IMPLEMENTING OPTIMIZATION FUNCTIONALITY ON NETWORK MANAGEMENT PLATFORMS FOR NEW DSO BUSINESS MODELS

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ABSTRACT

This paper address the emerging need for Distribution System Operators to optimise Distributed Energy Resources hosted in their networks. This paper presents the Active Network Management (ANM) technology platform elements developed and tested by the authors to host DSO optimization functionality and the requirements this addresses including: control platform architecture and properties; level of autonomy; solution speed for different use cases; fail-to-safes; real-time override; operator configuration and interface; market and system operator integration.
The paper also presents results of end-to-end lab test of the optimization platform and applications with an objective evaluation of the outcomes and outlook for further development towards implementation by DSOs.
Conclusions are drawn and presented on the technical, commercial business model and regulatory implications of implementing optimization functionality to deliver new DSO business models.

INTRODUCTION

The evolution towards future business models for Distribution System Operators (DSOs) have been shared in recent industry collective positions and visions from EDSO [1] and EURELECTRIC [2] in Europe and the LBNL Future Electric Utility Regulation Series in the US [3]. The roadmaps and visions towards the future DSO include industry structure, regulation, technology, market and business model changes. A common driver of these changes cited is the growth of Distributed Energy Resources (DER) and the need for DSOs and supporting industry frameworks to both facilitate the integration of DER in fair manner but also to enable the value of DER to be harnessed for the system at large (both locally and wider into regional and national levels).

The advent of grid scale energy storage (in larger individual units and meaningful aggregations of multiple smaller units) highlights many of the emerging DSO challenges in fair approaches to connection, enabling of multiple revenue 'stacking' business models and overall secure and efficient coordination of network and system operation. The 'co-optimization' of energy storage devices against the requirements of different service markets and value streams (e.g. local network constraint relief vs energy market arbitrage vs system services) places new requirements on DER device owners, aggregators, DSOs, the market and Transmission System Operators (TSO) and new means of coordination between them. More fully and formally CEDEC, EDSO, *et al* set out five emerging requirements for DSOs [4]:

- Congestion management
- Balancing
- Use of flexibility
- Real-time control and supervision
- Network planning

This paper argues that, to meet these requirements, optimization functionality is required at scales and applications not currently common to DSOs. This paper reviews recent innovation projects by DSOs that point towards the deployment of optimization functionality for a broader set of DSO use cases. This raises important questions on optimization techniques, algorithms, control platforms, problem objectives, sensitivity of optimization result to forecast or estimated input data, etc. There is a long list of issues to address and overcome before optimization becomes a standard tool in the DSO toolbox.

NEW DSO BUSINESS MODELS

In order for the DNO to transition to a fully-fledged system operator, there are a number of stepping stones which can be used to ensure gradual progression to a fully functioning DSO.
The three phases can be defined by the scale of change required for both the DNO/DSO and the regulatory framework within which they operate. The authors have been developing and exploring these new DSO Business Models to address DSO and DER trends and changing sector structures/frameworks. The summary presented here provides a high-level context for DSO optimization requirements developed in this paper.

Phase 1: Little Market, regulatory or energy price influence

Potential business models in this phase include operating as Managed Connections Provider or Active Flexibility Coordinator.
As a Managed Connections Provider, the DSO would have reactive control of demand, generation and storage to maintain network limits. This is a role already being provided by some DNOs across the UK where Active Network management schemes have been deployed in

areas of high constraints.
A more advanced role would be an 'Active Flexibility Coordinator. This would involve the coordination of multiple network-orientated objectives and use cases. This role would lead naturally on to Phase 2.

