IMPACT OF SYSTEM SERVICES DEPLOYMENT IN DISTRIBUTION SYSTEMS: NIE NETWORKS CASE STUDY

Avinash AITHAL Paul MORRIS
EA Technology – UK
Avinash.Aithal@eatechnology.com
Paul.Morris@eatechnology.com

Jonathan POLLOCK Ian BAILIE
NIE Networks – UK
Jonathan.Pollock@nienetworks.co.uk
Ian.Bailie@nienetworks.co.uk

ABSTRACT

The 'Delivering a Secure Sustainable Electricity System' (DS3) programme has identified the need for integrating additional System Services in the Single Electricity Market (SEM) to operate the electricity system securely whilst achieving the renewable energy policy objectives of Northern Ireland. Distributed Energy Resources (DERs) are therefore expected to supply an increasing proportion of whole system support services in the future. This paper investigated the influences upon network capacity to accept the deployment of System Services, within 'Northern Ireland Electricity (NIE) Networks' electricity distribution system. The available capacity to host System Services within 33 kV and 11 kV was found to be influenced by several factors, and, in some cases, had a nonlinear relationship with the key influencers. Passive methods to assess network capacity and manage DERs were likely to unduly restrict system access. This paper put forth pertinent considerations that advocate the need for actively managed allocation of System Service, substantiating NIE Networks' vision of evolving from a Distribution Network Operator (DNO) to a Distribution System Operator (DSO).

INTRODUCTION

The electricity sector is witnessing considerable disruption arising from a combination of policy, technological and customer change. Electricity distributors are in the frontline of the impact from the unparalleled progress on smart grid technology, growth of distributed generation (DG) (e.g. solar photovoltaic installations, wind farms), other distributed energy resources (DERs) and changing patterns of electrical demand. The transformational change towards a decentralised, digitised, decarbonised and democratised energy system in the UK is dramatically altering the Distribution Network Operator's (DNO) current role and capabilities, transitioning from being a traditional network operator to a Distribution System Operator (DSO) [1], [2].

In this low carbon future, the power system operator in Northern Ireland and Ireland has put in place the 'Delivering a Secure Sustainable Electricity System (DS3)' programme to ensure the secure, safe operation of their network [3]. The DS3 programme has identified the need for integrating additional System Services in the Single Electricity Market (SEM) to operate the electricity system securely whilst achieving the renewable energy policy objectives.

System Operator for Northern Ireland (SONI) and EirGrid (forming the Single Electricity Market Operator (SEMO)) have licence and statutory obligations to ensure sufficient System Services are available to enable the continuous balancing of electricity supply and demand guaranteeing the stability and security of the electricity system [4]. System Services are used to ensure that the network frequency remains within acceptable limits during system events.

Traditionally, System Services have almost exclusively been provided by large-scale generation that are connected to the transmission system. However, over the past few years, there has been a significant increase in the uptake of distributed energy resources (DERs) connecting to electricity distribution networks, displacing transmission-connected generation. DERs therefore, could supply an increasing proportion of whole system support services in the future. It is incumbent on NIE Networks as the relevant licence holder to ensure that the safety, security and quality of supply for all customers is not adversely affected through the provision of System Services. In addition, DSOs will also need to be conscious of some DER stakeholder expectations that the distribution network does not prevent DERs delivering System Services. This work explores how strongly these requirements conflict.

This paper investigates the influence upon network capacity to host System Services, within NIE Networks' electricity distribution system. This analysis quantifies the capacity for System Services that is likely to be available within NIE Networks. The results are then used to provide commentary on key influences of hosting System Services on distribution networks and how they may interact with the future vision of a DSO. In addition, the network management systems and procedures that a DSO may need in order to meet the stakeholder's expectations are also discussed.

METHODOLOGY

Test network

For this analysis, diverse network groups were defined with comprehensive criteria that constitute the best fit to real feeders that are representative of those in the NIE Networks' licence area. For example, the selection criteria were based on electrical (33 kV and 11 kV networks) and geographical attributes (e.g. rural, urban, etc.). Seven networks were selected as shown in Table 1. These networks were modelled using the IPSA power flow analysis package to study the impact caused by the operation of DER in the delivery of System Services at new and existing customer premises.

