SP Energy Networks 2015–2023 Business Plan

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Annex

Assessment of Overhead Line Performance During Severe Storms

EA Technology

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SP ENERGY NETWORKS

CONFIDENTIAL REPORT

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Assessment of Overhead Line Performance during severe storms

Author:
Andrew J McHarrie

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www.eatechnology.com

Delivering Innovation in Power Engineering

Project No: 82880

Assessment of Overhead Line Performance during severe storms

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EA Technology Limited, Capenhurst Technology Park, Capenhurst, Chester, CH1 6ES; Tel: 0151 339 4181 Fax: 0151 347 2404
http://www.eatechnology.com
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Summary

This document is an asset performance review of Scottish Power's Scottish network during the storms of December 2011 and January 2012. It evaluates the four storms of this period and compares them against the storm event of the 26th December 1998. The report concludes that the storm event of the 3rd January 2012 was the most similar to the storm event of 26th December 1998.

The comparison of the two storms allows the Scottish network's performance to be evaluated since the introduction of Scottish Power Energy Network's (SPEN) improvement policies post 1998. The Storm event of 2012 saw a total reduction of all faults of 87% over the 1998 event.

Whilst the storm event of 2012 is deemed to be comparable with the storm event of 1998 the main differences were:

- Dumfries had proportionally less faults in 2012 and central and Fife had proportionally more when compared to 1998. This observation could suggest that the 2012 storm's trajectory was slightly higher than that of 1998.
- The storm event of 2012 made a quicker impact on the network than 1998; however the maximum number of customers without supply was reduced by 18% compared to 1998. The 2012 storm clear up phase was also 39% quicker than 1998.
- The CML result for the storm event of 2012 was 64% lower than 1998, and the CI result was 48% lower.

The major cause of damage during the 1998 storm event was attributed to trees at 85%. During the storm event of 2012 only 61% of the damage faults were attributed to trees. It is known that a number of trees fell during the 2012 storm that had previously been assessed as healthy. The failure of these trees is suspected to be primarily due to the combination of excessive winds and saturated ground due to abnormally high rainfall (Figure 19).

The upgrading of OHLs and the carrying out of tree clearance to ENA TS 43-8 and ENA ETR 132 has had an impact on the amount of faults over the duration of a comparable storm event. The upgrading of OHLs and the frequency of tree clearance should be continued as per SPEN's current strategy, with the exception of spur lines with large numbers of connected customers, which should also be considered for inclusion into the improvement program.

It was found that the L10 Overhead Line (OHL) construction performed well during the 2012 storm event; therefore an assessment should be carried out into whether the L10 construction could be utilised within the current severe weather areas, thus allowing more OHL circuits to be rebuilt at a lower cost.

Further work should also be undertaken to refine the severe weather map for SPEN's Scottish network. The STP2[1] project S2641 is undertaking work to develop new wind/ice load maps, which are expected to be less onerous than those in ENA TS 43-40. The refinement of the severe weather map could also more accurately target the correct construction for the environment.

Consideration should be given into an insulated conductor construction, as a targeted solution for poorly performing circuits; or ones that are experiencing difficulties in obtaining permissions for a re-build and/or ETR 132 compliance.

No trees fell on any of SPEN's re-built OHLs, which are constructed to ETR 132. This would suggest that ETR 132 should be considered on a wider basis than re-build circuits. For circuits that will struggle to achieve ETR 132 compliance, consideration should also be given into declaring a percentage of the line as ETR 132 compliant; or dividing the circuit with ABS switches either side of the anomoly and declaring either side as ETR 132 compliant and the middle as non-compliant.

Pole condition should be added to the AIS inspections, as this will reduce the amount of poles that need re-testing plus it will give a better understanding of the Health of the pole asset class. As Ofgem move into the next price review (RIIO ED1) greater emphasis will be placed on a risk-removed output measure for asset classes. DNOs will be required to take a holistic risk-based approach to asset management, by reporting the risk of an asset class at the beginning of the ED1 price review and, with investment, its risk will be at the end of ED1. The important outcome at the end of the RIIO ED1 price review will be the Health and subsequent risk of an asset class rather than how many kilometers of line were re-built. Risk management processes like EA Technology's CBRM (Condition Based Risk Management) process can evaluate the risk of an asset class through age, environment, probability of failure and criticality, however it is much more accurate if condition data is also supplied.

Major investment is required in the upgrading of LV open wire constructions to ABC, the LV network was identified in the Boxing Day storm review report **[1]** as being in need of refurbishment after the storm event of 1998. The investment will help reduce the amount of LV faults during storm events plus it will drastically reduce the clear up duration and non-planned CMLs, as the majority of the time identified on the customer interuption graph, was due to LV circuits with low numbers of connected customers. Consideration should also be given to renewing the first LV poles from OHL substations and replacing the first span with ABC conductor during HV refurbishment. This should reduce the number of LV faults that escalate into HV faults, plus it will reduce the need for subsequent HV shutdowns during LV refurbishment, which in turn will help reduce 'Planned CIs'.

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[1] SPEN is a member company of STP2 and as such will receive a copy of the findings from the S2641 project.

Contents

1 Introduction

EA Technology was requested by Scottish Power Energy Networks (SPEN) to undertake an assessment of the performance of their Overhead Line Network in Scotland, during the severe weather storms of late December 2011 and early January 2012. The objective of this work is to determine if the Overhead Line Network investment undertaken since year 2000 has improved its reliability and resilience to severe storms.

To facilitate the objective the scope of the project was to:

1. Contrast and compare the OHL asset performance with previous storm events;

2. Identify potential asset performance improvements;

3. Make recommendations for performance Improvement.

SPEN's Overhead line network experienced a major storm event on the 26th December 1998 and as a result of the subsequent panel of inquiry, a number of policies were introduced that were designed to increase the network's resilience. The panel of enquiry's report **[1]** concluded that the major cause of storm related damage during the storm event was related to trees either falling or interfering with overhead lines.

The panel of inquiry assessed what and where Scottish Power could have done better, and proposed that lessons learnt, would improve how Scottish Power work and what they will do if a similar situation arises again.

The main areas of improvement were split into four categories:

1. Investment in the call centre to increase the number of calls it can handle.
2. Improve the processes and systems that are used to monitor and control the network and to restore supplies.
3. A more rigorous policy for making sure there are no trees near strategic power lines.
4. Strengthen the network in appropriate areas.

This document sets out to determine the effect on the network during a major storm event, of categories 3 and 4 since the storm event of 1998. A separate evaluation is currently being carried out to assess the operational performance during the recent storms; therefore category 1 and 2 will be covered in this report.

The 'Rural Care' policy was introduced in 1999, which set out to clear vegetation below and within falling distance of strategic or poorly performing overhead line circuits. This policy was updated in 2002 by introducing low and high risk zones. The low risk zone required a 2 metre clearance to be maintained from low risk vegetation, whilst the high risk zone required clearance of falling distance for high risk trees.

March 2006 saw the introduction of a risk based vegetation management methodology ETR132 **[2]** by the Energy Networks Association (ENA), SPEN currently strives to achieve compliance with ETR132 on all of its overhead line rebuild projects.

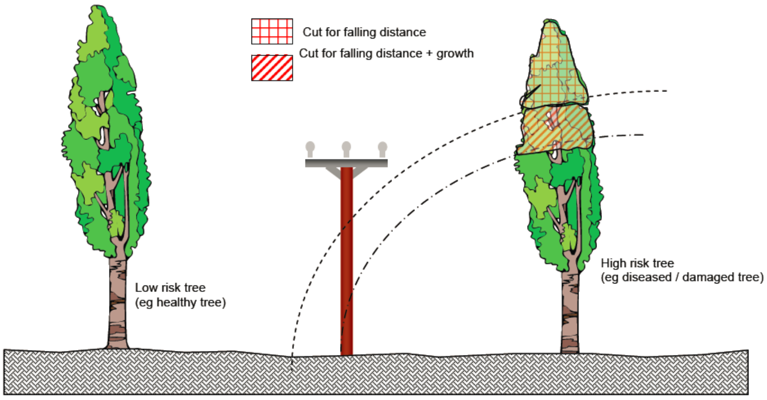


Figure 1 – Example of a Resilient Clearance (Source: ETR132 [2])

SPEN also implemented OHL-01-008 **[3]** in 2002; this set out to improve network resilience by introducing a number of overhead line standards that were more robust and therefore more resilient than older standards such as BS1320 **[4]**. A new heavy construction standard (L27) was created for HV overhead lines that were deemed to be within a severe weather area.

For clarity, the networks described within this document are as per the definition within ENA ER 43-3 **[5]**. An LV system is one which operates at a nominal voltage up to a 1,000 V; an HV system is one which operates at a nominal voltage in excess of 1000 V but less than 22 kV; an EHV system is one which operates at a nominal voltage equal to or greater than 22 kV, but less than 132kV.

2 Legal Obligations

SPEN are bound by many statutory and regulatory requirements, the following have been identified as being the most pertinent in regards to SPEN's network resilience under storm conditions.

2.1 ESQCR

The Electricity Safety Quality and Continuity Regulations 2002 (ESQCR) came into force on 31st January 2003 **[6]** and was amended in 2006 **[7]** and 2009.

2.1.1 ESQCR 2002 states in Part I, Paragraph 3 - (1)

"Generators, distributors and meter operators shall ensure that their equipment is:

> *(a) sufficient for the purposes for, and the circumstances in which it is used;*
> *and*
> *(b) so constructed, installed, protected (both electrically and mechanically), used and maintained as to prevent danger, interference with or interruption of supply, so far as is reasonably practicable".*

The introduction of the OHL-01-008 **[3]** after the Boxing Day storm of 1998 introduced severe weather constructions to increase network resilience. SPEN in conjunction with the Met office have Identified areas that would be prone to severe weather (see 5.3 Severe Weather Map). The identification of these areas allows SPEN to target, the correct OHL construction for the local conditions and environment, as well as targeting its more costly severe weather constructions more effectively.

2.1.2 ESQCR 2002 states in Part I, Paragraph 5:

"*A generator or distributor shall, so far as is reasonably practicable, inspect his network with sufficient frequency so that he is aware of what action he needs to take so as to ensure compliance with these Regulations and, in the case of his substations and overhead lines, shall maintain for a period of not less than 10 years a record of such an inspection including recommendations arising therefrom".*

The Regulations give no guidance as to the methods or frequency of inspections; however SPEN carry out AIS inspections on its LV and HV networks on a 6 year basis for poles categorised as normal risk. Poles that are deemed to have a raised environmental risk shall be inspected on a more frequent basis of 3 years. SPEN also carries out vegetation inspection every 3 years which would also identify any major defects.

SPEN also carries out aerial inspections on an annual basis for its EHV network.

2.1.3 ESQCR 2006 states in Part VA, Paragraph 20A:

“A generator or distributor shall, so far as is reasonably practicable, ensure that there is no interference with or interruption of supply caused by an insufficient clearance between any of his overhead lines and a tree or other vegetation.”

SPEN carries out vegetation clearance to ENA TS 43-8 **[8]** on a 3 year cycle, every fourth cycle (12 years) all OHLs will undergo tree clearance to ETR 132 **[2]**.

2.1.4 ESQCR 2002 states in Part VII, Paragraph 23(1):

“A distributor shall ensure that his network shall be—

> *(a) so arranged; and*
> *(b) so provided, where necessary, with fuses or automatic switching devices, appropriately located and set,*

as to restrict, so far as is reasonably practicable, the number of consumers affected by any fault in his network.”

SPEN achieve regulation 23(1) by its implementation of its Overhead Line Protection Policy (OHPP) that was introduced in 1993/94 (**6 OHL Protection Policy**).

2.2 DPCR 5

2.2.1 SLC 45

Ofgem’s Regulatory Instruction and Guidance (RIG) SLC 45 ‘Incentive scheme for quality of service’ places obligations on DNOs for reporting on quality of service. SPEN records and archives all of its planned and unplanned outages in it’s PROSPER outage reporting system, which is then uploaded into the National Fault and Interruption Reporting Scheme (NaFIRS). At present SPEN reports the majority of its short interruptions data in bulk (as defined in ENA ER G43-3 **[5]**) due to a majority of it automatic switchgear not possessing any signalling connections to SPEN control centres.

2.2.2 SLC 44A

Ofgem’s RIG SLC 44A ‘Network outputs regime’ places obligations for reporting on network outputs such as CMLs, CI’s and Health Indexes. SPEN complies with SLC 44A through it’s PROSPER and AIS systems.

3 Major Storm Events

3.1 Boxing Day 1998

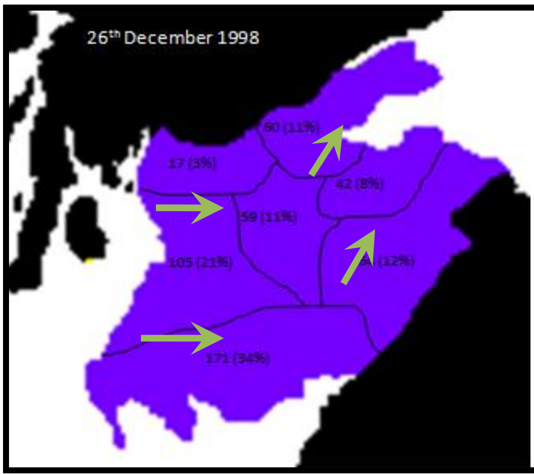
Between the 26th December 1998 and the 4th January 1999 Scottish Power experienced the worst storm event it had encountered in 30 years. The Boxing Day storm, as it became known, was second only to the 1968 'Glasgow hurricane' and covered a large area of southern Scotland.

The storm event resulted in 212,900 customer interruptions and 7,622 faults that were directly related to the storm event. Table 1 illustrates that the total CML score for the 1998 storm event was 94.11 and that the HV network was the largest contributor at 82.04.

Table 1 – CML and CI results for 26/12/1998 storm event

	CML due to the Storm Event			CI due to the Storm Event		
Voltage	**West Scotland**	**East Scotland**	**EN North**	**West Scotland**	**East Scotland**	**EN North**
EHV	8.61	0.1	**8.71**	1.88	0.04	**1.92**
HV	59.01	23.02	**82.04**	5.82	3.34	**9.15**
LV	2.5	0.86	**3.36**	0.22	0.07	**0.29**
Total	**70.12**	**23.99**	**94.11**	**7.91**	**3.45**	**11.36**

Figure 2 displays the main characteristics of the 1998 storm event upon which the initial comparisons will be made to the storm events of 2011/12.



26th December 1998

- Predominantly South West to Westerly winds.
- Maximum recorded gust speed 103mph.
- 17 hour duration at mean wind speed above 30mph.
- 6 hour duration at mean wind speed above 50mph.
- No Snow or Ice accretion.