Phase 2: Indirectly influence market and energy price with regulatory implications

Phase 2 requires a great deal of regulatory change, to allow the DSO to provide a role of market operator. This phase would likely require a greater deal of trials in terms of market platforms and market facilitation that needed for Phase 1.
Potential roles in this phase include Information Broker, Services Consumer, Services Merchant.
As an Information Broker, the DSO can provide information to supply and demand customers in order to encourage changes in behaviour. This would tie to the current roll out of Smart meter devices to domestic customers across the UK.
The roles of Services Consumer and Merchant are closely linked. Essentially as a Consumer, the DSO would perform advanced online operations and near real-time system operation to reduce network costs. As Services Merchant, the DSO would respond to SO tenders or negotiated contracts to create new revenue streams.

Phase 3: Directly influence and set market and energy price

The final phase requires significant regulatory and policy changes to enable full DSO operation. There are two roles proposed here. The first is Local Market Enabler where a hierarchy for control from local cells would coordinate in the buying and selling of services.
The second role proposed, is a full DSO with local mirroring of TSO functions and the creation of dispatchable Grid Supply Points (GSPs).

Linking business models to optimization

A technical platform is an essential part of the progression towards a DSO. Regardless of the level of regulatory or policy changes, the platform described in this paper can facilitate a range of potential business models, and can be tailored to suit the industry as the regulatory framework develops.

OPTIMIZATION IN DISTRIBUTION

Changing from the DNO (or existing DSO in Europe) current business model to the new/future DSO business model has deep implications on distribution networks management that above all implies greater visibility and control over network operation and operational planning.
The previous section presented a potential avenue of development of the DSO model. This section focuses on the existing gap between current technical capability and that required to deploy the new business models. In particular it pinpoints where optimization techniques need to be improved or developed.

The DSO model impacts almost every step in the distribution business chain:

- **Planning:** as managed DER connection and operation within a DSO business model can be used in network reinforcement deferral, DNOs need to incorporate new planning methodologies and tools. These tools consider DER as actively controlled elements in addition to network assets (e.g. tap changers, or capacitor banks). These also tend to consider multi-period analyses instead of the extreme scenarios minimum generation / maximum demand and maximum generation / minimum demand. By doing so optimization is normally used to provide a better representation of reality. There are numerous works on the subject, although very few industry grade tools.
- **Operational planning:** given the new control requirements, a similar set of tools to the ones used by TSOs is required. The DSO model requires tools for day-ahead or even longer time frames to intraday planning. These involve the conjunction of market and grid optimization. Many of the simplifications made at the TSO level for combined grid and market analysis are not applicable in distribution and so even though the number of control variables might be reduced the grid representation gains complexity.
- **Operation and DER Scheduling:** In operational planning the tools used are based on forecasts and some assumptions. These are naturally not 100% accurate and so need to be tweaked in real-time or quasi-real-time using the most up to date data available with final schedules for network and DER assets operation created.
- **Network and DER Control:** Execution of the operations schedules for DER and network assets with remediation of contingencies, response to final forecast error and real time override of DER delivery/non-delivery of network and system services.

The latter three levels imply that DNOs build a technology platform capable of linking with the different corporate systems, receiving real-time and forecast data about the network status and DER devices. This platform is a critical element for the DSO transition by allowing the optimization problems to hosted and operationalised.

To develop and operate an efficient distribution system requires that multiple network assets and controllable DER are optimized to operate them in the most economic and secure manner. At Operational Planning, the optimal use of available assets is studied to ensure that the built distribution network can be operated securely and that the optimal set of DER and network controls can secure the network under contingency and optimize the operation of DER. At Operations and Scheduling, the available DER are scheduled optimally to identify the most efficient running arrangement and the best way to deliver any contracted services to customer, DER Operators or TSO. In Control period the optimal schedules are implemented and any deviations, over-rides or fail-to-safe actions under contingent events require re-optimization of DER and network asset schedules to ensure optimal operation.