Table 1: List of network types used in this study

Network Type	Description
33 kV Semi-Urban network	33 kV Bulk Supply Points (BSP) with 5 33/11 kV primary substations and five 33 kV DGs
33 kV Urban network	33 kV BSP with 15 33/11 kV primary substations and no 33 kV connected generators
33 kV Cluster network	Cluster substation[1] with 5 wind farms
11 kV Urban feeder	11 kV Feeder urban areas with small scale DG (Medium penetration)
11 kV Rural feeder	Rural 11 kV feeder with small scale DG (High penetration)
11 kV Commercial feeder	11 kV Feeder urban areas with small scale DG (Low penetration)
11 kV Semi-Rural feeder	Rural 11 kV feeder with small scale DG (High penetration)

System Services

This work considers the impact of seven System Service products available to balance the system, including Fast Frequency Response (FFR), Primary Operating Reserve (POR), Secondary Operating Reserve (SOR), Tertiary Operating Reserve 1 (TOR1), Tertiary Operating Reserve 2 (TOR2), Replacement Reserve Desynchronised (RRD), Replacement Reserve Synchronised (RRS). Figure 1 illustrates how these different DS3 service products would deliver their response at different stages of frequency restoration. The DS3 arrangements are technology agnostic since an array of different technologies (i.e. Battery, Demand Side Response, Synchronous machine) can tender for System Services. Therefore, provision of these services is permitted from static and dynamic providers alike.

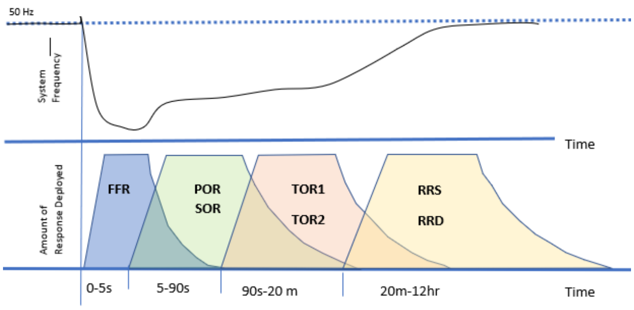

Figure 1 Deployment of response during event [4]

Network Limits

In order to determine the limit of System Services that could be accommodated in a network group; a set of rules were defined based on requirements for NIE Networks to maintain acceptable standards of steady state voltage, voltage step parameters and network loading [5]. The limits were defined based on the respective governing standards/ recommendation such as The Electricity Safety, Quality and Continuity Regulations (NI) [6] and Engineering Recommendation P28/2 [7].

The following analysis rules are used for the DS3 System Service allocation analysis.

1. Steady state voltage must remain within statutory limits.
2. Step changes in voltage must remain within P28/2 limits.
3. Absolute voltage must not exceed 1.1 per unit of nominal (Overvoltage setting of interface protection relays to prevented widespread tripping of DG due to a voltage excursion).
4. Steady State circuit rating values must be respected always (can be applied indefinitely, but changes depending on the season).

Analysis Approach

The hosting capability was investigated by quantifying the available capacity of System Services on the representative networks. Their threshold capacities were defined before either loading or voltage quality problems were observed within the selected network groups. A balanced load flow model was used to study the network under discrete number of snapshots of scenarios of generator output and electrical demand consumption.

A script was developed that would automatically test the quantity of System Services on each load flow model. The goal of the script was to iteratively calculate the total quantity of different DS3 System Services that can be allocated in each network, while considering all other nodes and respecting system limits.

The starting point in using the script requires the user to nominate the nodes which should have capacity checked and the nodes and circuits within the network that should be monitored. The script runs a base case load flow to capture network loading and voltages before System Services are applied. The capacity of the network to host System Services is then tested.

For 33 kV networks, generator exports are not always at their maximum export capacity (MEC). This may be through, for example, low wind speeds, low solar irradiance or through constrained output. Generators were therefore simulated at 0%, 20%, 40%, 60%, 80% and 100% of MEC to understand the impact that different pre-event generation levels may have on hosting System Services. These intervals are referred as “Pre-event generation level” in this paper. System Services are added incrementally onto registered generation in the group such that the amount of System Service allocated are in proportion to the MEC of the generator. The output from each generator was no allowed to exceed its MEC.