Figure 2 – Storm event of 26th December 1998 (regions are an indicative representation)

3.2 2011/12 Storm Events

SPEN's Scottish network was subjected to four significant storm events over 27 days from the 8th December 2011 to the 3rd January 2012. The four storm events of 2011/2012 were compared to the Boxing Day storm of 1998 to determine the storm that most closely matched to form the basis of the evaluation. The four storm events of 2011/12 were 8th December 2011; 13th December 2011; 28th December 2011 and 3rd January 2012.

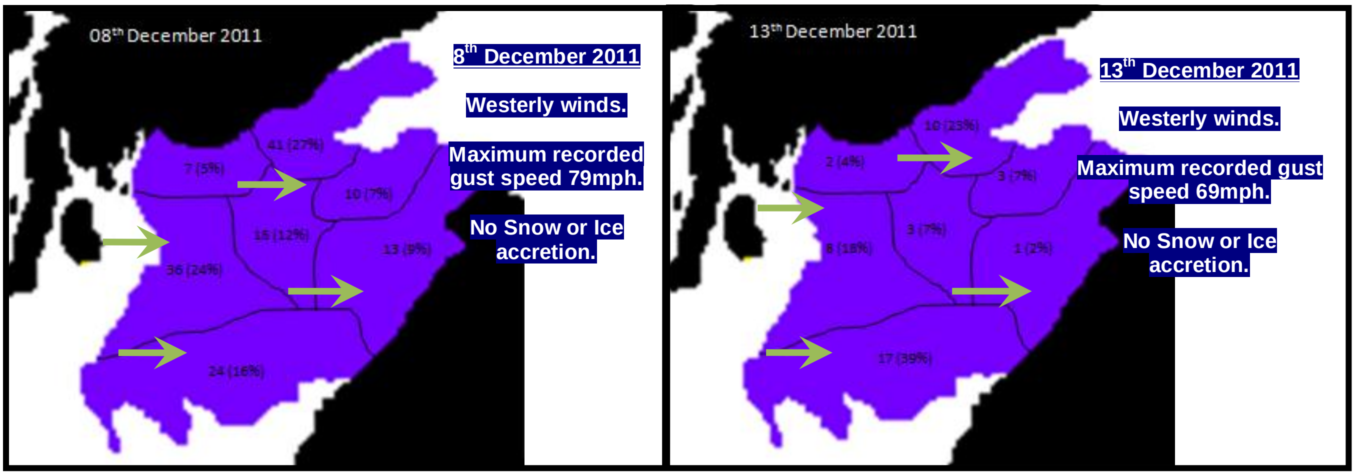


Figure 3 – Storm event of 8th and 13th December 2011 (regions are an indicative representation)

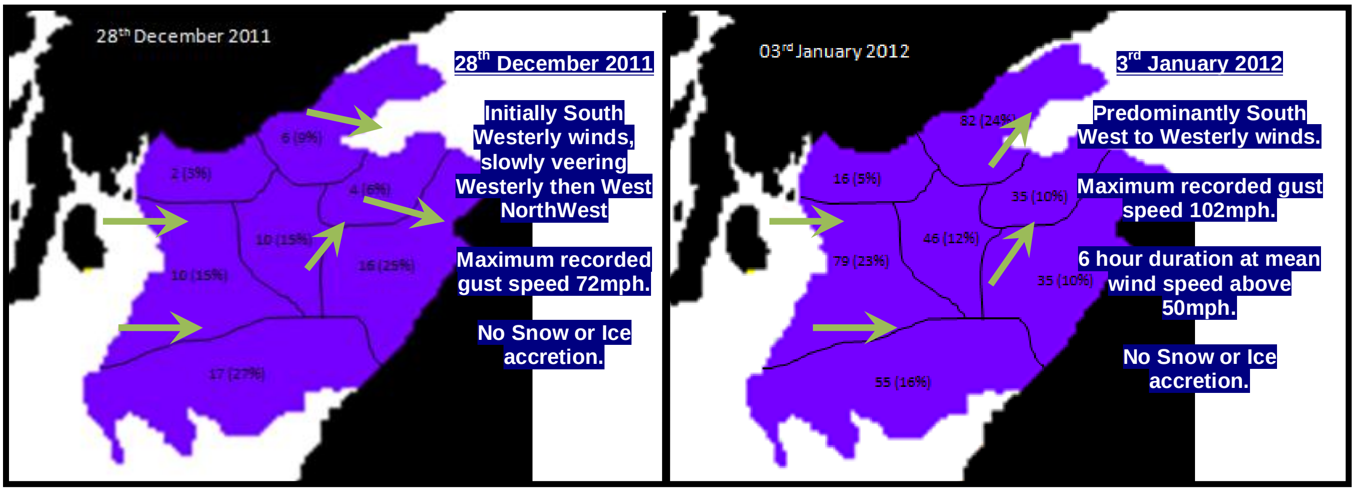


Figure 4 – Storm event of 28th Dec 2011 & 3rd Jan 2012 (regions are an indicative representation)

Figure 4 **shows that the storm event of the 3rd January 2012 is comparable to the Boxing Day storm event in magnitude and trajectory. The two storm events were synoptically similar as they both evolved from a rapidly deepening depression to the west of Ireland, which then swept across Highland Scotland on an East-Northeast trajectory [9].**

Figures 2 to 4 also display the HV faults that occurred within each of SPEN's Scottish regions, which are Ayrshire & Clyde; Borders; Central & Fife; Dumfries; Edinburgh & Lothians; Glasgow & Clyde North and Lanarkshire. Figure 6 illustrates these faults for comparison, and identifies that the proportion of faults for the storm events of 08/12/2011 and 03/01/2012 are very similar to each other, plus they closely resemble the storm event of 26/12/1998.

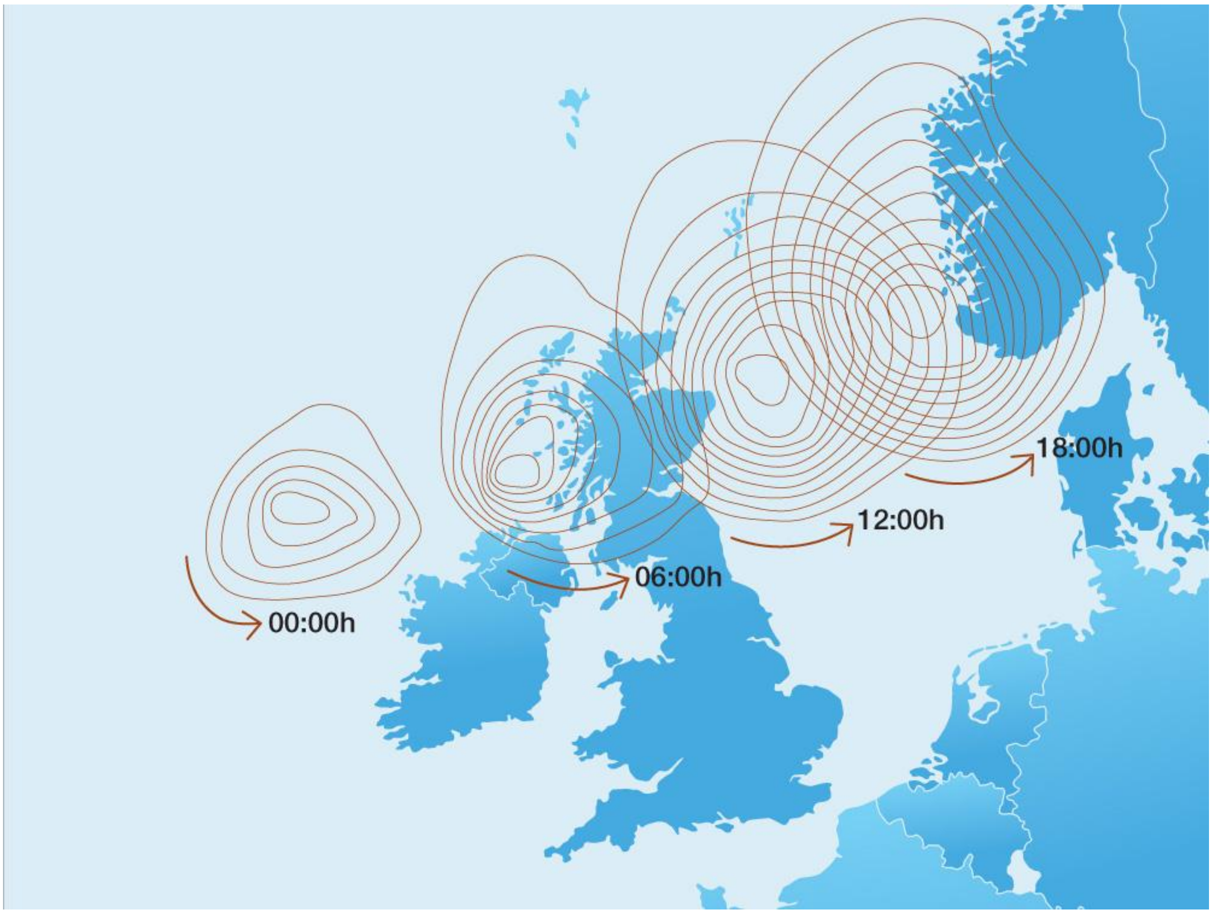


Figure 5 – 3rd January 2012 storm trajectory

The main difference between the pie chart of the 26/12/1998 and the pie charts of the 08/12/2011 and 03/01/2012 is that Dumfries suffered proportionally more faults in 1998 whilst in 2011/12 Central and Fife had more faults. This observation could suggest that the storm events of the 08/12/2011 and 03/01/2012 were similar in their trajectory to the Boxing Day storm however the Boxing Day storm's path travelled slightly lower across SPEN's Scottish Network.

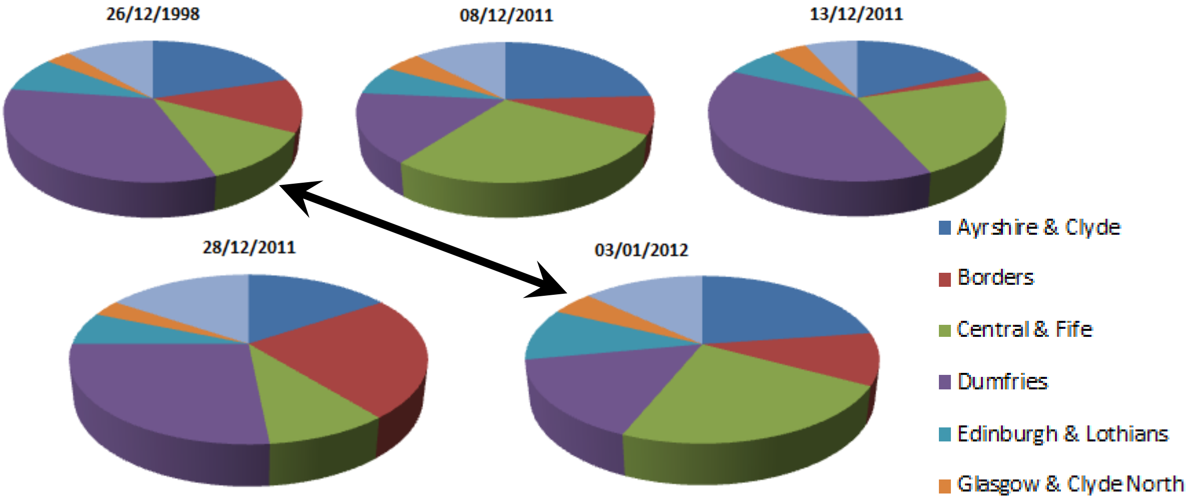


Figure 6 – Fault Locations

Table 2 **[10]** illustrates that the storm gust speeds of 3rd January 2012 are the highest since 1998 at a majority of the weather stations, it can also be seen that the max gust speeds are similar in magnitude.

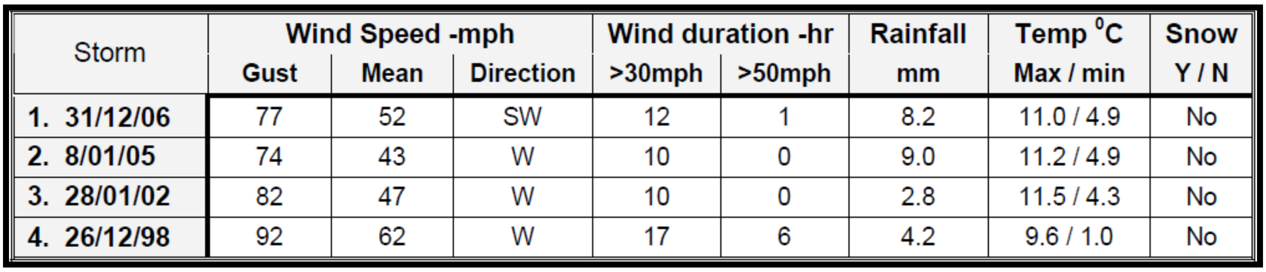
Table 2 - Highest gust speeds 3 January 2012 (excluding mountain stations)

Station	Elevation (m.a.s.l.)	Max gust speed (knots)	Highest gust since	%
Edinburgh, Blackford Hill	134	89	26 December 1998 93 knots	96%
Salsburgh, Lanarkshire	277	84	26 December 1998 95 knots	88%
Islay, Port Ellen	17	84	Highest gust on record – previously 26 December 1998 83 knots	101%
Aberdaron,	95	81	8 January 2005 89 knots	N/A
Drumalbin, Lanarkshire	245	80	26 December 1998 82 knots	97%
Machrihanish, Argyll	10	80	26 December 1998 82 knots	97%
Glasgow, Bishopton	59	79	Highest gust on record – previously 28 January 2002 67 knots. Records from 1999 only	118%
Capel Curig, Gwynedd	216	75	7 February 2011 75 knots	N/A
Dunstaffnage, Argyll	3	75	8 December 2011 76 knots	99%
Edinburgh, Gogarbank	57	74	Highest gust on record – previously 28 January 2002 71 knots. Records from 1999 only	104%
Isle of Portland, Dorset	52	74	25 December 1999 80 knots	N/A

Of the four storm events between the 8th December 2011 and 3rd January 2012 considered in this document, the storm event of the 3rd January 2012 will be the one compared to the storm event of the 26th December 1998

3.3 Storm Event of 2006

On the 31st December 2006 SPEN's Scottish network experienced a severe storm event that resulted in widespread damage to the overhead network. SPEN requested KEMA review its HV overhead line assets in terms of storm resilience **[11]**. KEMA searched Scottish Power's PROSPER reporting system to select the days between December 1998 and January 2007 that had experienced 50 or more storm related faults. This resulted in four storm events identified in Figure 7.



