THE FUTURE OF FLOOD RESILIENCE FOR ELECTRICITY DISTRIBUTION INFRASTRUCTURE IN GREAT BRITAIN (GB)

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ABSTRACT

This paper explores the journey that GB Distribution Network Operators (DNOs) have made over the past 15 years to improve the resilience of their networks to the risks of flooding. It uses case studies from the exceptional flooding events in the north of England in December 2015 to show where those measures have been successful and where further work is needed. It proposes how the lessons learnt from these incidents can be built into future resilience planning and policy on a national level with government and local stakeholders.

INTRODUCTION

Distribution networks form a critical part of the electricity infrastructure providing the link between the transmission network and end customers; both demand and generation. Northern Powergrid and Electricity North West Limited operate the distribution networks in the north of England.

The assets managed by DNOs range in size from major grid substations, where electricity enters the networks to the individual service points in customers' premises, with a wide variety of equipment in between. Ensuring that this equipment is available to transport electricity in a reliable manner to and from customers is the main priority of network companies and has involved appraisal of the options to improve overall resilience to extreme events such as flooding, ie Removal, Resistance, Redundancy & Response.

Studies [1] following recent flooding incidents have highlighted the increasing societal value of a resilient electricity supply to maintain communications and other essential services. The increasing number of flooding events that we have seen in GB since the turn of the century provide a challenge to this resilience and raise questions as to how customer and public interest is best identified and served.

Development of a consistent approach

Over the last 15 years, the industry has worked collaboratively to develop policy to invest in defending key assets to protect them from damage and loss of power to customers for extended periods of time resulting from flood events.

The timeline of development is as follows:

- 2000 – severe flooding experienced in the north of England prompting the start of flood risk assessment by DNOs
- 2007 – following major flooding across the UK, over half a million people were without water or mains electricity
- 2008 – Sir Michael Pitt publishes an extensive review of the lessons to be learned from the floods
- 2009 – working with the Pitt Review team, the Energy Networks Association publish Engineering Technical Report (ETR) 138 – Resilience to Flooding of Grid and Primary Substations

ETR138 [2] defined a formal approach to risk assessment and flood defence investment and the approach to prioritization of investment was agreed on a national basis with regulators and government agencies.

Applying this approach, DNOs invested more than £73m in flood protection measures in the five years from 2010 to 2015, primarily at EHV and 132kV substations. This investment has been focused on improving the Resistance of the assets to flood events and has generally been on hard defences such as increasing the height of perimeter walls, raising plant and installing flood proof doors, but has also included purchase of pumps and other mobile defences.

In their business plans for the RIIO-ED1 price control period, DNOs identified a further £100 million to be spent between 2015 and 2023. This was advised by updated Flood Risk Assessments based on revised flood risk data from the Environment Agency, but is subject to review based on the learning from the 2015 flood events.

The unprecedented severe storms of December 2015, particularly Storms Desmond and Eva, provided a stringent test of these flood defence measures, but also raised the question as to whether resilience strategies were overly focused on strategic assets.

Whilst the deterministic method of addressing flood risk has largely been successful in improving asset Resistance to extreme events, recent events have shown that infrastructure operators need to move to a more probabilistic methodology which also looks at asset Redundancy, ie not just at the risk of flooding at each major substation, but also at the consequences of flooding and also to consider local impacts on smaller assets that customers rely on.

STORMS DESMOND AND EVA

Storm Desmond hit the UK in the first week of December 2015. The rainfall levels exceeded previous 24 and 48 hour national records, with more than 300mm falling in some locations.

As the rain was falling on already saturated ground, it caused rivers to 'flash' with river levels spiking beyond previously recorded levels.

Storm Eva followed on Saturday 26 December 2015, again causing extensive flooding over a different geographical area (Figure 1).

Figure 1 - Hebden Bridge, Calderdale during Storm Eva

In both events Environment Agency (EA) alerts warned that a large number of operational electricity substations across the north of England were in danger of flooding. A significant number were subject to Severe Warnings indicating a danger to life.

The floods posed a range of challenges to DNO infrastructure and customers, and tested company Response strategies.

Substations where most customers are not flooded

Prior to Storm Desmond it had largely been assumed that if a substation was flooded then customers supplied from that substation would generally also be flooded.

The flooding incident at Lancaster proved otherwise as most of the customers connected to the substation remained 'dry'. Severe flooding of the River Lune during Storm Desmond caused defences to be overtopped at Lancaster 132kV Grid substation, and on Saturday 5 December the decision was taken to switch off supplies to 60,987 customers, who had not been subject to the same level of flooding.

Because of its location on the network it was not possible to restore these customers from neighbouring circuits, so 75 large mobile generators were brought into the city and connected to the network restoring power to 22,000 customers. These generators constituted a substantial proportion of the large mobile generators that were available in the UK and Ireland at the time. If a similar incident had occurred elsewhere at the same time then their customers would have spent significantly longer periods off supply.