For 11 kV networks the export from all service providers are increased at simultaneous and equal steps until network load flows are observed to have reached their limits. The values are recorded for each of the limits.

This investigation considered the network capacity available during normal system operation (NSO) and one first circuit outage (N-1) condition on NIE Networks’ system across several electrical consumption scenarios. The methodology used was limited to studying one common (N-1) outage which was the outage of a main transformer at the source BSP.

1 A 110/33kV substation with only generation connected.

SIMULATION RESULTS

The simulation results are analyzed under two categories. These limits show the total amount of system services that can be allocated, assuming that only one service type is delivered at a time.

33 kV Networks

The available capacity to host System Services in the 33 kV Urban, Semi-Urban and Cluster network groups were investigated. The results were used to determine the variability of capacity and the key influences. The amount of capacity available in each network under different snapshot of electrical consumption and under outage conditions are summarised in Figure 2.

This analysis has shown that the most common network parameters which limit the quantity of System Services are either the exceedance of steady state voltage limit or the exceedance of a step change limit in voltage. In the case of the Cluster network, with increase of pre-event generation, the limiting factor changed from steady state voltage limit to a voltage step change limit.

The results showed that the effect of transitioning from a system under NSO arrangements to the N-1 system with a 110/33 kV outage had a significant effect on the available system capacity. There are likely to be other factors such as electrical demand consumption or reactive power instructions to generations that may also influence the capacity for services in the N-1 condition. Therefore, it is expected that outages of 33 kV circuits can result in system access restrictions that are even tighter.

The study of the effect of prevailing generation output upon the capacity to host System Services indicated that the pre-event generation level is not always the most influential driver of capacity. It was also observed that the prevailing network electrical consumption or reactive power instructions to generation can be just as influential.

The effect of the pre-event generation level upon capacity to host System Services was not always linear. This means that in any operational context a full network model will be required to assess network capacity for System Services and the use of fixed lookup tables or linear approximations would be likely to restrict system access unduly.