Storm	Wind Speed -mph			Wind duration -hr		Rainfall	Temp °C	Snow
	Gust	Mean	Direction	>30mph	>50mph	mm	Max / min	Y / N
1. 31/12/06	77	52	SW	12	1	8.2	11.0 / 4.9	No
2. 8/01/05	74	43	W	10	0	9.0	11.2 / 4.9	No
3. 28/01/02	82	47	W	10	0	2.8	11.5 / 4.3	No
4. 26/12/98	92	62	W	17	6	4.2	9.6 / 1.0	No

Figure 7 – Summary of storm characteristics

The KEMA report is based exclusively on the performance of HV assets; therefore for evaluation against the 2011/12 storm events, only HV fault data was used. Figure 7 displays the storm event characteristics evaluated by KEMA and, as they are less of a match to the Boxing Day storm than the storm event of the 3rd January 2012, none of these will be used in the evaluation. Figure 8 illustrates the number of HV faults reported compared to the maximum wind speed recorded during the storm events.

Figure 8 – HV Faults Vs. Maximum Wind Speeds

In conclusion, from the eight storm events illustrated in Figure 8 the 1998 and 2012 storm events are the most comparable.

4 Network Performance

The storm event fault data detailed in Table 3 was sourced from '*Boxing Day Storm Divisional Report.pdf*' **[1]** and '*Energy Networks North – Exceptional Conditions.pdf*' (Appendix 1). It details that the whole network suffered from 87% less faults than the 1998 storm event.

Table 3 – Storm Event Fault Data

Weather related Faults	26/12/1998	03/01/2012	% Reduction
LV	6,051	518	92%
HV	1,421	501	65%
EHV	150	17	89%
Total	7,622	1,064	87%

Transmission	179	28	84%

Table 3 illustrates that the HV and LV networks are, as would be expected, the major cause of faults during both of the storm events. These networks are inspected on a less frequent basis than the EHV networks; their inspection frequency is dependent on their environment risk. HV and LV assets defined as Low risk are inspected on a 6 yearly basis whilst assets defined as High risk are inspected every 3 years.

4.1 HV Network Performance

All statistical analysis of the HV network was carried out on information detailed in '*HV OHL Damage faults only 261298.xlsx*' and '*HV OHL Damage faults only 030112.xlsx*', which contained data on damage faults only. The data within the '*HV OHL Damage faults only 261298.xlsx*' spreadsheet was based on data from the **PROSPER** corporate system. This data is known to have been massively under reported due to a number of failures in the **TroubleCall** and **ICOND** systems during the 1998 storm event. These figures have been used for proportional evaluation, however it has to be recognised that when compared to the '*Boxing Day Storm Divisional Report.pdf*' **[1]**; these are incorrect to a factor of 3 for EHV, 2 for HV and 8 for LV.

The storm event of the 26th Dec 1998 (Figure 9) had 44% mainline faults and 27% spur lines. The storm event of 2012 in comparison with 1998 experienced a 31% reduction in HV (Damage) faults, these were categorised as 56% mainline and 41% spur lines. The main line and spur line figures are not comparable due to the large number of overhead lines categorised as 'Other' in 1998. What it does display, is that the reporting of the circuits line type has drastically improved with only 3% reported as 'Other' in 2012.

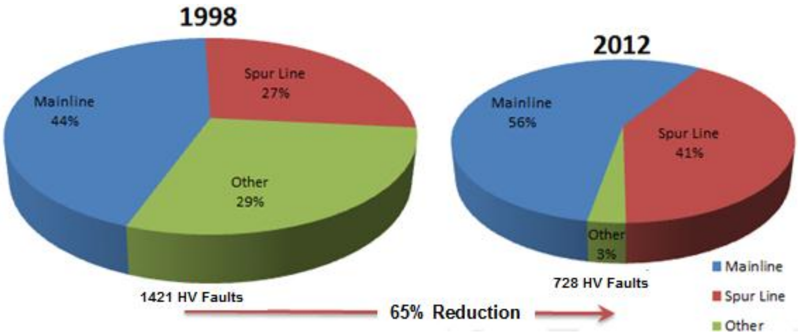


Figure 9 – Overhead Line types

Figure 10 illustrates the HV damage fault counts for the storm events of the 26th Decemeber 1998, 8th Decemebr 2011 and the 03rd January 2012. It can be seen that the two storm events of 1998 and 2012 are fairly similar in shape, except that the peak in the 2012 graph is 31% smaller than the 1998 graph (in reality the 1998 graph would be much larger due to the under reporting problem). The cutout at the top right corner of Figure 10 expands the start of the storm event and shows that the storm event of 2012 (2011 graph removed for clarity) had a much more explosive impact. An analysis was carried out on the first 34 faults reported on both of the storm events, this figure was selected as it is approximately where each of the graphs start to rise in parallel. The storm event of 1998 reached 34 faults at 19:09 which was 14 hours 7 minutes after the initial fault, the storm event of 2012 reached 34 faults at 07:35 which was 2 hours 5 minutes after the initial fault was recorded.

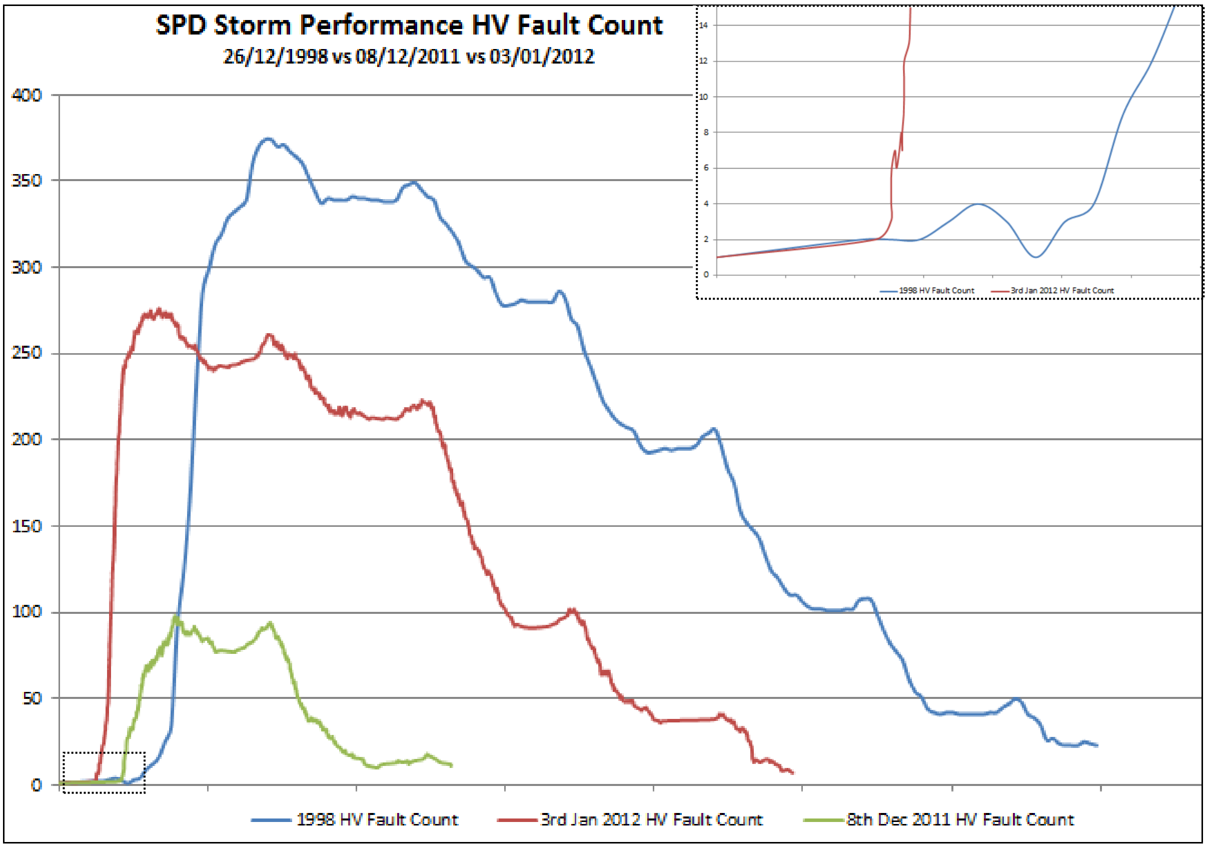


Figure 10 – HV Fault Count

Figure 11(A) shows the amounts of customers off supply during the storm events. Again the graph illustrates the number of customers effected at the start of the storm is greater at the start of the 2012 event and rises more sharply than the storm event of 1998. Figure 11 (B) illustrates the main timings of the two storm events. The 1998 storm reached its peak number of customers (87,868) in 19 hours 35 minutes (***2***) and had a clear up duration of 7 days 18 hours and 37 minutes (***4***), this is compared to the 2012 event, which reached its peak number of customers (72,082) in 4 hours 51 minutes (***1***) and its clear up duration lasted 4 days 16 hours and 59 minutes (***3***).

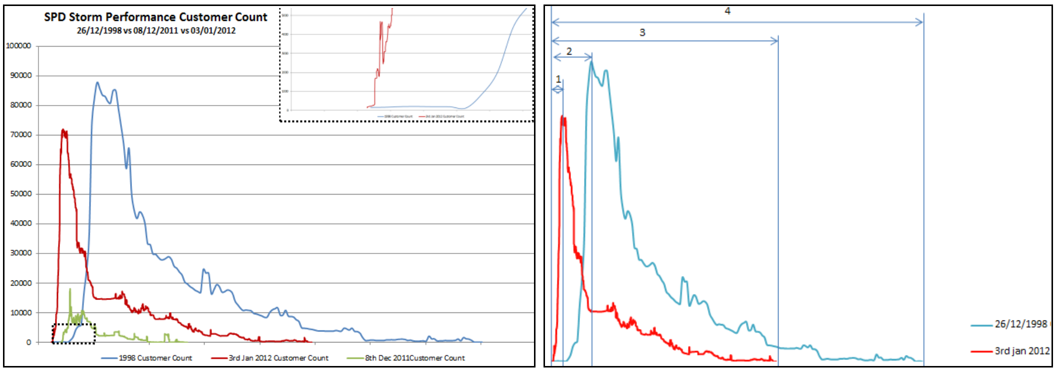


Figure 11 – (A) Customer Interruptions Count (B) Storm Times

The HV network during the storm event of 2012 had the following characteristics compared to the storm event of 1998:

- The fault (Damage) count was 31% lower than 1998.
- **The main damage happened 86% quicker than the storm of 1998.**
- **The maximum number of customers off supply at any one point was 18% lower than 1998 (customer figures reported in the Boxing Day storm review report would suggest that this value is 42% lower than 1998).**
- **The clear up duration was 39% quicker than 1998.**

4.1.1 Network Failures

HV network faults are categorised as 'Conductor', 'Insulators', 'Jumpers', 'Poles', and 'Others'. Figure 12 illustrates the fault distributions from each storm event, and shows a proportional increase in Insulator faults.

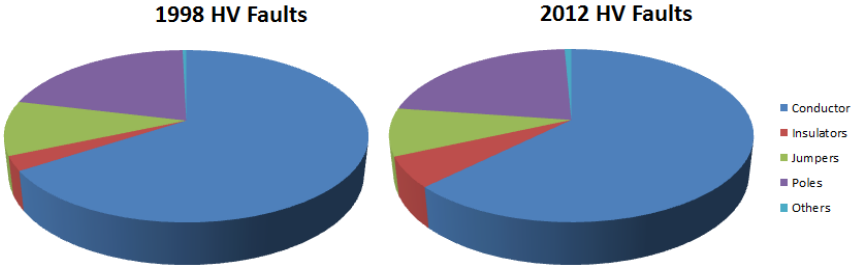


Figure 12 – Fault distributions

Figure 13 shows that for the 2012 storm event compared to the storm event of 1998 there was a 48% reduction in Conductor faults; **14% increase in Insulator faults**; 53% reduction in Jumper faults and a 43% reduction in Pole faults.

In the 1998 storm event 16% of the HV damage faults were attributed to trees and 84% were classed as windborne damage. The panel of inquiry set up after the Boxing Day storm reported **[1]** that the primary cause of 85% of all LV and HV faults was due to trees, therefore the statistic of 85% tree damage will be used for 1998 in this document.

The reporting process and data handling during storm events has been improved since the 1998 storm. The 2012 data has 35%[2] of the faults had no secondary cause compared to 77% of the 1998 data; therefore the reporting of the 2012 fault data should have a higher degree of accuracy.

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[2] The data set was incomplete, as the secondary cause was not available for 'Central & Fife' and 'Dumfries' regions at the time of writing.

During the 2012 storm event 61% of the HV damage faults were attributed to trees and 39% to other factors, mainly windborne debris.

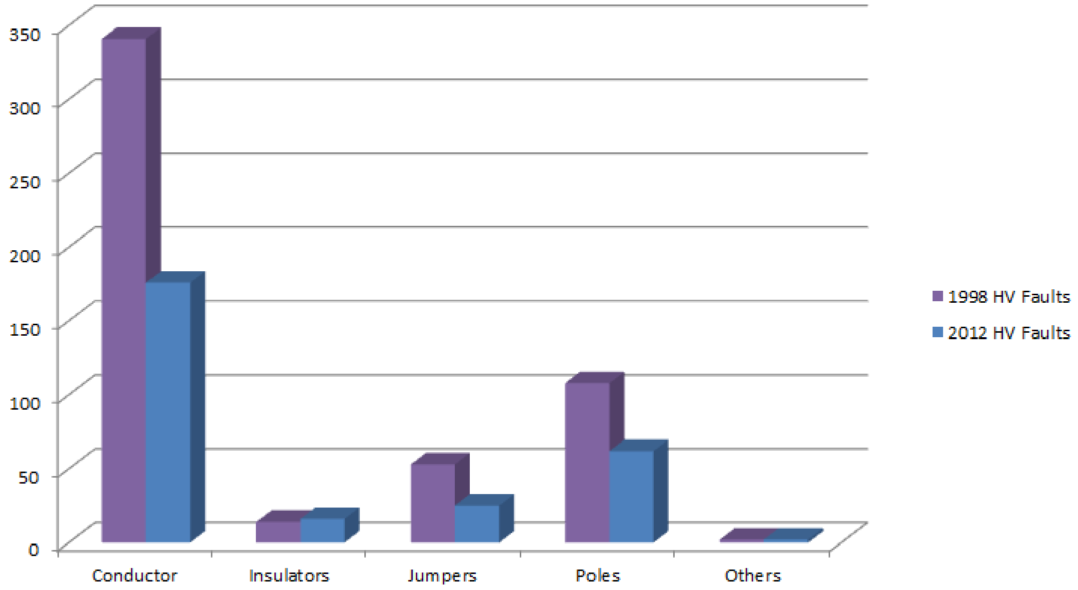

Figure 13 – Fault Categories

4.2 LV Network Performance

The LV network suffered from 6,051 LV faults during the 1998 storm event whilst in 2012 it suffered from 518. **This is a reduction in LV faults of 92%.**

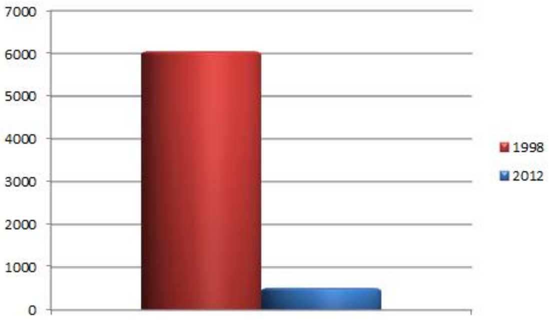

Figure 14 – LV Faults

After the 1998 storm event the panel of inquiry found that there had been a lack of focus on the LV network, and that it appeared to be less well maintained than other networks. The poles were also generally considered to be in a worse state than other voltage networks plus coupled with the difficulty of obtaining permission to clear vegetation due to householders wanting to shield the view of the overhead line, made the LV more prone to storm damage.