Supplies to most customers were restored on Monday 7 December, but unfortunately a further fault on a busbar caused supplies to be lost again to 45,525 of those customers. Supplies were restored successively to these customers with the final restoration on Tuesday 8 December. At this point, the generators began to be progressively withdrawn, three days after their initial connection.

At Kirkstall C 132kV substation (Figure 2) in North Leeds, the defences were overtopped during Storm Eva when the River Aire burst its banks. Very few local customer properties were affected by flood waters, however supplies to over 27,000 customers in the nearby Leeds Central Business District were lost. Supplies were restored in less than three hours which was only possible due to the level of electrical interconnection on that part of the network, a valuable lesson that alongside physical defences, network interconnection is one of the most valuable means of ensuring resilience.

Figure 2 - Flooding at Kirkstall C substation in North Leeds

By contrast in the centre of York, the defences of two major substations supplying the city successfully held back the floodwaters but had either of these sites been lost the restoration time for customers would have been longer due to the more limited interconnection.

Substations where significant customers are also flooded

Most substations were able to withstand the challenges posed by Storms Desmond and Eva, either because the existing defences were sufficient, because effective temporary defences were added or pumping was used to remove water from the affected area.

However because of the severity of the floods, there were incidents where substations were flooded at Willowholme, Calderdale, Leeds, York and Rochdale. In all these cases a large number of properties in the surrounding area were also flooded.

All these events had their own specific features, but the response followed a common pattern in line with standard emergency plans:

1. De-energise the flooded areas to safeguard the emergency and rescue services staff from electrocution.
2. As substation water levels fall, clean equipment to remove water contamination and repair where necessary.
3. Enter customers' properties to inspect and replace service terminations. This is undertaken in conjunction with suppliers to enable metering equipment to be changed at the same time.
4. Once all customers' properties in the area are safe, re-energise supplies by LV feeder area.

This approach was shown to work effectively in each case, particularly where effective co-ordination between suppliers was in place.

Damage to other types of assets

As well as substations, damage was incurred on other types of assets, with differing results.

- In Storm Eva, two cable bridges, each carrying two HV circuits across the River Irwell were severely damaged and both required replacement. The Milltown Street Bridge suffered severe damage and was unstable, but was still carrying a live 11kV circuit and a damaged 6.6kV circuit. Lomax Street was a pedestrian footway, carrying two 6.6kV cables, which was completely washed away.
- Tadcaster Bridge partially collapsed which contained live 11kV cables that had to be urgently isolated (Figure 3).
- In Halifax, two bridges collapsed containing 33kV and 11kV cables that also had to be isolated.

Figure 3 - Damage to Tadcaster Bridge

Also affected by the increased flow of water on the River Irwell were the foundations of an overhead tower structure which had previously stood on dry land but was now located partially in the river (Figure 4).

Figure 4 - foot of tower 132kV following movement of river

The tower remained stable, but if it had failed power would have been lost to 64,339 customers fed from Bury Grid.

RESPONSE TO STORMS

Customer support and reaction

Following a national review into the way DNOs managed the consequences of the series of wind storms and floods that affected large parts of Southern England in 2013, significant improvements had been implemented in customer support and Desmond and Eva demonstrated their effectiveness. DNOs adopted a pro-active media and social media strategy which proved to be highly effective with customers very satisfied with the response. Sentiment expressed by customers engaging with Electricity North West via social media during Storm

Desmond was over 75% positive, with only 4% negative comments.

Preparedness

As the electricity network companies had been working on flood resilience since 2000, there are agreed plans in place to improve resilience and respond to incidents largely through the implementation of defences in line with ETR138.

In its 'National Flood Resilience Review' of September 2016 [3] the UK government required that "the water and telecoms sectors will develop and implement plans for temporary improvements to resilience in line with those already available in the electricity supply industry", which is a strong endorsement of the work that has been done.

These plans stood the industry in good stead during the floods ensuring that the majority of substations withstood the flooding risk.

Working with other agencies

During each incident the communication and co-operation with other agencies such as the police, fire service and army was vital to a successful outcome. This co-ordinated response to civil emergencies is planned through Local Resilience Forums across the country.

Depending on the severity of the event, local incident centres are established and the emergency response agencies work together through a gold-silver-bronze command structure. DNOs play a key role in these command structures, liaising with the other agencies to ensure that best use is made of all resources.

DNOs also utilise a mutual aid arrangement (NEWSAC) which facilitates the transfer of staff and other resources between companies to support response to localised emergencies.

LESSONS LEARNED

Following the Lancaster flooding event, the Royal Academy of Engineering published a report "Living without electricity - One city's experience of coping with loss of power" [1], which brought together many valuable insights into the vital role that electricity plays in society today.

The importance of electricity in supporting other utility companies is apparent from the report. Gas supplies, phones, sewage and transport are all reliant to varying degrees on a reliable electricity supply.