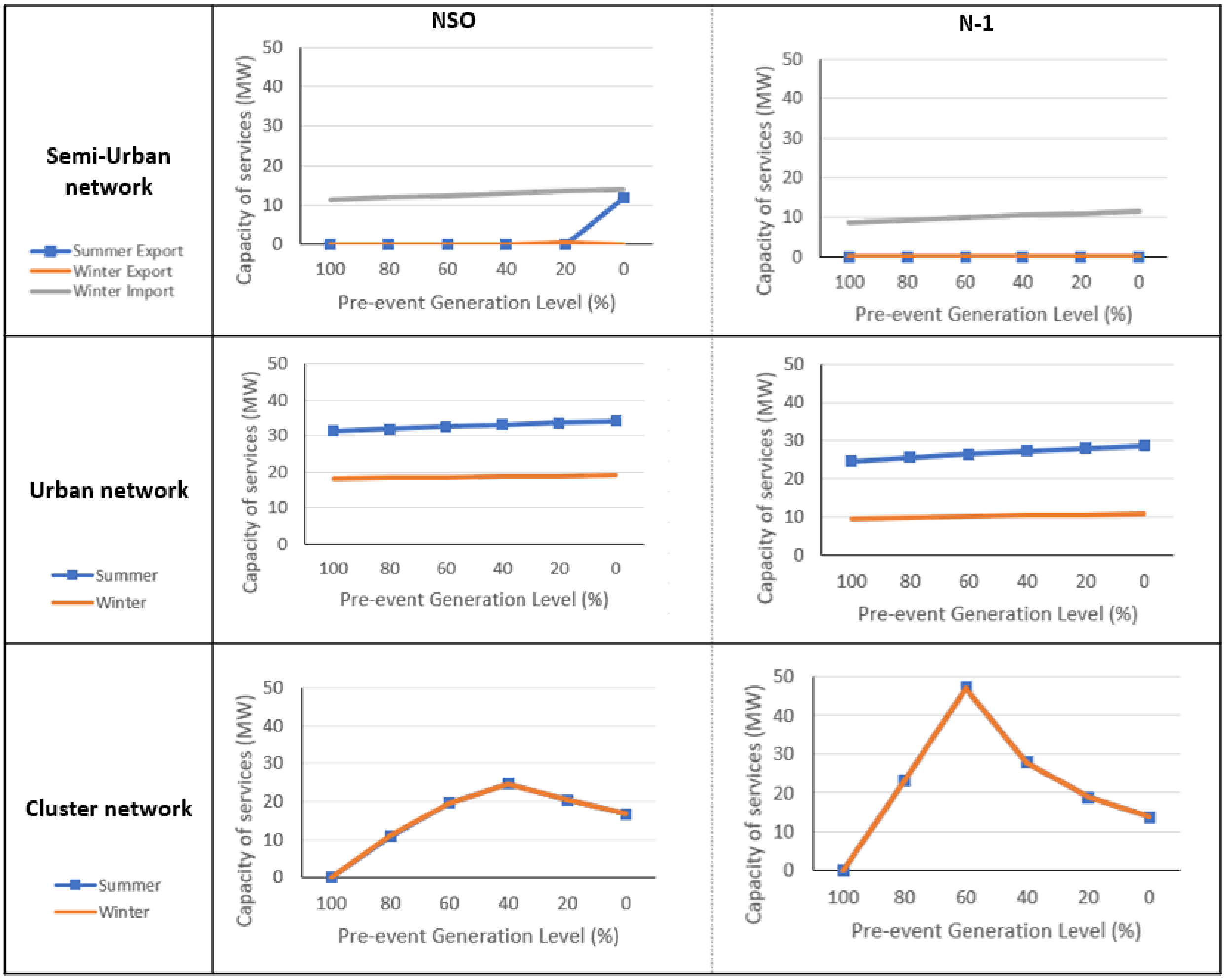

Figure 2 Overview of System Service allocation capacity for 33 kV Networks

11 kV Feeders

The behaviour of 11 kV networks (MV distribution feeder) regarding hosting System Services is different from the 33 kV networks because of the radial nature of 11 kV feeders. In the case of an outage on 11 kV feeders, unlike 33 kV networks there may not be an alternative meshed path for the power to flow and the entire feeder is rendered disconnected. For this reason, N-1 analysis results are not considered. Figure 3 illustrates the overview of System Service allocation capacity for 11 kV networks during different seasons.

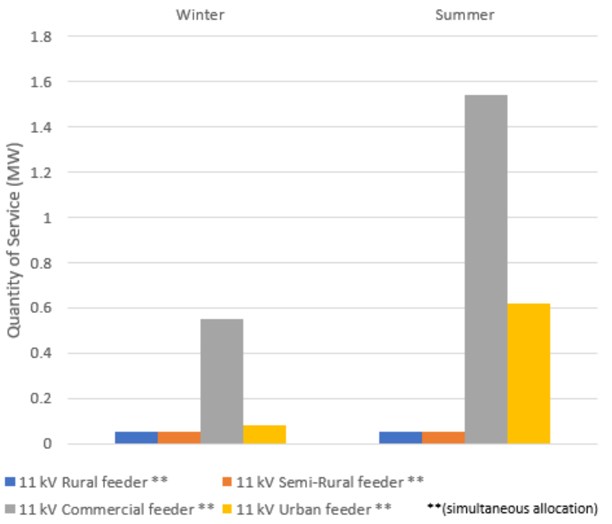

Figure 3 Overview System Service allocation capacity for 11 kV Networks

In general, the sparsely populated 11 kV feeders which connected large numbers of customers over a long distance demonstrated that the main barriers to connection of System Services was voltage related whereas 11 kV feeders that are more tightly packed began to show thermal loading problems instead of voltage problems.

The Commercial and Urban 11 kV feeders both show a capacity to host System Services whereas the Rural 11 kV feeders show a minimal to zero capacity to accommodate new System Services. This was because these feeders had generation connected to them which had consumed the existing capacity. However, both Commercial and Urban 11 kV feeders showed a pattern of being able to offer greater capacity to host System Services during the summer. This is expected considering the power consumption in the UK is at a minimum during the summer period which would result in higher voltage and greater reverse power flow.