4.2.1 Network Failures

Figure 15 shows that ENA TS 43-30 **[12]** (LV open wire) suffered the highest proportion of the 2012 storm event's LV faults with The population of SPENs Scottish LV network is approximately 95% ENA TS 43-30 and 5% ENA TS 43-12 **[13]** (ABC).

The total proportion of ABC faults is 3% (2% ABC Main, 1% ABC Service), which would indicate that ABC has an increased resilience during storm damage over open wire construction. The major component in the LV fault figures is conductor damage (Figure 12), therefore as the population of ABC increases within SPEN's Scottish LV network the LV fault levels should further reduce during storm events.

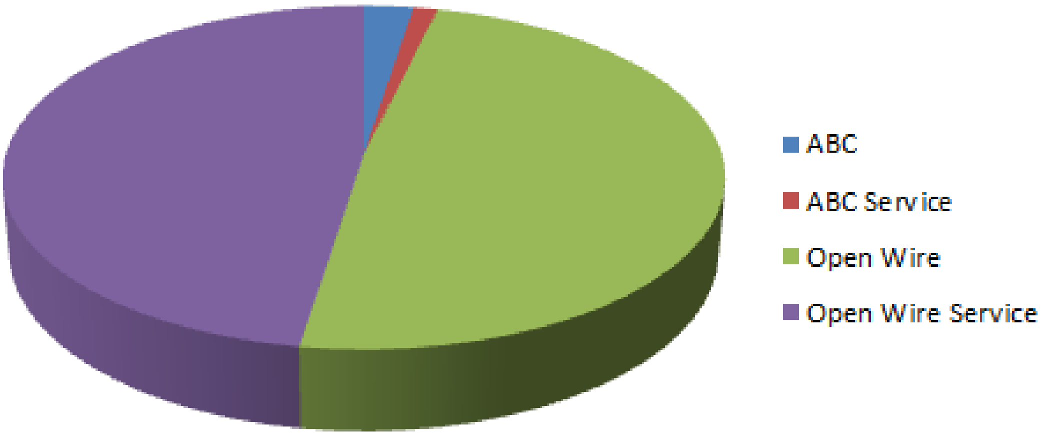

Figure 15 – LV faults per construction

4.2.2 LGC Programme

Currently approximately 95% of Scottish Power's LV network is constructed to ENA TS 43-30 **[12]** construction specification. This specification entitled 'Low voltage overhead lines on wood poles' uses wood pole supports and bare wire conductors attached to reel or screw-in insulators. This specification is prone to clashing of the conductors due to their relatively small spacing of 300mm. The main alternative to the 43-30 construction is ENA TS 43-12 **[13]** which uses Aerial Bundled Conductors, which due to their insulated nature do not have the problems associated with clashing.

SPEN have now introduced a large LV modernisation programme (LGC Programme) and plans to intervene on 1,000 km of LV every 5 years. This programme initially looks to replace ENA TS 43-30 construction with ENA TS 43-12 or sections or underground cable.

Due to the cost of undergrounding overhead lines, the main component in the LGC programme will be upgrading LV OHLs to ENA TS 43-12.

4.3 ABC

SPEN’s long term modernization strategy for LV overhead lines encompasses a prioritized investment programme of Aerial Bundled Conductor (ABC) and selective undergrounding **[14]**. The strategy states that no more bare wire LV OHLs will be added to SPEN’s LV network.

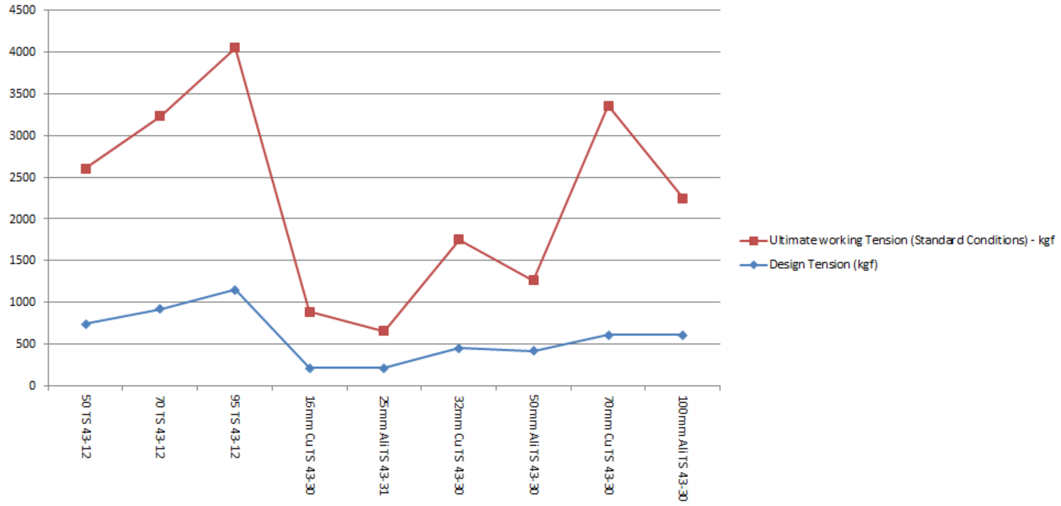

Figure 16 – LV Constructions

Figure 16 illustrates the difference between the conductors design and ultimate working tensions; all three of the ABC conductors show a very large extra capacity over its design tension. This can sometimes be detrimental to an OHL as poles become the weakest link. ABC has such tension capabilities that it has been witnessed were stays have pulled through their concrete blocks and the pole snapped before the conductor failed. This can be remedied by introducing weak parts in the suspension or tension fittings.

During HV refurbishments SPEN’s Manweb area has carried out re-conductoring of the first span from OHL substations plus renewing the first pole if required. This was carried out to reduce the need for a further HV shutdown during the refurbishment of the LV network; however during storm conditions there has been a reduction in the amount of HV faults caused by the failure of the first LV span.

4.4 Ofgem Metrics

In the DPCR5 price review, Ofgem specifies a number of outputs from each DNO that are designed to define and measure a company's performance. These are based on the systems and information that is available in each company; however the areas of customer interruptions (CI) and customers minutes lost (CML) will be reported as common metrics across the industry.

The definition of CMLs and CIs is as per Ofgems definition **[15]**:

CML – *The duration of interruptions to supply per year – average customer minutes lost per customer per year, where an interruption of supply to customer(s) lasts for three minutes or longer, calculated as:*

$$\frac{\text{The sum of the customer minutes lost for all restoration stages for all incidents}}{\text{The total number of customers}}$$

CI – *The number of customers whose supplies have been interrupted per 100 customers per year over all incidents, where an interruption of supply lasts for three minutes or longer, excluding re-interruptions to the supply of customers previously interrupted during the same incident. It is calculated as:*

$$\frac{\text{The sum of the number of customers interrupted for all incidents} * 100}{\text{The total number of customers}}$$

Table 4 – CML and CI results for the 03/01/2012 storm event

Voltage	CML due to the Storm Event			CI due to the Storm Event		
	West Scotland	East Scotland	EN North	West Scotland	East Scotland	EN North
EHV	2.30	0.02	**2.32**	0.52	0.10	**0.63**
HV	13.98	15.98	**29.97**	2.28	2.80	**5.08**
LV	1.09	0.91	**1.99**	0.10	0.09	**0.19**
Total	**17.37**	**16.91**	**34.28**	**2.91**	**2.99**	**5.90**

Table 5 displays the comparison of the 2012 storm events CI and CML results identified in Table 4 when compared to 1998's in Table 1 shows:

Table 5 – 1998/2012 CI and CML comparison table

	CML due to the Storm Event			CI due to the Storm Event		
Voltage	1998	2012	Reduction	1998	2012	Reduction
EHV	8.71	2.32	**73%**	1.92	0.63	**67%**
HV	82.04	29.97	**63%**	9.15	5.08	**44%**
LV	3.36	1.99	**41%**	0.29	0.19	**34%**
Total	94.11	34.28	**64%**	11.36	5.90	**48%**

- **A 64% reduction in the overall CMLs.**
- **A 48% reduction in the overall CIs.**

5 Improvement Policies

5.1 OHL Policies

OHL-01-008 **[3]** was introduced in 2002 in response to the storm event of 1998. It was introduced to improve network resilience by addressing the inadequacy of lightweight constructions such as BS1320. This was particularly pertinent to main lines that were built during the electrification of rural areas in the 1950's and 60's.

OHL-03-099 **[16]** lays out Scottish Power's specifications for all new or re-build 11kV and 33kV OHL circuits. All of the specifications are of unearthed construction with AAAC Conductors, supported on single and "H" type wood pole supports. OHL-03-099 has nine construction specifications (Table 6), each of which are categorised as severe and non-severe. OHL-01-008 specifies the heavier construction standard of L27, for HV circuit main lines being constructed or re-built in the defined Severe Weather area. It also states that a HV spur less than five spans in length can be constructed to the L27 specification if connected solidly to the main line.

The heavier L27 specification is designed to be resilient in severe weather area conditions; however there is anecdotal evidence that L10 lines withstood the 2012 storm event within the defined severe weather areas.

Table 6 – OHL construction designs (OHL-03-099)

Construction	Conductor	Voltage	Conductor Size	Weather Area
All Aluminium Alloy Conductors (AAAC)				
L10	Hazel	11kV	50mm AAAC	Non-Severe
L27	Oak	11kV	100mm AAAC	Severe
L27	Ash	33kV	150mm AAAC	Non-Severe
L33	Poplar	33kV	200mm AAAC	Non-Severe
L33	Poplar	33kV	200mm AAAC	Severe
L35	Upas	33kV	300mm AAAC	Non-Severe
Optical Phase Conductors (OPPC)				
L34	Poplar equivalent conductor	33kV	200mm OPPC	Non-Severe
L34	Poplar equivalent conductor	33kV	200mm OPPC	Severe
L36	Upas equivalent conductor	33kV	300mm OPPC	Severe

Each of the OHL designs has a basic recommended span, which when plotted against the conductors maximum span and clashing factor as per ENA TS 43-40 can illustrate how likely the particular OHL design's conductors are likely to clash.

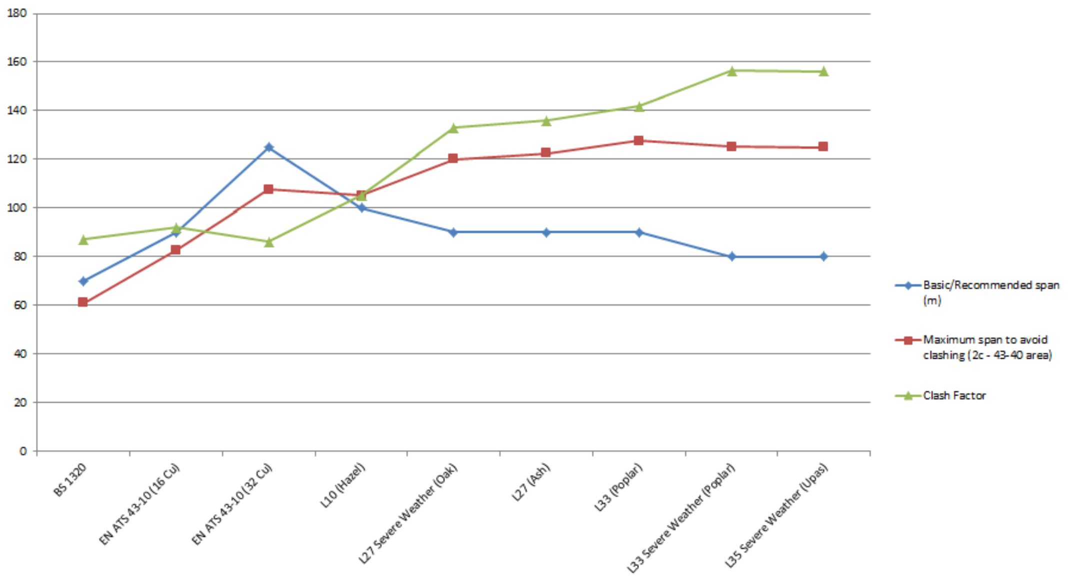

Figure 17 – OHL: Basic – Maximum Spans

Figure 17 shows the difference between an OHL's basic recommended span and its maximum span, which will avoid clashing dependent on the designs conductor spacing (crossarm size). The maximum span was calculated for an ENA TS 43-40 2C weather area, which is defined as the OHL would be subjected to a wind pressure of 380N/m^2 and a diametric ice acretion of 30mm. It shows that BS1320 and ENA TS 43-10 constructed lines would be prone to clashing as their basic recommended spans are greater than the 43-40 calculated maximum span. Prior to 2007, SPEN constructed its L10 lines to the Severe weather appendix of ENA TS 43-10. In 2007 L10 was re-written to an increased specification. Figure 17 also displays the 43-40 clashing factor, which for display purposes has been factored by 100.

