RESPOND Project Fault Level Report for Electricity North West Ltd

ENWL Fault Level Report 1 V3, 21/07/2016

Report written by John Outram

Change record		
Date	**Edited by**	**Reason**
29/3/2016	J.D.Outram	
25/4/2016	J.D.Outram	All Fault Level and other Current results for Wigan adjusted by 1.25 to suit corrected sub-station CT values (2000:1 c.f. 1600:1)
21/7/2016	J.D.Outram	Original minimal data from Broadheath Substation replaced with full results from subsequent Broadheath trial. Appendix 2 (Broadheath) replaced.

Contents

Introduction

This report documents the results obtained from Fault Level Monitors installed at five ENWL sites in the first half of 2016. These installations and the fault level results obtained are listed below. Detailed results and interpretations are included in the appendices for each site.

On 18th March 2016, data was received from ENWL for the four FLMs for five substations. The original data for Broadheath was incomplete, and more complete data from a subsequent trial was received at the end of June 2016. This more recent data is reported on below and is detailed in the new Appendix 2. The five substations are:

FLM serial No	Installed at	Recording Start Date	Recording End Date
0887	Wigan BSP (200421)	24/12/2015	09/03/2016 [1]
0888	Broadheath (100134)	11/03/2016	16/06/2016 [2]
0889	Irlam Primary (100615)	05/01/2016	07/03/2016
0890	Hindley Green ()	24/12/2015	13/01/2016 [3]
0890	Denton West (100111)	13/01/2016	08/03/2016 [3]

[1] Results for Wigan have been adjusted to suit a Secondary CT ratio of 2000:1. (The original data was recorded with CT ratio entry of 1600:1, i.e. all currents were initially reported at 80% of correct value.)

[2] On the initial trial, connection to Phase C current sensor was faulty. Consequently Ic was not recorded correctly. All connections were correct on the subsequent trial, and Broadheath reporting below refers to this second recording.

[3] The FLM serial No 890 was initially installed at Hindley Green, but moved from there on 13th January to Denton West.

Connection checks

Connection checks were made on all sites by examination of phases of typical waveforms obtained during the recording. All sites showed correct phase relationships.

Fault Level results

Fault Level results were obtained for each site as shown in the table. All results are in kA.

FLM serial No	Installed at	10ms Peak Upstream	10ms Peak Downstream	90ms RMS upstream	Combined 10ms Peak[4]
0887	Wigan BSP (200421)	16.83	1.60	7.51	18.43
0888	Broadheath (100134)	29.56	3.217	10.16	32.78
0889	Irlam Primary (100615)	29.4	4.27	11.63	33.67
0890	Hindley Green () - A	22.16	2.72	9.64	24.88
0890	Hindley Green () - B	17.95	2.72	8.4	20.67
0890	Denton West (100111)	34.84	3.47	14.08	38.31

[4] Assuming the Upstream and downstream results are relevant at the same time, and that the phase of the downstream contribution is exactly in phase with the Upstream contribution. This assumption implies that the downstream phase remains constant and worst case. In practice, it has been observed that some motor contributions slowly rotate in phase from the inception of the disturbance, consequently the vectors may not precisely line up, and hence this figure may be slightly overstated.

General comment on results

The results all appear to be good. For the Upstream Fault Level contributions, there is more scope for manipulation of the Broadheath results, for which disturbances were generally small, than for the others, but all appear unambiguous. The downstream contributions depend heavily on what motors or other downstream energy sources were present and in operation at the time of the upstream disturbances upon which the downstream assessments depend, but even these distributions are tighter than have been encountered at other sites. Although Hindley Green was a shorter test, it proved interesting as it does appear to have two distinct Fault Level regimes A and B, as listed in the table above.

General sources of error

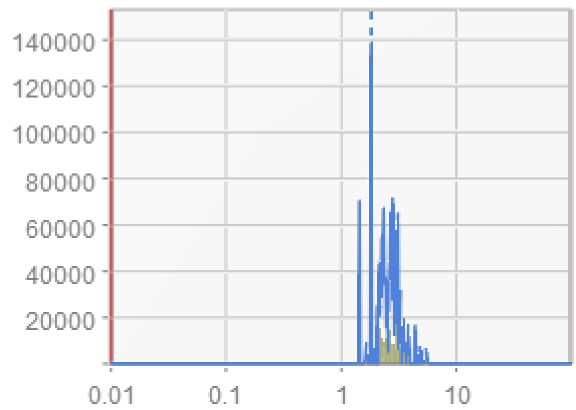
Quality of the Fault Level results are susceptible to noise, incorrect hook-up, sensor failure, short term frequency measurement accuracy, and less obvious but nevertheless systematic faults such as VT and CT errors. Amplitude errors clearly translate into equivalent Fault Level errors. In particular phase error in VTs and CTs can have a significant effect on Peak Fault level, as impedance phase measurement is crucial to X/R assessment, and hence the DC offset associated with the Peak asymmetric Fault Level at ½ cycle. At high X/R ratios, 1 degree of phase error can cause Peak Fault Level to be wrongly calculated by 2.5%.