TECHNOLOGY PLATFORM

The ANM platform upon which the optimization functionality has been implemented makes use of centralised and decentralised control to control DER. Centrally, a real-time control engine and integration adapter host share a common data model which allows for the execution of algorithms and optimization problems, and for the interface to external systems and controllers respectively. The integration adapter host has a number of industrial protocols which interface to external systems such as Supervisory Control and Data Acquisition (SCADA) systems, transducers, and Remote Terminal Units. Legacy protocols such as IEC 61805, DNP3 and Modbus are supported. At the device under control, typically a generator, control logic resides on a device to receive and process set points, monitor the communications channel, interface to the device controller and ensure compliance. In the event of a loss of communication channel or should the generator not respond in a satisfactory manner, a fail-safe action can be applied locally.

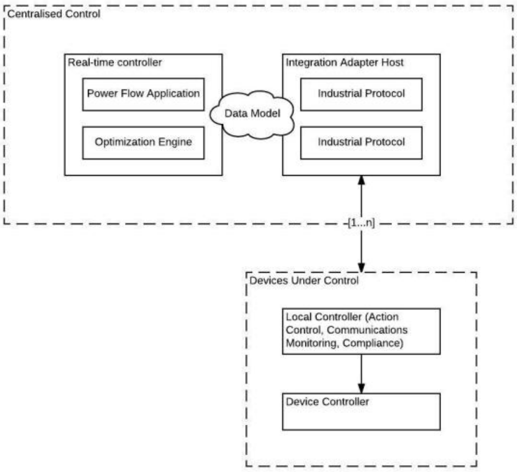

Figure 1. Technology platform architecture.

A Java Virtual Machine (JVM) is tuned to make use of Real-Time Specification for Java (RTSJ) [5] ensuring that algorithms can be processed and solved in a deterministic manner. Additionally, hosted on the real-time controller are the Application Programming Interfaces (APIs) for commercially available optimization platforms, namely GAMS and AMPL. Offline models and data can be executed through the API. Forecast or live data can be obtained from the data model and results from the optimization problem exposed to the data model. The results of the optimization problem can be used to schedule the control of devices. In parallel, to ensure the forecasted results do not result in a breach of network constraints, real-time measurements can be taken and observed. Should a constraint become active, corrective actions can then take precedence to ensure the system remains within operational limits.

LAB TEST IMPLEMENTATION

The example presented in this section describes the lab test implementation of the optimization embedded in the ANM technology platform.

A very simple system, based on a real network, was considered, as later presented in Figure 8. For the purpose of describing the implemented optimization problem this system can be simplified to the one depicted in Figure 2. Given that there is only one constraint at the substation a full network model is not required for this case study. The model gets reduced to the sum of all export and import values of the loads, generators and storage devices.

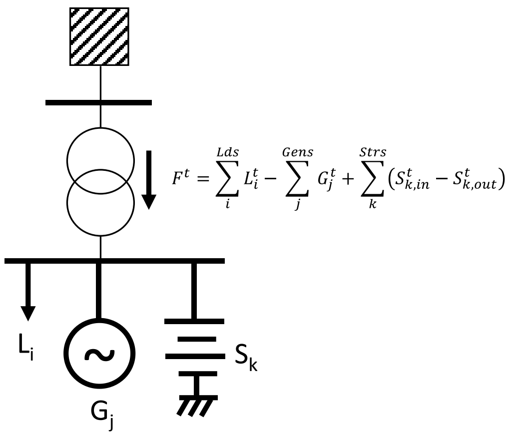

Figure 2. Simplified diagram of the case study.

The primary goal of building an optimization problem in this case is to avoid curtailing generation to control the flow at the substation. An electric storage system is put in place to exploit the otherwise curtailed energy. The following equations formulate the problem:

$$\min Z = C_{Shed} \sum_t^T \sum_i^{Lds} L_i^t + C_{Curtail} \sum_t^T \sum_j^{Gens} G_j^t + C_{Stor} \sum_t^T \sum_k^{Strs} S_{k,in}^t - R_{Stor} \sum_t^T \sum_k^{Strs} S_{k,out}^t$$

s.t.