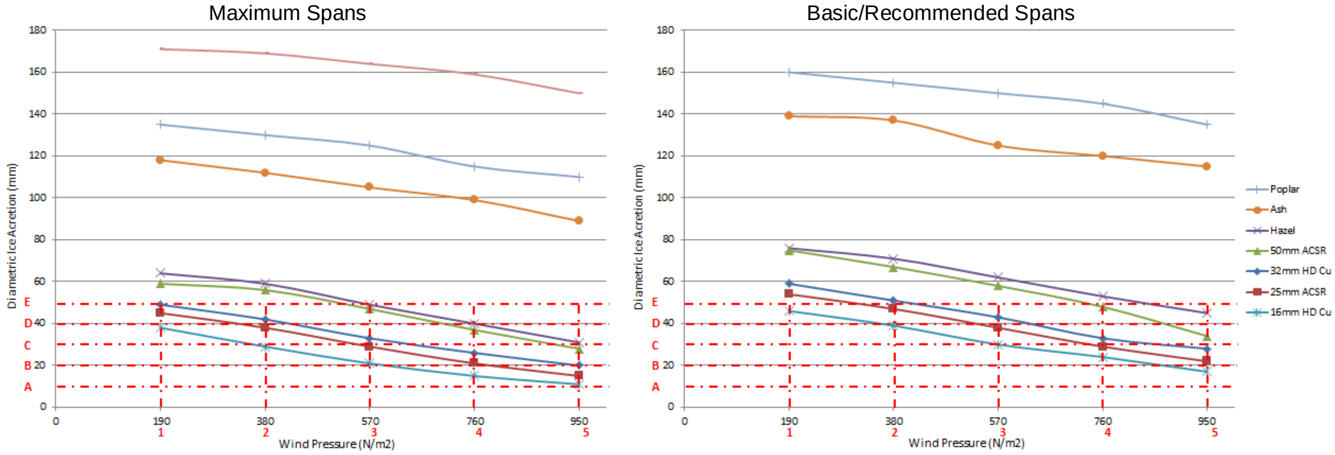

Figure 18 – OHL Conductors

Lines designed in accordance with ENA TS 43-40 are more likely to withstand the likely wind and ice loadings as identified within the relevant UK weather zone maps. Figure 18 shows the conductor failure curves against the wind and ice loadings for span lengths equal to the basic/recommeded and maximum span lengths. These findings have been replicated from the STP project S0283 **[17]**. The conductor failure curves display the maximum conductor load that can theoretically be applied to the conductor. It illustrates the load at which the conductor would fail either by reaching its elastic limit or by exceeding the conductors actual ultimate tensile strength (UTS). The graphs have the 43-40 weather areas overlaid in red, for extra clarity 380N/m^2 is equal to 55.7mph, 570N/m^2 is equal to 68mph and 760N/m^2 is equivalent to 78.9mph. Upas is only displayed in the maximum span length graph as the L35 specification recommended span length of 80m greatly out performs the programme (used for calculations) limit of 180mm diametric ice acretion.

Figure 18 identifies that Hazel conductor 'maximum spans' can withstand 1E, 2E, 3D, 4C and 5B ENA TS 43-40 weather co-ordinates. SPEN rate their L10 specification (Hazel conductor) to a maximum of 2D & 3C weather co-ordinates, and anecdotal evidence suggests that it performed very well during the 2012 storm event.

During the storm event of 2012, 4 permanent faults occurred on main lines that had been upgraded by the improvement policies and one on an OHL that had been refurbished. 713 km of HV OHLs have been upgraded so far out of an asset population of 14,048km, which equates to 5% of the HV OHL population. The fault rate of upgraded mainlines is 1%, this illustrates an overall improvement in HV mainline resiliance due to the proportion of faults being significantly lower than the proportion of population.

There was no permanent faults on any refurbished Spur lines during the 2012 storm event.

5.2 Vegetation Management

The first improvement programme implemented post 1998 was 'Rural Care', which saw a change from vegetation clearance on a cyclic basis to one that concentrated on tree clearance for vegetation below or within falling distance of HV overhead lines. This policy was applied to OHL construction and refurbishment projects plus circuits identified as poorly performing. This policy attempted to clear all trees identified within the proximity zone 1 defined within ENA ER G55 **[18]**, in reality this policy was not liked by landowners and the general public and consents were hard to get approved especially within TPO (Tree Preservation Order) areas.

The introduction of OHL-01-008 in 2002 introduced Rural Care 2, which was a more measured approach to vegetation management by considering vegetation control within high and low risk zones. Zone 1 maintains a 2.0 metre clearance zone around HV lines and Zone 2 requires high risk trees to be cleared within falling distance of HV lines. Arborists give guidance for the condition of certain tree species within Zone 2. Rural Care 2 is applied to all overhead line rebuild and refurbishment projects.

In 2006 the Energy Networks Association (ENA) issued ENA ETR 132 **[2]** which saw a move towards "a risk based methodology that provides guidance on how to proactively improve the overall performance of a Network by improving the Resilience of the Network to Vegetation related faults that can occur under Abnormal Weather conditions". ETR 132 recognises the fact that policies such as rural care are unacceptable, on an environmental basis; however a risk will remain under abnormal storm conditions that healthy trees might still fall causing Network faults. There is anecdotal evidence that during the storm event of 2012 trees that would have been regarded as healthy had in fact fallen causing a permanent fault.

Figure 19 illustrates the monthly rainfall figures for 2009 to 2011 plus the mean average from 2001 to 2010. The 2011 graph shows above average rainfall figures for most of the year, the December figures show a massive increase above average. It would be safe to assume that the significant increase in rainfall had contributed to some tree foundation instability, contributing to some of the healthy tree failures.

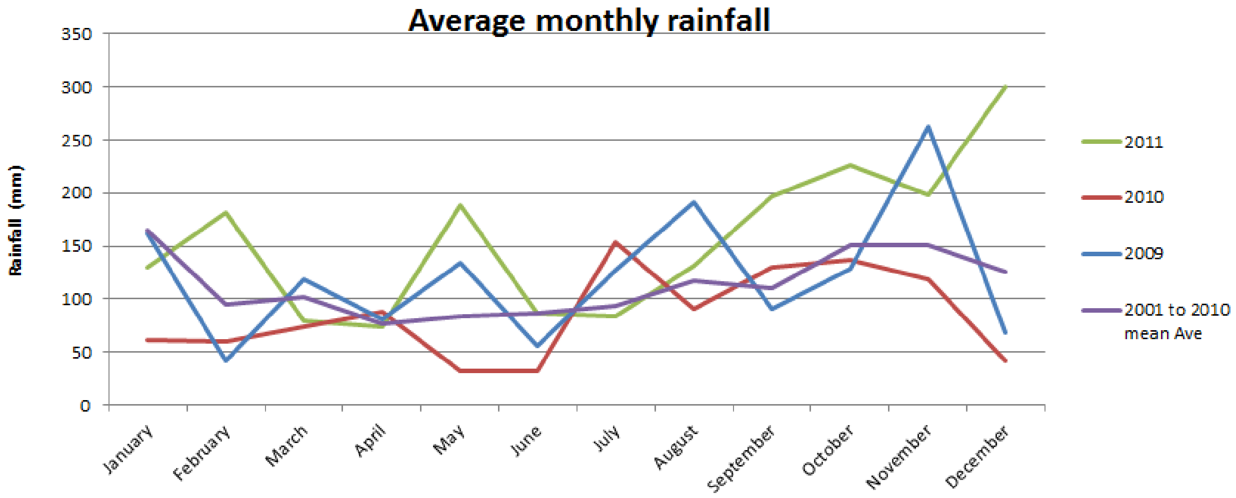

Figure 19 – Monthly Rainfall

Climate change is predicted to bring about climatic changes that will produce more extreme storms, which will be classed as exceptional events or conditions. A Met Office report **[19]** predicts that the UK will experience increasingly adverse climatic conditions over the coming decades. DNOs will therefore require increasing levels of investment due to the increased difficulty in maintaining Network Resilience, including Vegetation Management.

The World Meteorological Organization (WMO) defined "Abnormal Weather" as a climatic phenomenon that occurs only every 25 years or more. Since 1998 SPEN’s Scottish network has been subjected to 10 storm events with maximum wind gusts in excess of 70mph plus severe snow storms in early 2001 and March 2010. In date order the severe weather events were:

- “Snowblitz” – February 2001 (Snow storm);
- “Cyclone Noah” – 1 January 2002;
- “Cyclone Erwin” – 8 January 2005;
- “Cyclone Gero” – 11 January 2005;
- “Cyclone Franz” – 10 January 2007;
- “Hungry Snout” – March 2010 (Snow Storm);
- “Hurricane Katia” – 11 September 2011;
- “Cyclone Xaver” – 25 November 2011;
- “Cyclone Friedhelm” – 8 December 2011;
- “Cyclone Hergen” – 11 December 2011;
- “Cyclone Ulli” – 3 January 2012;
- “Cyclone Andrea” – 4 January 2012.

It can be observed that six storm events occurred in the 2011/2012 winter period and four of these were within one month at the end of 2011 and start of 2012. These would substantiate the Met Office’s prediction of increased adverse climactic conditions.

SPEN originally operated a five year cyclical vegetation clearance programme; this has now been reduced to a three year programme. The vegetation programme has been reduced to a three yearly cycle as SPEN does not believe that clearances as specified in ENA TS 43-8 **[8]** can be achieved with a cycle greater than 3 years. This is largely due to the increased growth rate of vegetation and the restricted cuts enforce by landowners.

During re-build projects it has sometimes been difficult obtaining compliance with ETR 132 due to small areas of excessive vegetation or reluctant landowners. As ETR 132 compliance has to be reported on the whole line this could become a factor in not refurbishing an OHL.

During the 2012 storm no ETR 132 trees fell causing any permanent faults.

5.3 Severe Weather Map

Scottish Power with assistance from the Met Office developed a severe weather map for the Scottish network (Figure 20). The severe weather map illustrates two distinct weather areas:

- Severe (Blue) – with mean hourly wind speeds up to 70mph, gusts up to 105mph.
- Normal – with mean hourly wind speeds up to 50mph, gusts up to 75mph.

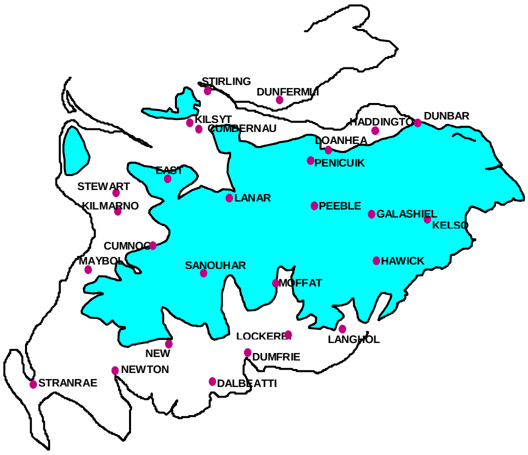

Figure 20 – Severe Weather Map

Figure 21 illustrates the UK weather zone maps from ENA TS 43-40, which were created to define diametric ice and mean wind pressure co-ordinates for sites between 0m and 500m. The maps from left to right are 0 to 100m; 100m to 200m; 200m to 300m; 300m to 400m; 400m to 500m.

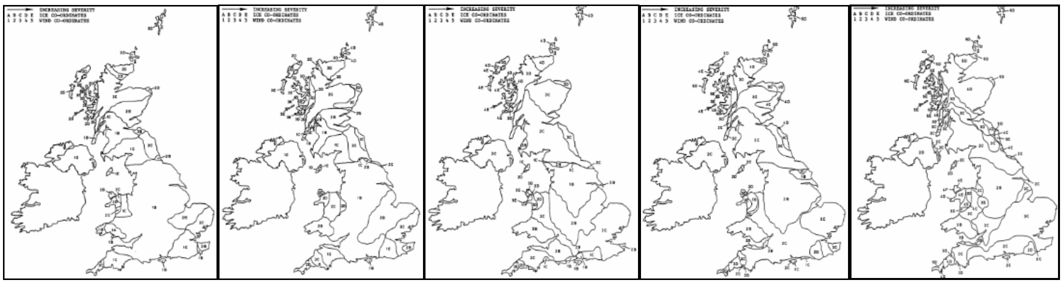

Figure 21 – 43-40 Weather Zone Maps

The comparison between the ENA TS 43-40 weather zone maps and SPEN's severe weather map illustrates that SPEN's severe weather map would benefit from some refinement.

Figure 22 illustrates the storm event's HV fault distribution for each region divided in to their respective weather areas. 79% of the faults occurred within non-severe weather areas and 19% occurred within severe weather areas. The distribution of faults that occurred within severe weather areas were:

- Borders – 46%
- Dumfries – 12%
- Lanarkshire – 42%

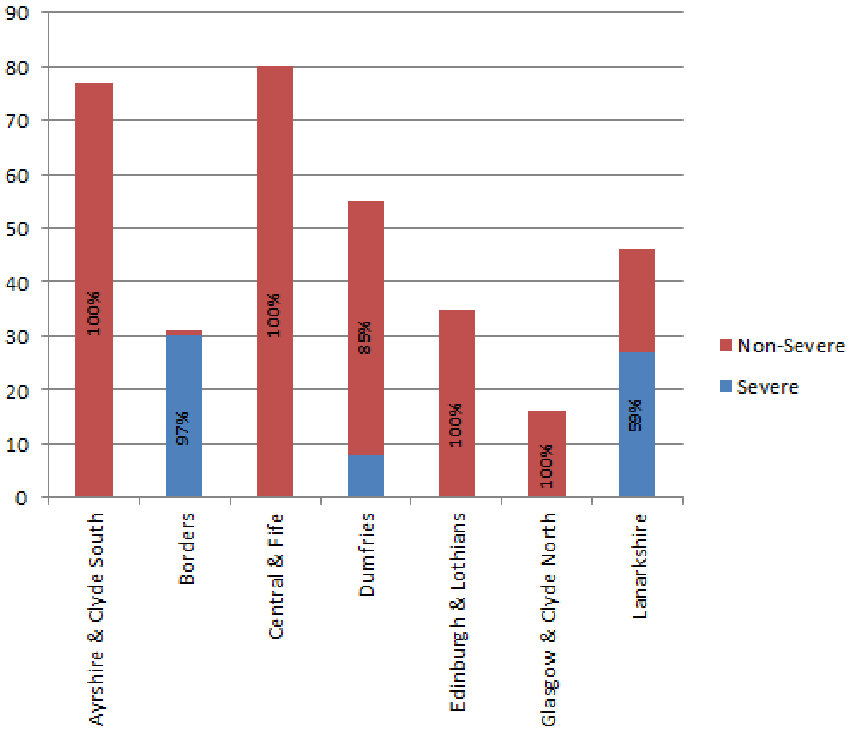

Figure 22 – Weather zone faults

97% of the HV faults in the Borders region occurred within a severe weather area; 59% of Lanarkshire region's HV faults occurred within a severe weather area and the Dumfries region had 15% of their HV faults occur within a severe weather area.

The severe weather map (Figure 20) identifies that:

- Ayrshire & Clyde South has a small severe weather area (Approximately the bottom half of the small blue area above Stewarton (Figure 20)). All of Ayrshire & Clyde South region's 77 faults occurred within the non-severe weather areas. Although the severe weather area is quite small it would have been expected, given the large number of faults for this region, that some damage would have occurred within it.

- The Borders region is predominantly a severe weather area, which is reflected in the fact that 97% of the faults were classified as occurring within a severe weather area.

- The Central & Fife region has a severe weather area (above Kilsyth (Figure 20)), which accounts for approximately 20% of the region. This region suffered the largest amount of HV faults; however none had occurred within the severe weather area. It would have been expected to see damage within the severe weather area given its size and the number of faults report in this region.