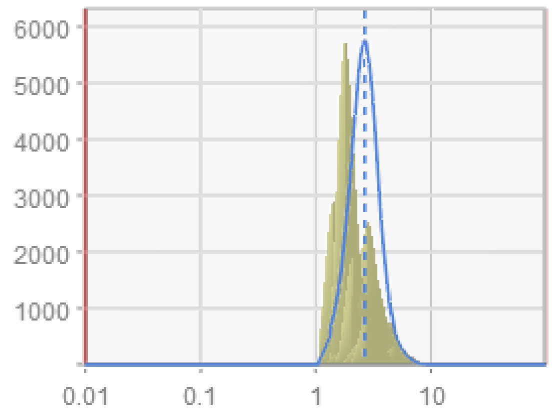
Manipulation of the data, data lumping, smoothing/filtering

For general application of the Pronto manipulation tools, please see the “Outram PM7000FLM Operating Procedure.pdf”. The manipulation of results for the individual sites and the specific Fault Level parameters are included in the discussion of each site in the Appendices.

The main manipulation tool used on the data shown in this report is the Filter/Smoothing function. This tool works with the distribution of Fault Level results and the “Peak of the distribution” detector either to isolate or share a discrete Fault Level result with its neighbours. The process of finding the best Fault Level from a distribution involves automatically scanning the distribution looking for the peak. If the distribution of results is spasmodic, or non-gaussian, the position of the peak may not be a good representation of the Fault Level. The Filter tool shares the “strength” of each Fault Level result with adjacent cells which effectively broadens out each result making it easier to see the aggregate strength of clusters of results. The degree of broadening is controlled by the filter selection.

The left hand Fault Level graph below shows a distribution without filtering, and the peak detected by the distribution scanning process (the dotted line), which is at ~1.8kA. (Fault Level is on the horizontal axis, and strength of result, or weight or value, is on the vertical axis.) The right hand graph shows the same input data with heavy filtering applied, enabling the cluster of results above the single large result at 1.8kA to be more strongly represented. The peak is now detected at 2.6kA.