$$F_{min} < F^t < F_{max}$$
$$0 < E_x^t < E_x^{max}$$

Where:
Z is the objective function
C_{Shed}, $C_{Curtail}$, C_{Stor} are the costs associated with load shedding, generation curtailment and storage import
R_{Stor} is the revenue associated with storage export
T is the total number of t time periods
Lds is the total number of L loads
$Gens$ is the total number of G generators
$Strs$ is the total number of S storage units
L_i^t is the load i value at time t
G_j^t is the generator j power at time t
$S_{k,in}^t$, $S_{k,out}^t$ are respectively the storage k import and export power at time t
F^t is the flow at time t in the substation
F_{min}, F_{max} are the minimum and maximum flow capacities
E_x^t is a generic variable that represents all the changing variables that are bound between 0 and E_x^{max}

When deployed in the ANM technology platform this optimization problem periodically defines and updates the storage system schedule based on the most up to date forecasts of load and generation.

If the scheduled set-points are not effective and the constraint at the substation is still breached then the platform will curtail generation in real-time according to the active network management principles [6].

RESULTS

Figures 3 to 7 show the result of the application of the scheduling system over a 24h period assuming perfect forecasts, i.e. forecasts and actuals match. Figures 8 and 9 illustrate what happens when forecasts and consequently the scheduling fail to address the constraint issues properly in a pre-empting manner.

Figure 3 starts by depicting the flow at the substation. The flow is expected to breach the flow upper and lower limits.

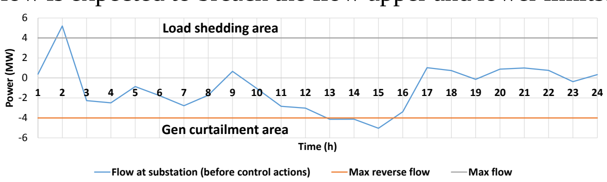

Figure 3. Un-curtailed flow at the substation.

If the scheduling algorithm is switched in, but considering no storage, load is expected to be shed as shown in Figure 4 and generation to be curtailed as presented in Figure 5.

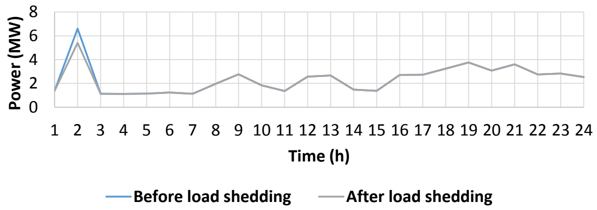

Figure 4. Load before and after load shedding.

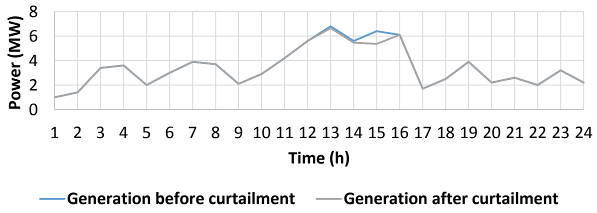

Figure 5. Un-curtailed and curtailed generation export.

However, when the storage scheduling system is set in service these breaches are compensated by the storage effect and no curtailment is necessary. The action of the storage system is shown next, Figure 6.

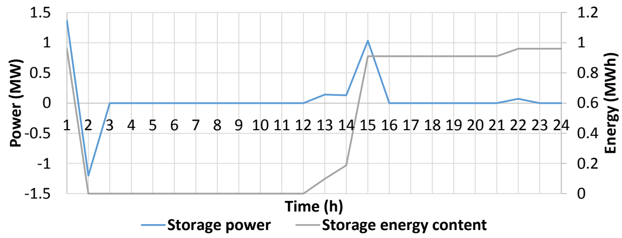

Figure 6. Storage import/export and energy across a 24h period.

The action of the storage device prevents load shedding and generation curtailment and, as illustrated in Figure 7, controls the flow in the substation to be kept within the statutory limits.