It was observed that there may be opportunity to host System Services in urban areas but deployment of services in rural areas may encounter barriers from the need to maintain an acceptable voltage profile. In some cases, use of short-term ratings may help overcome some network restrictions at 11 kV and improve system access.

DISCUSSION

33kV and 11kV networks were studied in this paper as these are likely to be the networks to which the early adopters of system services will be connected (larger energy users, producers); however, it is acknowledged that additional analysis will need to be performed on the LV network to assess the impact of LV connected system service providers.

This paper developed a view that across existing 33 kV and 33/11 kV networks the capacity to host System Services is finite and variable and influenced by a number of factors. The factors which influence the available capacity include:

1. Network topology, electrical characteristics, configuration of the network and circuits which are available and on load. Outages, both planned and unplanned (faults), on different circuits will have varying effects upon the available capacity for each customer.
2. The quantity of electrical power being consumed, which changes over daily and seasonal cycles on a minute to minute basis.
3. The quantity of power being exported by local generators. Some generators will be able to control how much power and when to export. Whereas others, such as wind turbines will export power in accordance with the wind resource and hence will infrequently export at 100% of rated capacity.

Opportunities in the DSO future

The analysis was carried out on candidate distribution network groups within NIE Networks' licence area. There could be a number of more specific differences such as structural, geographical, size, voltage levels and penetration of DERs across other licence areas.

Based on the results, some key influences and possible interaction with the future vision of a DSO are noted. This analysis highlighted some opportunities to optimize the capacity to host System Services through DSO functions. They are as follows:

1. Network visibility: Capacity to host System Services (particularly radial feeders) will change depending on its feeding path. It is conventional practice for Network Operators, to rely upon manually updated records to show which feeding path a System Service provider is connected to (at both MV and LV levels). This means that instruction sets which regulates System Services may need to be conscious of when an LV or MV feeder changes from NSO conditions to N-1 conditions. At present the network operators take an approach which limits system access based on the worst view from NSO and N-1 conditions. Network visibility is a key aspect of future DSO models that could substantially improve performance of the networks such as safety, quality and security

of supply parameters.

2. Active network management: The capacity to host System Services is strongly coupled with the outage planning and network management processes. It might not be possible to allow all generators to pro-rata the available capacity for each outage condition as they might have to be part loaded as a precaution against overloads during the local 33 kV outage. Furthermore, the network limits are strongly influenced by reactive power instructions sent to generators and the minute by minute network demand. At present, it would be feasible to manage using fixed look up tables, at least during NSO conditions but going forward, such an approach may prove to restrict system access.

   In the DSO future, the network operator may choose to enhance their Network Management System to develop capability that allows rapid reassignment of the network's capacity to host System Services. The availability of real time information, in terms of network status, where services are allocated, what quantity, type of System Services allocated and when it is required can allow real time power flow analysis. This allows updating of network limits based on prevailing network conditions and/or in the event of network changes since capacity is sensitive to outages. An active network management approach is more onerous on the network infrastructure, due to the diversity of loads and generation and also their probability of operation. However, it allows coordinated dispatch of System Services through dynamic instruction, potentially delivering greater ability to host System Services when compared with the current passive approach. An active network management, approach, although expensive, could offer greater benefits in the long run in terms of better network access to DERs and optimum utilization of existing assets.

CONCLUSION

This paper has provided an insight into the likely capability of NIE Networks' electricity distribution system to host System Services at new and existing customer premises and from a range of technologies. Simulations were carried out on seven candidate networks, to quantify the hosting capability available for each service. Limiting factor(s) were determined for the networks across a number of different scenarios of generation output and electrical demand/consumption. Capacity to host System Services becomes limited when their deployment would result in unacceptable voltage quality or loading of circuits outside of capability.

The results from this analysis has shown that capacity to host System Services within 33 kV and 11 kV network groups is finite and variable and, in some cases, has nonlinear relationships with key influences. It was observed that passive methods to assess network capacity and manage DERs are likely to unduly restrict system access and the non-linear relationships and the potential magnitude of the System Services market will make it extremely difficult to continue with the current passive approach. The results for this study advocate an evolution to a more active network using improved network visibility, real time data and active network management systems to determine the available capacity to host System Services. Therefore, evolving to a DSO could offer greater network access and allow better utilization of existing assets.

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