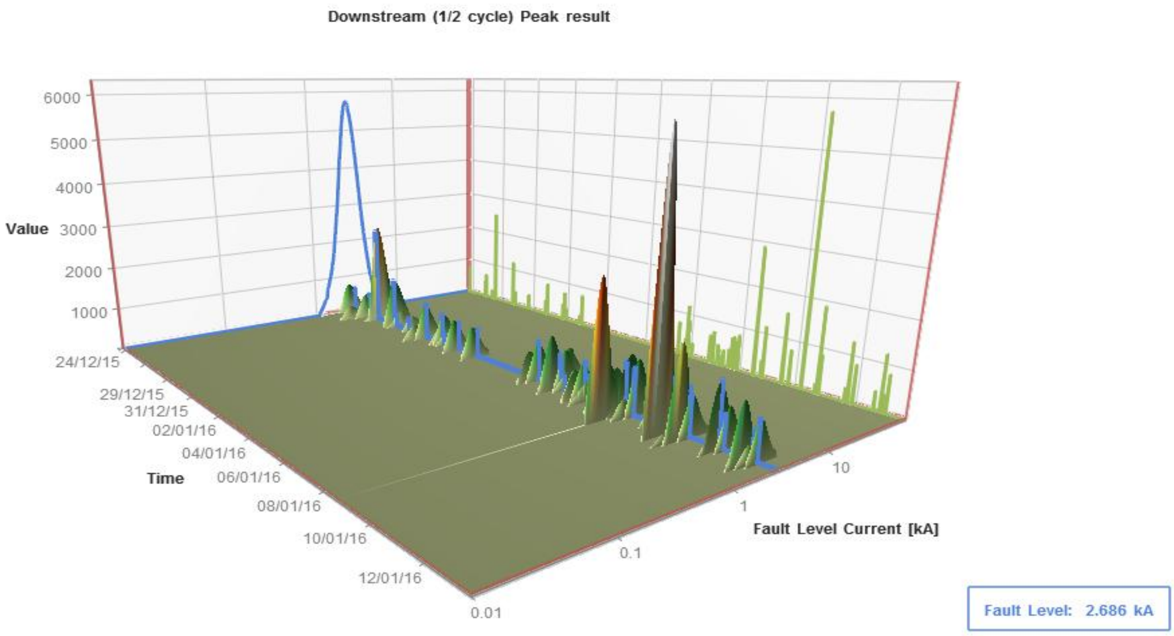




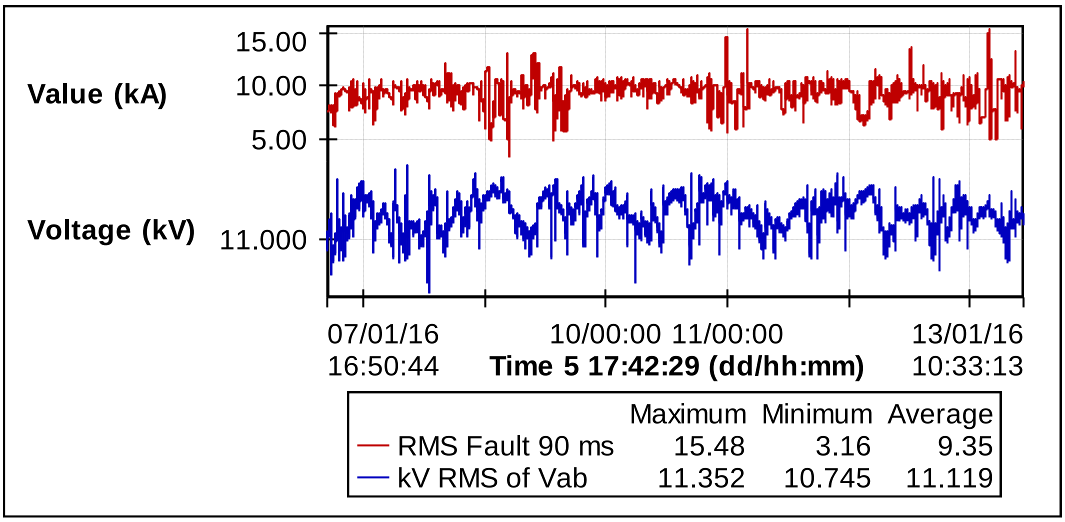
The general rule is to use as little filtering as is necessary to create a bell–shaped distribution around the area of interest.

Fault Level Graphing. Two and three dimensional distribution surface plots versus using standard Pronto graphing against time

Fault Level data is best graphed in the Pronto software using the two dimensional distribution plot, as shown above, or the three dimensional surface plot method, shown below. These graphs are built up from arrays of data stored at specific intervals during the recording period.



If Fault Level is also recorded against time just as Voltage is recorded, then it may be graphed against time in the same way as voltage. An example is shown below.



BEWARE that this type of Fault Level data presentation though containing useful information, can be very misleading and should be treated with caution.

Presentation of Fault Level results and weighting data against time in the standard Pronto graphing system may not be recognisable and will generally never produce the same average results as might be expected from the Fault Level 2D and 3D graphic presentations. This is because of the irregular arrival times of evaluated disturbances. The averages calculated from the standard graphing system take into account the time between consecutive results, and the longer the time between result A and next result B, the greater the weight (in the average calculation) attributed to result A. Thus a high quality result A of great weight (large disturbance) followed after interval T1 by a poor result B of low weight will have an influence directly proportional to the interval T1. If a third result C is obtained after a further interval T2, the significance of A and B are completely dependent on the intervals T1 and T2. If T1 is long and T2 short, A will be more heavily weighted (in the average calculation) than B. If T1 is short by comparison with T2, B is more heavily weighted. The average result over any period will therefore depend very much on the disturbance arrival times.