The report describes how society has become increasingly reliant on electronic communications, through the internet and Wi-Fi, such as

> *"doctors replacing paper files by computer systems, a government department ceasing production of hard-copy leaflets and moving to online information systems or the banks phasing out cheque books and introducing contactless cards"*

Each of these individual actions changes the risk profile of society as a whole. If the power network was less reliable consumers may choose to invest in their own resilience measures, but this cannot be justified with current frequency of outages.

The paper also questioned the Value of Lost Load (VoLL) measure which is a figure designed to indicate how much an individual customer in GB is willing to pay to avoid an outage. Experience at Lancaster and in other situations suggests that rather than being a single figure, VoLL may be different for different groups of consumers. This is an area of ongoing research for the industry.

The level of network redundancy in North Leeds in Yorkshire meant that although Kirkstall C 132kV substation was partially flooded, reconfiguration of the network enabled all supplies to be restored in three hours with the repair to damaged equipment carried out once the flood waters subsided. This experience demonstrates the benefits of both hard flood defences (where part of the substation sat above flood water) and importantly, network resilience. This level of interconnection was not available at Lancaster or in the centre of York and the impact of the event at Lancaster 132kV Grid substation demonstrates that physical defences alone are only part of the solution to mitigate the risk of extended loss of supplies.

PLANNING FOR THE LONGER TERM

Valuing the impact of floods

As regulated monopolies, DNOs must agree their expenditure plans with Ofgem, the economic regulator, and from these plans the allowed revenue is agreed.

Historically DNOs have assessed their programmes of flood mitigation against the direct benefits of avoided repair cost and the impact on customer service incentives.

Following the storms there is a greater awareness of the impact on society at large of a major loss of electricity supply, so at the next price control review DNOs will be discussing with Ofgem how this will be valued in investment decisions. DNOs already consider the Cost of Carbon in investment appraisals, so it should be possible to include the impact on the wellbeing of society in future assessments given this is a critical aspect of flooding events.

Figure 5 illustrates a possible hierarchy of factors to be included in such an assessment.

Figure 5 – increasing range of impacts to be considered

Associated with this is a need to look at how spending can be prioritised for the overall public benefit, when customer willingness-to-pay surveys may not support the required levels of investment.

Planning standards

Increased frequency and severity of floods was the main risk identified by DNOs in their Climate Change Adaptation Reports, and ETR138 had been updated in 2015 to reflect the potentially higher flooding levels in the latest climate predictions. It was also expanded to set protection requirements for surface water flooding and dam bursts.

As noted in the National Flood Resilience Review (NFRR), DNOs and other infrastructure owners have always prioritised the security of supply to sites of Critical National Infrastructure. Following the 2015 floods and subsequent publication of the NFRR, the electricity network companies are in the process of further updating ETR138 to consider enhancing the protection provided to primary substations supplying more than 10,000 customers. These are considered as 'key local infrastructure' within the NFRR.

It is often uneconomic to remove the risk of flooding entirely so future developments in flood resilience, both nationally and within companies, are likely to develop the deterministic approach set out in ETR138 to a more holistic approach of managing the risk to the whole network. This will focus on the consequences of the failure of any asset and may include a wider definition of benefits in future investment appraisal.

Locally Significant Infrastructure

In addition to 'key local infrastructure', the floods have shown that DNOs also need to be aware of 'locally significant' infrastructure.

An example of this is the network supplying the village of Patterdale in the Lake District.

Patterdale is a small village in the Ullswater valley with a population of around 500 people. During Storm Desmond Glenridding Beck burst its banks and the village was flooded with the main road between Glenridding and Patterdale being underwater for three days, so the village was effectively cut off with no phone lines, no mains water and intermittent power.

It is arguable that the electricity supply in this type of community is more critical than for more urban, better connected communities, so DNOs will need to develop a way of valuing the criticality of these sites to ensure that appropriate levels of protection are provided.

Interdependencies

The Lancaster incident showed the vital role that electricity has in powering other utilities, so electricity companies need to work with other infrastructure providers to ensure that a reliable supply is in place. This is likely to require discussions with the various economic regulators to identify a suitable level of resilience and how society as a whole should pay for the benefits this brings.

The other area identified for improved co-operation is for organisations to work together to co-ordinate resilience plans. The National Flood Resilience Review notes that:

> *The Government has also agreed with the utilities that we will work together to improve the mechanisms for cooperation and information sharing between the Government (e.g. Met Office and Environment Agency flood forecasts) and infrastructure operators on resilience, both in relation to flooding and more broadly*

Through the adoption of a co-ordinated approach, infrastructure providers will be able to develop mutually beneficial schemes, reducing the overall cost and increasing the benefits to society as a whole.

REFERENCES

[1] Royal Academy of Engineering, 2016, *Living without electricity - One city's experience of coping with loss of power*

[2] Energy Networks Association, *Engineering Technical Report (ETR) 138 – Resilience to Flooding of Grid and Primary Substations*

[3] HM Government, 2016, *National Flood Resilience Review*