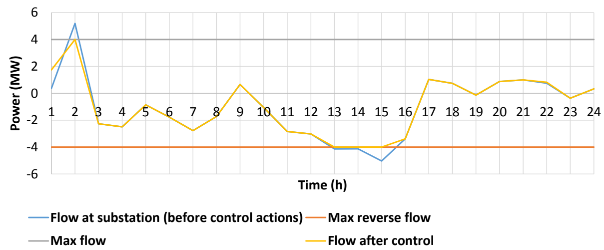

Figure 7. Flow at the substation when the storage system is under scheduled mode.

Evidently, the results presented so far do not take into account potential deviation of forecasts with respect to the actual load and generation in the system. In these cases the scheduling algorithm solution may not be able to fully address the constraint breaches and further real-time control actions are needed.

Figure 8 depicts the network diagram as seen on the platform user interface when such an event takes place.

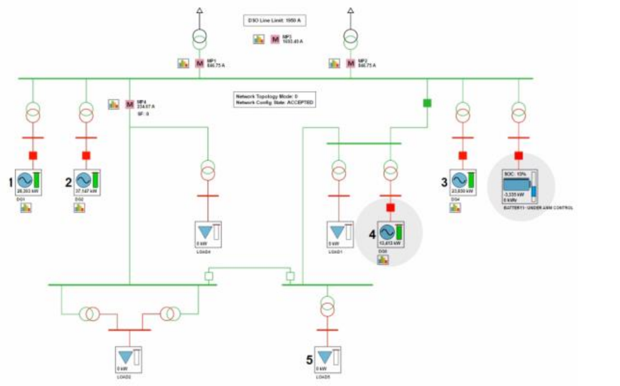

Figure 8. Snapshot of network diagram taken from platform user interface, when ANM system is forced to intervene.

Figure 9 shows how after the breach the ANM system takes over control and brings the power flow at the substation to a safe level, starting to release generators a short while after in a controlled fashion.

The combined actions of a scheduling system and the proven action of ANM lead to a better utilisation of resources, unlocking potential for the described platform to support the DSO model deployment and the new business models.

CONCLUSIONS

This paper has briefly described the need for optimization functionality in the emerging DER penetrated distribution system. Optimal planning and operation for DER services and new DSO business models is an emerging topic with the developments in smart grid, flexibility and DSO-TSO interactions creating a need for firm platform solutions to underpin new types of DSO operation.

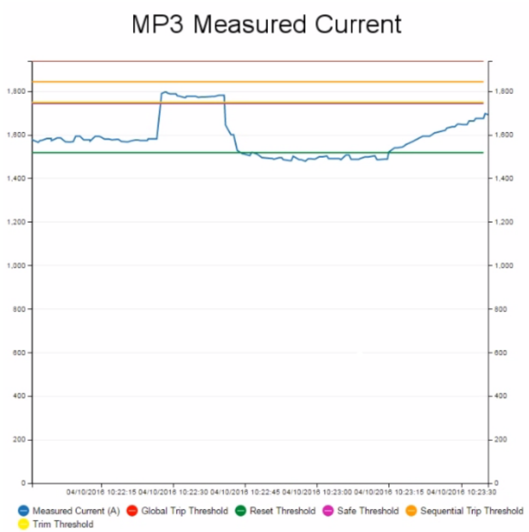

Figure 9. ANM control curtailing and releasing generation to correct scheduled set-points.

The laboratory testing of optimization functionality on a proven ANM control platform has yielded several important points of learning:

- 'Off the shelf' industrial optimization tools can be integrated with an existing DER control platform.
- The developed ANM optimization platform can be configured to DER use cases including scheduling of energy storage.
- Many other DER and network operation optimization configuration patterns are now possible – the authors are specifying, developing and testing these in internal and customer-facing programmes.
- Field testing of the proven ANM optimization capability is required building on previous experience of ANM for flexible/non-firm/curtailment generation control.

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