GSP connected to the transmission network is very stiff which means changing the voltage profile must be coordinated across the South Coast GSPs to achieve the best results.

These studies show effective opimisation of DER reactive power services by DERMS as VPP, in order to achieve National Grid's voltage instructions at GSP whilst mantaining all distribution network consraint within limits.

CONCLUSION

This paper has presented the technical framework proposed in the Power Potential project for coordination and control of transmission and distribution networks in Great Britain during real-time operation. This project will improve interaction between National Grid, UK Power Networks and energy resources connected to the distribution system, through a technical and commercial solution. Power Potential is a significant step towards the transition of Distribution Network Operators to Distribution System Operators, and informing the future role of the System Operator.

This paper also presented the simulation results obtained from testing the functionality of the DERMS (Distributed Energy Resources Management System) when providing real and reactive power services to National Grid. The simulation results demonstrate that the DERMS algorithm works by coordinating and controlling the operation of DERs as VPP in order to meet National Grid's requirements at GSP level.

The successful demonstration of DERMS functionality in real-time under simulation environment shows effective interactions and mechanics between TSO and DSO can lead towards procuring the cheapest resources available in order to manage transmission network constraints. The proliferation of Distributed Energy Resource Management Systems (DERMS) on distribution network where all the network data, schedules and information are available, provides the infrastructure to effectively manage/optimise the distribution system constraints and offer TSO services to National Grid.

The solution proposed in this paper can develop the key capabilities for the DNO to actively manage networks and evolve into an active DSO role.

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