- Approximately 66% of the Dumfries region is a non-severe weather area, and 85% of all of the faults that occurred in this region were classified as occurring within the non-severe area.

- The Edinburgh & Lothians region also has approximately 66% of its area defined as non-severe; however all of its faults were categorised as occurring in this area.

- The Glasgow & Clyde North region has a small severe weather area (Approximately the top half of the small blue area above Stewarton (Figure 20)). Given the small severe weather area and the relatively small amount of HV faults that occurred in this region, no conclusion can be drawn from the fact that all of the faults occurred within the non-severe area.

- The majority of the Lanarkshire region is classified as a severe weather area and 59% of the HV faults were reported as occurring within this area.

As Figure 22 illustrates the Ayrshire & Clyde South, Central & Fife and Edinburgh & Lothians regions' HV faults were all classified as occurring within non-severe weather areas; however Figure 20 identifies severe weather areas within these regions.

A number of reasons could explain the lack of severe weather area HV faults within the regions identified above:

- The storm passed below the severe weather areas. The storm did pass through all of these areas, as there is anecdotal evidence that the storm passed through the Loch Lomond area, which is north of all of these regions. There is also evidence that SSE suffered OHL faults across the central belt of Scotland.
- The OHLs within the severe weather areas could have received a higher percentage of improvement than other regions, or the population of OHLs in these regions are lower than other regions.
- The data regarding the weather regions could have been incorrect.

An investigation into why the Ayrshire & Clyde South, Central & Fife and Edinburgh & Lothians region's severe weather areas performed so well compared to other areas could identify that the severe weather map requires some refinement or some other reason that could benefit the other regions.

6 OHL Protection Policy

Remote areas and areas of low population density are usually served by OHLs; restoration of supplies to these areas can sometimes be delayed by difficult terrain and longer distances between DNO depots and customers. Also during storm events these areas will be given a lower priority over higher population density circuits. 50% of faults on overhead lines are transient faults, which can have many causes, including debris being blown onto the lines, birds or lightning. The effect of a transient fault on a standard OHL would trip the protection; the fault would then disappear (usually by being blown away by the power of the initial fault). The OHL would therefore be in a serviceable condition and off supply; SPEN introduced the overhead line protection policy (OHPP) in 1993/94 to overcome these issues.

The OHPP uses microprocessor-controlled OHL switchgear that disconnects faulty equipment as quickly as possible. After a pre-set time the switchgear will automatically attempt to restore supplies, if the fault was transient then supplies would be restored. The customers connected to the OHL during transient faults would only experience a short disconnection compared to a lengthy one.

Originally due to their design automatic switchgear would have a number of operations before they would ‘lock out’, resulting in a loss of supply. Although this would result in a lengthy loss of supply it would alert SPEN to the fact that there is a potential problem with the affected circuit. Since the inception of the OHPP automatic switchgear can now carry out many thousands of operations without maintenance; therefore they can be set to unlimited operations. SPEN’s automatic switchgear has a reclose time of 10 seconds and reclaim time of 10 seconds. If a fault is detected within the reclaim time the switchgear will proceed through its 3 shot cycle every time a fault is detected before the reclaim time; after 3 cycles if lock out indicating a permanent fault. If the circuit stays on supply for longer than the reclaim time the switchgear will reset back to zero shots.

Spur lines under OHPP are protected by pole-mounted automatic sectionalisers. These discriminate between a transient and persistent fault by counting the passage of fault current during the auto-reclose sequence of the controlling switchgear. Sectionalisers operate during the dead time of the auto-reclose sequence after a pre-determined number of passages of fault current. They are only fitted to circuits protected by a multi-shot auto-recloser with minimum number of trips to lock-out being one more than the sectionaliser count.

Many overhead line faults are transient in nature due, for example, to wind activity or lightning. The application of the above overhead line protection policy, introduced in 1993/94 improves system performance under transient fault conditions and limits the number of customers disconnected under persistent fault conditions **[14]**.

There is some anecdotal evidence to suggest that some OHPP equipment did not perform in the way that it was designed during the recent storm event. These were mainly thought to be primarily sectionaliser links and failures of GVR batteries. Sectionaliser links are periodically tested and during these tests earlier versions with known problems are routinely replaced.

The GVR batteries have a 10 year life expectancy and are checked at 5 years, some failures are detected at this time. It is thought however that approximately the same percentage of failures were experienced during the storm event as would be expected during a standard inspection.

There is also anecdotal evidence that some customers have suffered from many short interruptions (NaFIRS description [5]), and SPEN are only aware of the problem once a complaint is made. Other UK DNOs have applied the automatic switchgear at primary substations, this has the advantage of SCADA communications but the downside is, more customers being affected and counted on each short interruption.

As rural pole mounted automatic switchgear does not usually have any SCADA communications, devices can be employed in customer's premises, streetlights etc. that can communicate with the control office and register that they have experienced a loss of supply. This would alert SPEN to persistent transient faults before customers start to complain.

7 Poles

7.1 Installation

The two main excavation methods for pole installations are with an excavator or auger. All of Scottish Power's HV OHL constructions employ pole baulks on all of their poles; therefore no HV poles can be installed with the auger method. Some other UK DNOs allow HV poles to be installed without pole baulks as long as the poles are installed 0.5m deeper than normal.

As LV poles do not have any pole baulks installed, LV poles can be installed with the excavator or pole auger methods. Installing poles with the auger method minimises the amount of ground that needs excavating, however augered holes are usually so tight to the pole that no reinstating can be carried out (Figure 23A) or so large that too much reinstatement is required (Figure 23B). In other words no reinstatement material can be packed down the sides of a tightly augered hole and too much ground is removed on large augered holes. Both of these scenarios result in leaning poles.

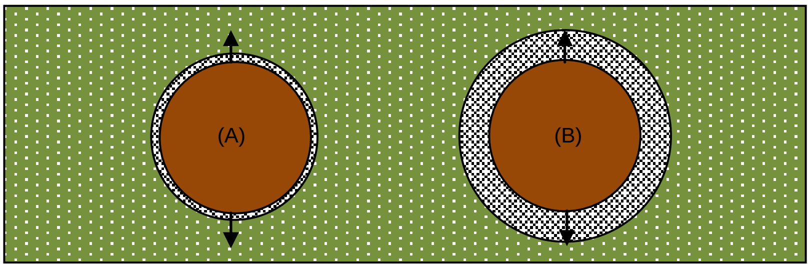

Figure 23 – Augered pole holes

Poles installed with an excavator are usually easier to obtain a tight hole as it can be reinstated through the corners (Figure 24). Both of these pole installation methods are valid, however the quality of the pole's foundation is directly attributable to the quality of the installation. Therefore auditing of pole installations or holding contractors to account for leaning poles for at least 2 years will increase the quality of pole installations.

There is no evidence of pole failures due to poor foundations during the storm event of 2012; however these failures can go undetected, as leaning poles do not always threaten the security of the supply.

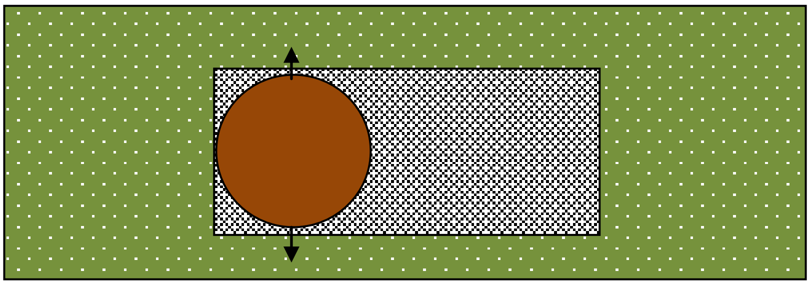

Figure 24 – Excavator pole hole

7.2 Condition

SPEN currently carry out AIS inspections every 6 years pole poles categorised as normal risk, high risk poles are inspected on a more regular 3 year basis. Figure 25 illustrates the timeline of inspections for OHL circuits. It shows that inspections are carried out for the vegetation management programme every 3 years, OHL inspections are carried out every 6 years (3 years for high risk poles). The OHLs are refurbished every 12 years (8% of population), the interim OHL inspection between refurbishments are to catch any defects between refurbishments. No decayed poles will be expected during these inspections as inspectors are asked to assess the poles on Refurbishment inspections for a minimum of 12 years life. OHLs will be evaluated at the 12 year period for refurbishment, 1% of the circuits would be selected for re-building.

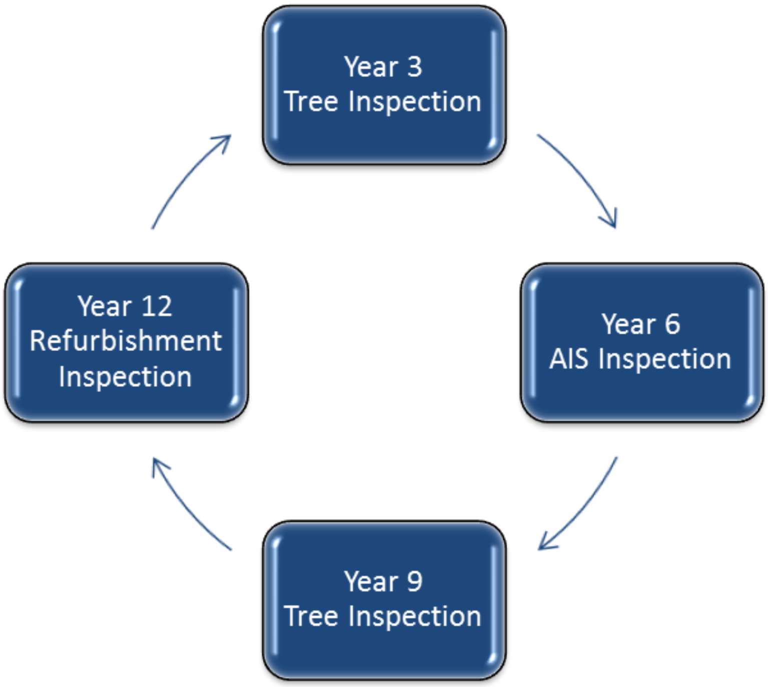

Figure 25 – Inspection Timeline

Inspectors carrying out OHL inspections evaluate a poles condition through visual inspection and a hammer test (Figure 26). The pole's condition is then reported in the AIS system as OK or defective. If SPEN encounter a larger than usual amount of defective poles, a further evaluation is carried out by an outside contractor to ascertain the levels of decay using more advanced pole testing methods.

When poles are evaluated with such a basic test as a hammer test poles that are in really good, normal or really poor condition are easily identified. Poles that the inspector is not sure about, end up being classed as defective just to be on the safe side. If the AIS pole evaluation was categorised into 4 levels such as 'New', 'OK Normal Wear', 'Poor' and 'Bad Work Required', the poles that are not easily determined with a hammer test would fall into the 'Poor' category and could be tested further. Some UK DNOs ask their inspection contractor to carry out the further test on site with equipment that can easily be carried to the pole such as a 'Matson Corer' or 'Purl Tester'.

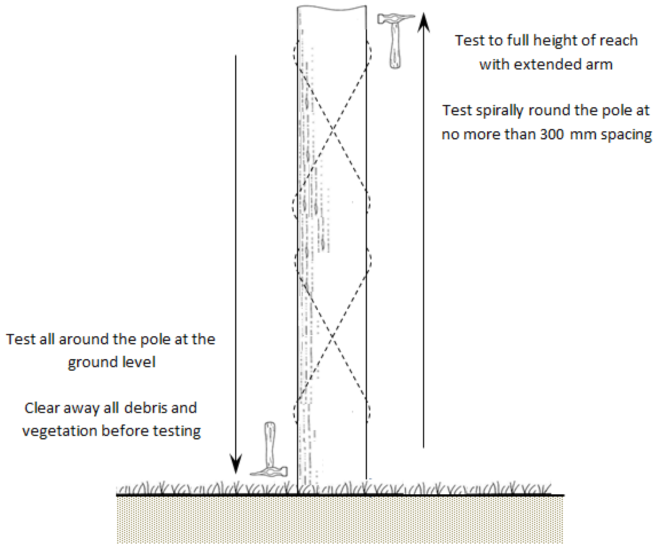

Figure 26 – Hammer Test

Whilst pole testing using the 'Hammer Test' is very subjective using a condition rating should improve the quality of pole testing. It can also increase the ability to audit an inspectors work as level 3 poles ('Poor') should never be reported as any other level, just as level 4 poles ('Bad, Work Required') should only ever be reported as level 4.

One common cause of missed diagnosis of a pole is that the inspector does not carry out a full hammer test. The test should be carried out from the ground level right up to full height with extend arm. One UK DNO experienced a pole failure after a pole had been assessed for pole rot and categorised as 'OK,Normal Wear', this was later found to be because the inspector was not bothering to bend down and hit the pole at the ground line. Simple auditing carried out after an inspection can detect if vegetation has been cleared and or whether hammer marks extend down to the ground line.

There is no evidence that any poles failed solely through pole decay during the 2012 storm event. One pole was described as having pole decay; however it is not explicit that this was the primary cause of the failure.

8 Targeted Solutions

Predominantly SPEN's HV network is constructed of bare wire horizontal construction standards with a small amount of old historic specifications such as Genu 3. SPEN also has a small amount of covered conductor (approx. 6km), which accounts for 0.04% of its HV network. **The use of a targeted solution could improve the performance of some OHL circuits that currently are experiencing difficulties due to harsh or difficult environments that are not conducive to bare wire construction. For example OHLs that have a poorly performing section due to bird strikes, could have this section replaced with a more visible and possibly insulated conductor. The performance of the network during the 3rd January 2012 storm event has shown that wholesale employment of alternative OHL constructions is not required, however the recognition and approval of alternative construction/s would allow SPEN more flexibility when encountering problem areas. It is recognised that having small quantities of alternative OHL constructions can present problems during maintenance and fault work, due to the workforce having very little experience of the constructions. SPEN currently has small quantities of BLX and Ericsson OHL construction, which was constructed by a previous OHL contractor. This means that SPEN and its current OHL contractor has very little experience these constructions; and therefore it would be prudent to train some of SPEN's workforce in these constructions. There is also a need for some material and equipment to be purchased for maintenance and fault work to be carried out.**

The targeted solution could also allow OHLs to be built with reduced tree cutting, where ETR 132 tree cutting has been restricted or refused due to landowner issues.

Detailed below are a sample of constructions that could be targeted at problem areas, the use of targeted solutions would give SPEN a greater ability to match the OHL construction to its environment.

8.1 BLX

BLX is taken from the Norwegian 'Belagt Linesystem', or overhead line system, insulated with XLPE. The line consists of a stranded, alloyed aluminium conductor with cross-section from 50 mm^2 to 150 mm^2, covered with a cross-linked and UV resistant polymer. The conductor is grease filled during the manufacturing process to make the covered cable watertight and corrosion proof.