Appendix 1. Wigan BSP. FLM Serial No 887

Sources of error

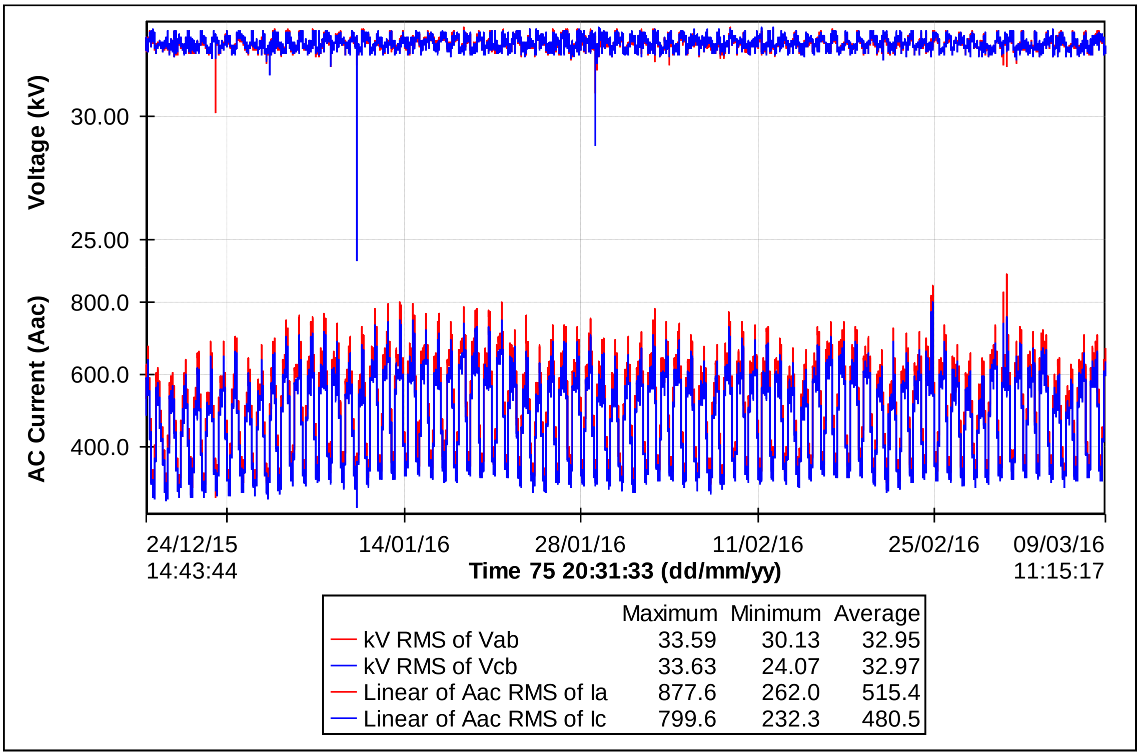
The overall results for Wigan BSP over the 10 week period are as clean as any we have seen. There is very little room for manipulation of these results, so sources of error are principally the systematic ones of incorrect assumptions, wrong CT settings, faulty sensors, cables etc. If the current and voltage results recorded by the PM7000 and shown below match the independent measurements reported by the ENWL SCADA or other systems, then it is very unlikely that these results are wrong.

To give an indication of possible error magnitudes, we can examine how the smoothing filter variation affects the results. The spread of peak results on the noisiest data, (the 90ms RMS result) from no filtering to maximum (10% of span) is just 5.6%. For the quietest, the ½ cycle RMS, the spread is 2.5%. In both cases, 10% filtering is far more than is needed, and since the higher filter values include more of the (potentially anomalous) outliers, if they can be avoided, i.e. if the shape of the distribution is bell-shaped and clean at low filter values, then the low filter values are likely to give the most accurate results. Filter variation from 2% to 5% on the 90ms RMS result gives a peak spread of 1.3% (2% is about the minimum filtering needed in this case to get a clean distribution), and for the ½ cycle Peak result, the spread for filter variation from 0 to 5% is just 1%.

As the total accrual period for assessment is reduced from the total 10 weeks, the noise can become more significant. Graphs 16 and 20 below show 24 and 12 hour windows.

Wigan BSP results, General observations

Graph 1 shows the voltage and current for the full recording period.



Graph 1. Volts and Current for the full recorded period.

There appear to have been three voltage events (actually four, the event on the 29th January is two, about 38 minutes apart). None of them appear to have been caused by a load downstream of this substation/feeder. Graphs 2-5 show the RMS detail.