One of the main benefits of BLX is that unlike conventional bare wire OHLs the phases can be suspended very close together (Figure 27). The smaller crossarm size allows for a much reduced wayleave than for a standard OHL, plus it would apply much less torque to the pole top if it or the conductors were hit by a fallen tree or windblown object due to its smaller size.

In an early pilot study in Norway, trees were deliberately felled at their roots in order to fall onto the BLX line. The line remained live throughout the study and regular inspections were carried out to investigate any damage. After a year the study revealed no signs of mechanical wear on the covering of the line.

Experience with BLX over lakes and rivers in landing/ascent areas for swans and other water birds have also been very positive. Seen against the sky, the line is both more visible and compact than bare line and the birds in flight seem better able to avoid it.

The working practices associated with building conventional bare line can easily be applied to BLX installations. The covered conductors can be drawn through rollers and guided so that the covering is not damaged.

There is anecdotal evidence that during fault conditions BLX has been reconductored with bare conductor due to insufficient stocks and knowledge of the construction. The use of bare conductor on BLX crossarms subsequently resulted in clashing problems.

Figure 27 - BLX

8.2 Ericsson

Ericsson cable is a multi-purpose cable that can be installed in different environments and conditions from being installed as an underground cable, submersed in water and suspended as an OHL. The cable has to be robust enough for laying underground; have adequate density that it will sink for laying in water; possess self-damping properties and be able to withstand the sometimes extreme conditions a self-supporting aerial cable can be exposed to from ice and wind loadings.

The internal design of the cable affects the way vibrations and galloping are damped by the cable. At EA Technology's test field on the Shetlands the Ericsson cables were installed on spans up to 90 meters for a period of 18 months **[20]**. The cables were monitored by load cells and video cameras and performed well under weather conditions with wind speeds (10 minutes average) of up to 82 knots (94 mph). Ericsson cables were further tested at EA Technologies Deadwater Fell test site **[21]**.

If a falling tree lands on an Ericsson OHL, there is a risk that the cable could fail if the tree falls close to a terminal or section pole. If it however fell in the middle of the OHL then the cable will stay intact by slipping through the suspension clamps; there could also be some elongation of the cable. After removal of the tree the line would require re-regulating and any elongation removed through the nearest termination.

Figure 28 – Ericsson Cable (Mull of Galloway Lighthouse)

8.3 Spacer Cable Systems

Spacer cable systems consist of a tensioned messenger wire under which is supported, three covered conductors (CC) in a polymeric support (spacer) cradle. The CC phase conductors are configured in a close triangular formation and can be double or triple sheathed. The Spacer cable system has high mechanical strength to weather severe storms, and good electrical strength that prevents phase to phase and phase to earth faults plus animal and tree contact **[22]**.

The messenger wire provides a high strength physical shield against falling branches and trees. Its compact nature and its ability to withstand temporary tree contact makes it a good candidate for areas where cost or refused permission means only a reduced tree clearance can be obtained.

9 OHL Maintenance

SPEN currently refurbishes 8% of its OHL circuits and re-builds 1% on an annual basis. The average cost of re-building a km of OHL is 10 times, the cost of refurbishment.

Circuits are identified for refurbishment or re-building by a formula that weights ‘decayed/damaged poles’, ‘conductor faults’, ‘stay faults’, ‘insulator faults’, ‘customer numbers’ and ‘fault rate’ to rate the circuits in order of priority. The top 8% of circuits would be selected and 7% selected for refurbishment and 1% would be selected for the re-build list.

SPEN has an obligation to deliver the refurbishment and rebuild quantities as part of a DPCR5 output, circuits selected for refurbishment that are subsequently found to cost vastly more than the refurbishment budget are placed on the re-build list. Once a circuit reaches the top of the re-build list it would take a minimum of 2 years to progress it from start to actually re-building the OHL largely due to landowner issues.

As part of this network review process a 33kV pole was identified as having failed in one of the recent storms on a line that was thought to have been refurbished. It was decided that this would be investigated to see why it had failed. During the investigation it became clear that the circuit was due to be refurbished, however due to cost of replacing a large number of rotten poles on the circuit, it was placed on the rebuild list. This circuit had been prioritised and it is due to be re-built in 2012/13.

Currently the choice is to refurbish or re-build a circuit, however there is no category for circuits that require urgent attention but would cost more than the refurbishment budget per km, except to be classed as rebuild. An interim choice would allow OHLs to have a degree of re-build to the older specification of the original line i.e. original span lengths.

9.1 Prioritisation

9.1.1 HV

Figure 29 illustrates the amount of faults per population of connected customers, it shows that of the 20 faults with more than 2000 connected customers 17 (85%) are HV main Line, 2 (10%) are EHV and 1 (5%) is a HV spur line. Whilst the spur line only represents a small percentage of the faults with more than 2,000 connected customers it would be prioritised within the storm clear up work due to its number of customers. **Therefore spurs with large numbers of connected customers should be considered for inclusion within the improvement programmes and be controlled by its own auto-recloser.**

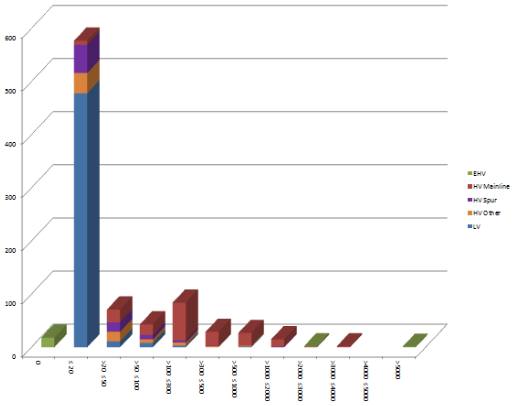

Figure 29 – Faults per population

9.1.2 LV

Figure 30 shows that the majority of all faults from the 2012 storm event occurred on the LV network. Figure 29 illustrates that 1 (4%) of the greater than 500 customer connected faults was an LV fault, however this is thought to be a miss-reported piece of data, as it is doubtful that SPEN has an LV OHL with more than 500 connected customers, as SPEN restrict their LV OHLs to 200amps per phase.

11 LV OHLs with permanent faults had between 50 and 300 connected customers these circuits would have been quite highly prioritised during the fault repair stage of the storm event.

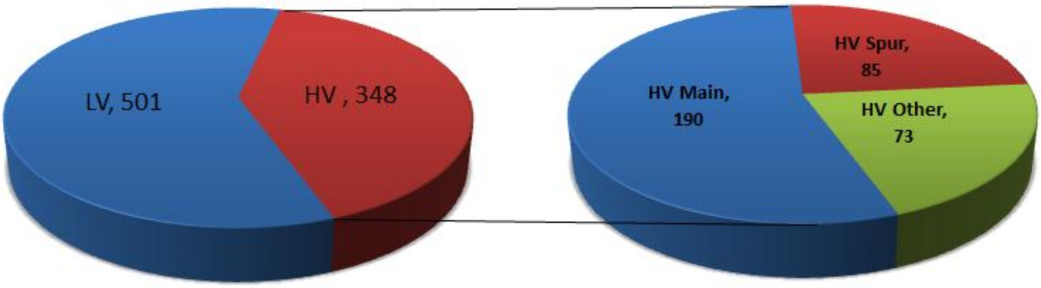

Figure 30 – Fault distribution

The majority of the LV faults are, as would be expected in the less than 20 connected customer's category. As the customer interruption count curve shows in Figure 31, the tail end reduces a lot slower than the start of the storm event; this is due to the amount of less than 20 connected customer faults. One metric that is important to a DNOs customers after a storm event, is being off supply for longer than 48 hours. During the storm event of 2012 4,792 customers were off supply for more than 48 hours, this is a reduction of 66% over the 1998 storm.

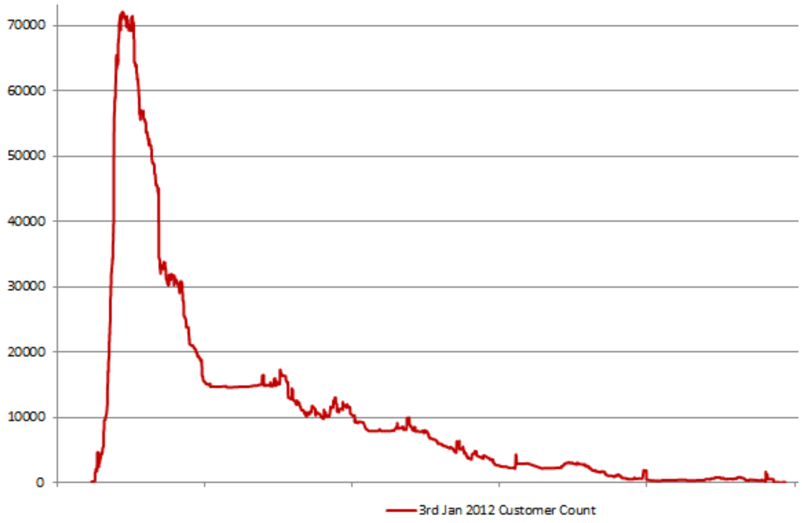

Figure 31 – Customer Count

10 Conclusions

- The storm event of the 3rd January 2012 was comparable to the storm event of the 26th December 1998.
- The storm event of 2012 had an 87% reduction in total faults compared to the 1998 storm event.
- The storm event of 2012 reached its peak number of customers interruptions 31% quicker than 1998.
- The maximum number of customers off supply at any one point was 18% lower in 2012 than 1998.
- The 2012 storm clear up duration was 39% quicker than 1998
- From a diminishing number of faults from 1998 to 2012, ‘Insulator’ faults rose by number and therefore proportion.
- The major cause of damage was attributed to trees at 61% in 2012 compared to 85% in 1998.
- The CML result for the storm event of 2012 was 64% lower than 1998
- The CI result for the storm event of 2012 was 48% lower than 1998.
- The resilience of the HV and LV networks during the 2012 storm event has dramatically improved compared to the storm event of 1998; however the same level of improvements has not been reflected in the CML and CI values for the LV Network. As the LV CML reduction is similar to the LV CI reduction the problem would indicate that more customers were effected per fault
- The L10 OHL construction performed well under storm conditions.
- According to the STP2 project S0283, Hazel conductor ‘maximum spans’ can withstand 1E, 2E, 3D, 4C and 5B ENA TS 43-40 weather co-ordinates. SPENs L10 specification is rated by SPEN to a maximum of 2D & 3C, these conservative design restrictions have been proved to work, due to the excellent performance of L10 OHLs during the 2012 storm event.
- Upgraded HV main lines suffered 1% of HV faults and upgraded spur lines suffered no faults.
- Some trees identified as healthy failed during the 2012 storm event.
- Obtaining ETR 132 compliance is not always possible to attain for a complete OHL circuit.

- The severe weather map is not as detailed as the ENA TS 43-40 weather maps.
- No HV faults occurred within the Ayrshire & Clyde South, Central & Fife and Edinburgh & Lothians region's severe weather areas.
- Adding condition levels to the pole testing in AIS will improve the quality of inspection data for the pole asset class.
- All new or re-build LV OHLs should be constructed to OHL-03-101.
- The renewing of all the first LV poles and spans to ENA TS 43-12 during HV refurbishment / Re-build work increases the HV network resilience.
- There is insufficient knowledge of alternative constructions such as BLX, Ericsson or Spacer Cable systems.
- During the 2012 storm, no ETR 132 trees fell, caused any permanent faults. The increased use of ETR 132 should be considered before having small amounts of alternative contructions on the network.
- Some circuits are taken from the Refurbishment list and placed on the Re-build list due to budgetary and OHL design restrictions.
- An increase in LV OHL re-builds (LGC) should shorten the Storm clear up duration by the number of small LV OHL faults.
- Spurs with large numbers of connected customers should be considered for inclusion within the improvement programmes.

11 Recommendations

The upgrading of OHLs and the carrying out of tree clearance to ENA TS 43-8 and ENA ETR 132 has had an impact on the amount of faults over the duration of a comparable storm event. The upgrading of OHLs and the frequency of tree clearance should be continued as per SPEN's current strategy.

An assessment should be carried out into whether the L10 construction could be utilised within the current severe weather areas, thus allowing more OHL circuits to be rebuilt at a lower cost; and allowing a more targeted approach to the use of L27. Further work should also be undertaken to refine the severe weather map for SPEN's Scottish network. The STP2 project S2641 is undertaking work to develop new wind/ice load maps, which are expected to be less onerous than those in ENA TS 43-40. The refinement of the severe weather map taking into account the findings of S2641 could also more accurately target the correct construction for the environment.

The S2541 project is a large project which may form a revision of the current UK wind and ice loads. It will use details of major wind/ice incidents dating back to 1870, along with UK Met Office and Deadwater Fell data to develop rime ice, wet snow and extreme wind models.

Consideration should be given into an insulated conductor construction, as a targeted solution for poorly performing circuits; or ones that are experiencing difficulties in obtaining permissions for a re-build and/or ETR 132 compliance.

For circuits that will struggle to achieve ETR 132 compliance, consideration should be given into declaring a percentage of the line as ETR 132 compliant; or dividing the circuit with ABS switches either side of the anomoly and declaring either side as ETR 132 compliant and the middle as non-compliant.

Pole condition should be added to the AIS inspections, as this will reduce the amount of poles that need re-testing plus it will give a better understanding of the Health of the pole asset class. As Ofgem move into the next price review (RIIO ED1) greater emphasis will be placed on a risk-removed output measure for asset classes. DNOs will be required to take a holistic risk-based approach to asset management, by reporting the risk of an asset class at the beginning of the ED1 price review and, with investment, its risk will be at the end of ED1. The important outcome at the end of the RIIO ED1 price review will be the Health and subsequent risk of an asset class rather than how many kilometers of line were re-built. Risk management processes like EA Technologies CBRM (Condition Based Risk Management) process can evaluate the risk of an asset class through age, environment, probability of failure and criticality, however it is much more accurate if condition data is also supplied.

Major investment is required in the re-building of ENA TS 43-30, it was identified in the Boxing Day storm review report **[1]** as being in need of refurbishment after the storm event of 1998. The investment will help reduce the amount of LV faults during storm events plus it will drastically reduce the clear up duration and non-planned CMLs; and therefore the amount of customers that experience supply interuptions in excess of 48 hours.

Although the re-building of OHLs with ENA ETR 132 tree cutting is the prefered method of upgrading; the introduction of alternative OHL designs should be considered for areas of restricted ETR 132 compliance or other environmental anomalies. Training will be required for all of SPEN's workforce that will come into contact with any alternative constructions, plus stocks of materials and equipment should be made available for any maintenance.

An investigation into why the Ayrshire & Clyde South, Central & Fife and Edinburgh & Lothians region's severe weather areas performed so well compared to other areas. This could identify that the severe weather map requires some refinement or some other reason that could benefit the other regions.

During HV refurbishment consideration should be given to renewing the first LV poles from OHL substations and replacing the first span with ABC conductor. This should reduce the number of LV faults that escalate into HV faults, plus it will reduce the need for subsequent HV shutdowns during LV refurbishment, which in turn will help reduce 'Planned CIs'.

Spurs with large numbers of connected customers should be considered for inclusion within the improvement programmes.

As HV 'Insulator' faults increased proportionally during the 2012 storm event it would be prudent to investigate if SPEN's network received more windborne damage or whether there is an underlying problem with insulators. SPEN however are currently in the process of issuing a new insulator tender, which will specify that all new tension insulators are manufactured from silicone and, HV pin insulators will be manufactured from polyethylene. Therefore there is very little value in such an investigation.

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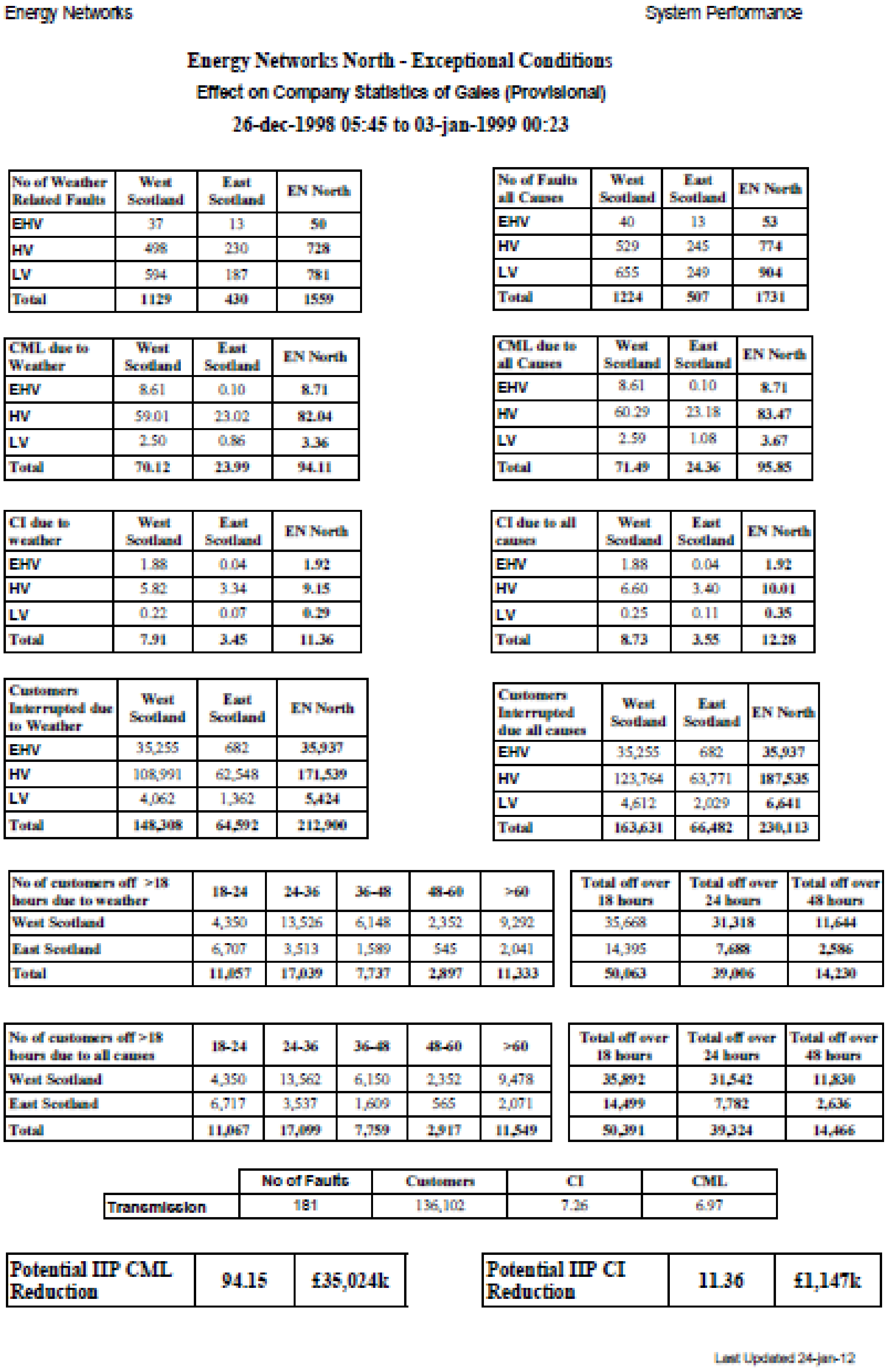
Appendix 1



Energy Networks System Performance

Energy Networks North - Exceptional Conditions

Effect on Company Statistics of Gales (Provisional)

26-dec-1998 05:45 to 03-jan-1999 00:23

No of Weather Related Faults	West Scotland	East Scotland	EN North
EHV	37	13	50
HV	498	230	728
LV	594	187	781
Total	1129	430	1559

No of Faults all Causes	West Scotland	East Scotland	EN North
EHV	40	13	53
HV	529	245	774
LV	655	249	904
Total	1224	507	1731

CML due to Weather	West Scotland	East Scotland	EN North
EHV	8.61	0.10	8.71
HV	59.01	23.02	82.04
LV	2.50	0.86	3.36
Total	70.12	23.99	94.11

CML due to all Causes	West Scotland	East Scotland	EN North
EHV	8.61	0.10	8.71
HV	60.29	23.18	83.47
LV	2.59	1.08	3.67
Total	71.49	24.36	95.85

CI due to weather	West Scotland	East Scotland	EN North
EHV	1.88	0.04	1.92
HV	5.82	3.34	9.15
LV	0.22	0.07	0.29
Total	7.91	3.45	11.36

CI due to all causes	West Scotland	East Scotland	EN North
EHV	1.88	0.04	1.92
HV	6.60	3.40	10.01
LV	0.25	0.11	0.35
Total	8.73	3.55	12.28

Customers Interrupted due to Weather	West Scotland	East Scotland	EN North
EHV	35,255	682	35,937
HV	108,991	62,548	171,539
LV	4,062	1,362	5,424
Total	148,308	64,592	212,900

Customers Interrupted due all causes	West Scotland	East Scotland	EN North
EHV	35,255	682	35,937
HV	123,764	63,771	187,535
LV	4,612	2,029	6,641
Total	163,631	66,482	230,113

No of customers off >18 hours due to weather	18-24	24-36	36-48	48-60	>60
West Scotland	4,350	13,526	6,148	2,352	9,292
East Scotland	6,707	3,513	1,589	545	2,041
Total	11,057	17,039	7,737	2,897	11,333

Total off over 18 hours	Total off over 24 hours	Total off over 48 hours
35,668	31,318	11,644
14,395	7,688	2,586
50,063	39,006	14,230

No of customers off >18 hours due to all causes	18-24	24-36	36-48	48-60	>60
West Scotland	4,350	13,562	6,150	2,352	9,478
East Scotland	6,717	3,537	1,609	565	2,071
Total	11,067	17,099	7,759	2,917	11,549

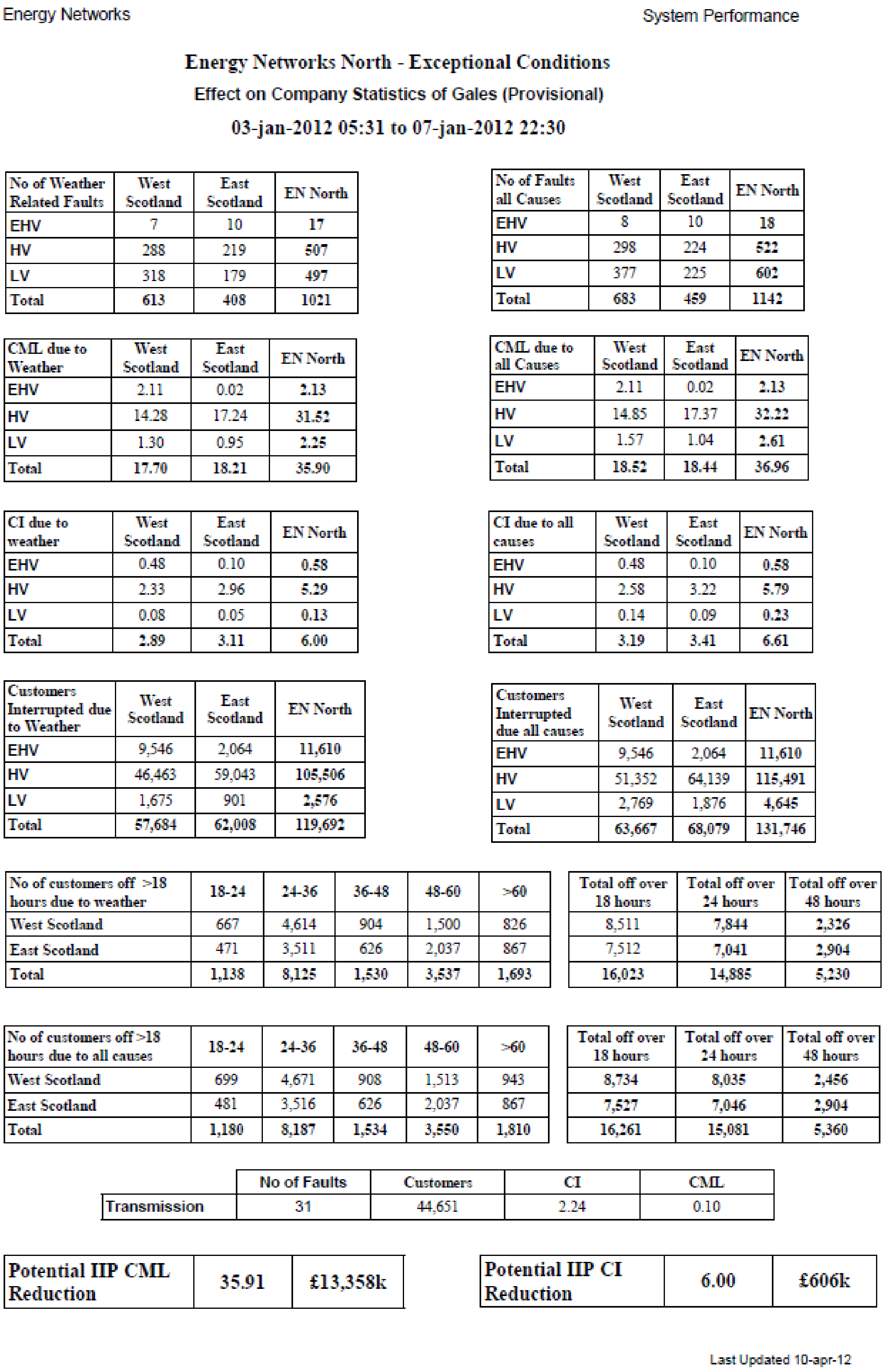
Total off over 18 hours	Total off over 24 hours	Total off over 48 hours
35,892	31,542	11,830
14,499	7,782	2,636
50,391	39,324	14,466

	No of Faults	Customers	CI	CML
Transmission	181	136,102	7.26	6.97

Potential IIP CML Reduction	94.15	£35,024k

Potential IIP CI Reduction	11.36	£1,147k

Last Updated 24-jan-12



Energy Networks System Performance

Energy Networks North - Exceptional Conditions

Effect on Company Statistics of Gales (Provisional)

03-jan-2012 05:31 to 07-jan-2012 22:30

No of Weather Related Faults	West Scotland	East Scotland	EN North
EHV	7	10	**17**
HV	288	219	**507**
LV	318	179	**497**
Total	**613**	**408**	**1021**

No of Faults all Causes	West Scotland	East Scotland	EN North
EHV	8	10	**18**
HV	298	224	**522**
LV	377	225	**602**
Total	**683**	**459**	**1142**

CML due to Weather	West Scotland	East Scotland	EN North
EHV	2.11	0.02	**2.13**
HV	14.28	17.24	**31.52**
LV	1.30	0.95	**2.25**
Total	**17.70**	**18.21**	**35.90**

CML due to all Causes	West Scotland	East Scotland	EN North
EHV	2.11	0.02	**2.13**
HV	14.85	17.37	**32.22**
LV	1.57	1.04	**2.61**
Total	**18.52**	**18.44**	**36.96**

CI due to weather	West Scotland	East Scotland	EN North
EHV	0.48	0.10	**0.58**
HV	2.33	2.96	**5.29**
LV	0.08	0.05	**0.13**
Total	**2.89**	**3.11**	**6.00**

CI due to all causes	West Scotland	East Scotland	EN North
EHV	0.48	0.10	**0.58**
HV	2.58	3.22	**5.79**
LV	0.14	0.09	**0.23**
Total	**3.19**	**3.41**	**6.61**

Customers Interrupted due to Weather	West Scotland	East Scotland	EN North
EHV	9,546	2,064	11,610
HV	46,463	59,043	**105,506**
LV	1,675	901	**2,576**
Total	**57,684**	**62,008**	**119,692**

Customers Interrupted due all causes	West Scotland	East Scotland	EN North
EHV	9,546	2,064	11,610
HV	51,352	64,139	**115,491**
LV	2,769	1,876	**4,645**
Total	**63,667**	**68,079**	**131,746**

No of customers off >18 hours due to weather	18-24	24-36	36-48	48-60	>60
West Scotland	667	4,614	904	1,500	826
East Scotland	471	3,511	626	2,037	867
Total	**1,138**	**8,125**	**1,530**	**3,537**	**1,693**

Total off over 18 hours	Total off over 24 hours	Total off over 48 hours
8,511	**7,844**	**2,326**
7,512	7,041	**2,904**
16,023	**14,885**	**5,230**

No of customers off >18 hours due to all causes	18-24	24-36	36-48	48-60	>60
West Scotland	699	4,671	908	1,513	943
East Scotland	481	3,516	626	2,037	867
Total	**1,180**	**8,187**	**1,534**	**3,550**	**1,810**

Total off over 18 hours	Total off over 24 hours	Total off over 48 hours
8,734	8,035	**2,456**
7,527	7,046	**2,904**
16,261	**15,081**	**5,360**

	No of Faults	Customers	CI	CML
Transmission	31	44,651	2.24	0.10

Potential IIP CML Reduction	**35.91**	**£13,358k**

Potential IIP CI Reduction	**6.00**	**£606k**

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EA Technology Limited
Capenhurst Technology Park
Capenhurst, Chester UK
CH1 6ES

tel +44 (0) 151 339 4181
fax +44 (0) 151 347 2404
email sales@eatechnology.com
web www.eatechnology.com

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