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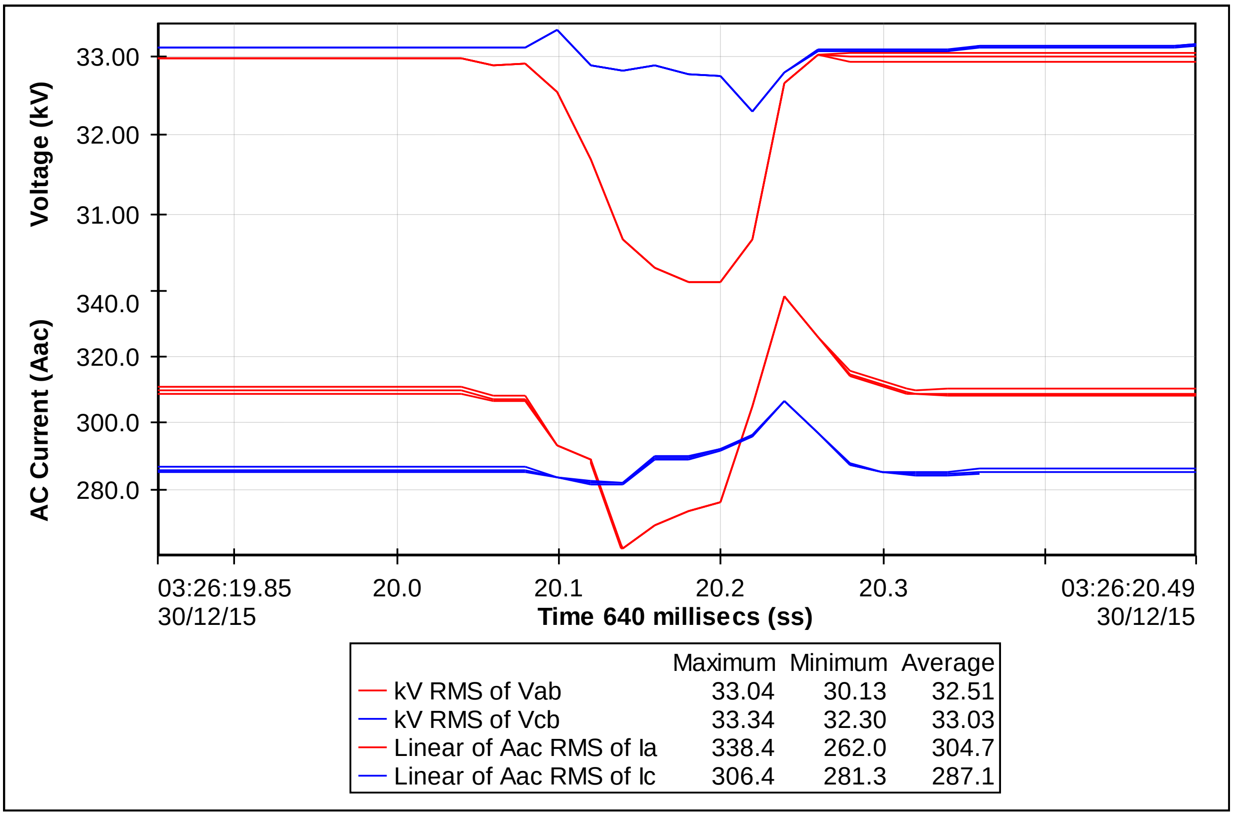

Graph 2. A-B phase voltage disturbance on 30th December 2015.

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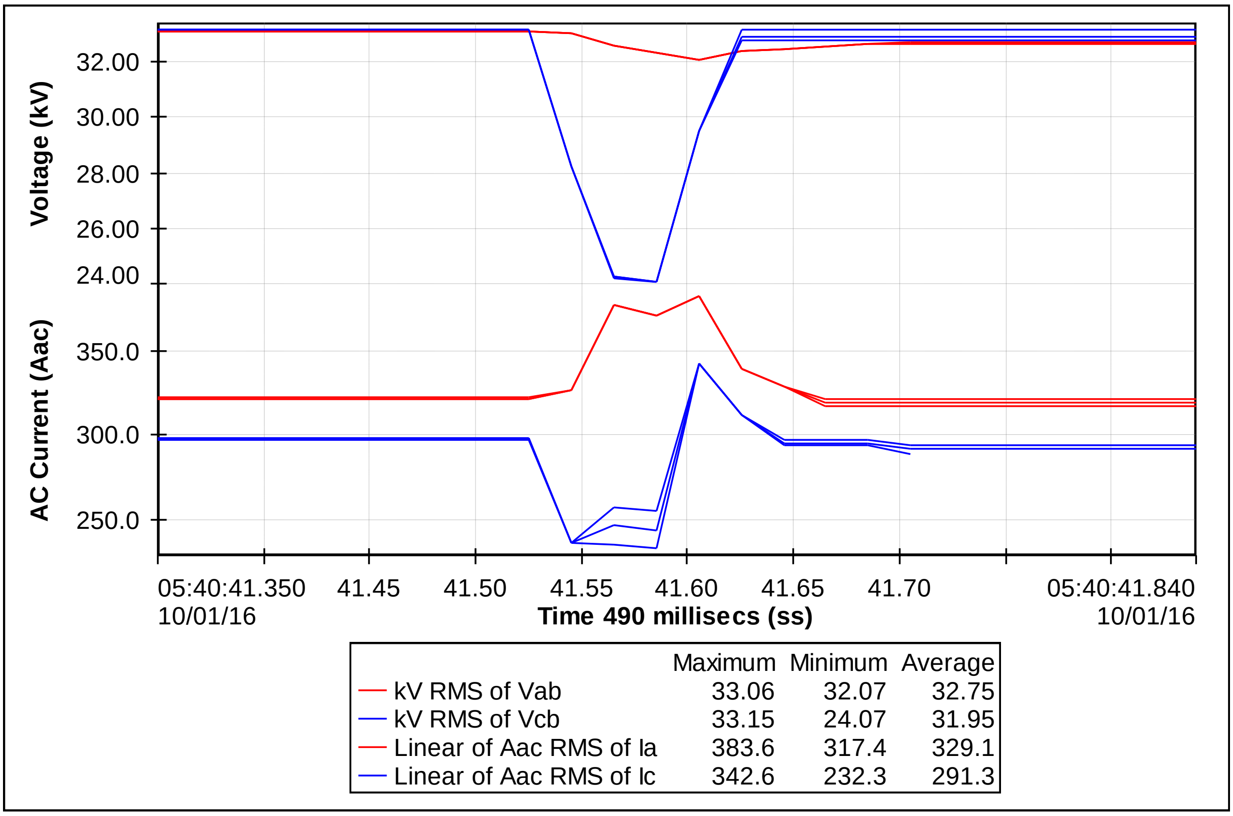
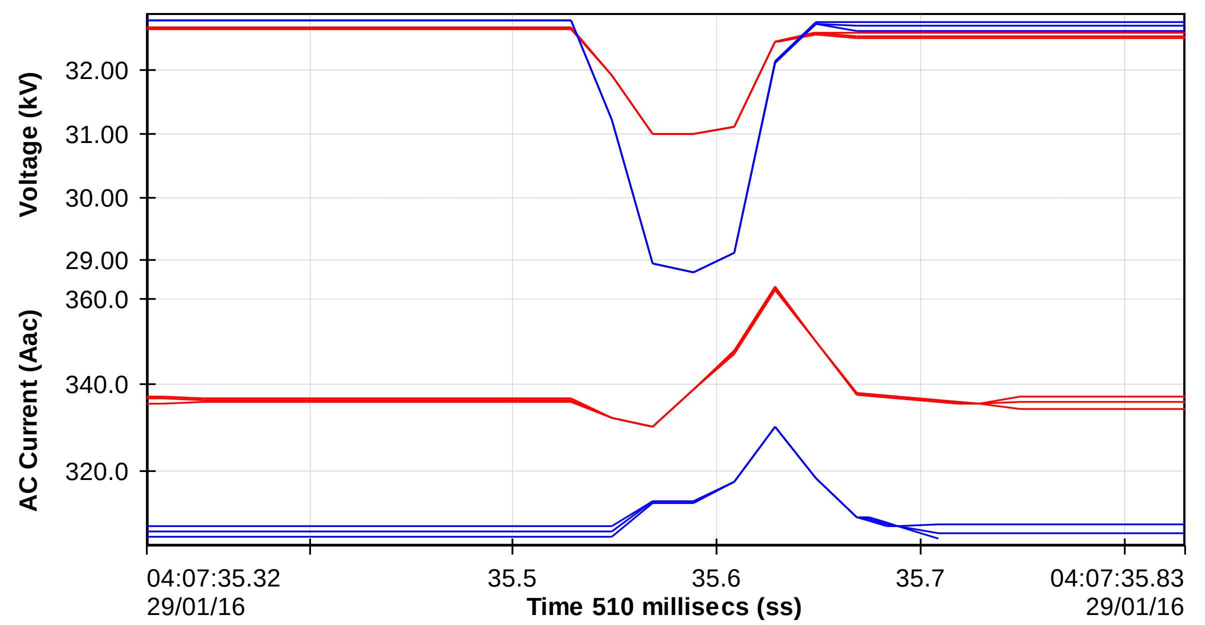
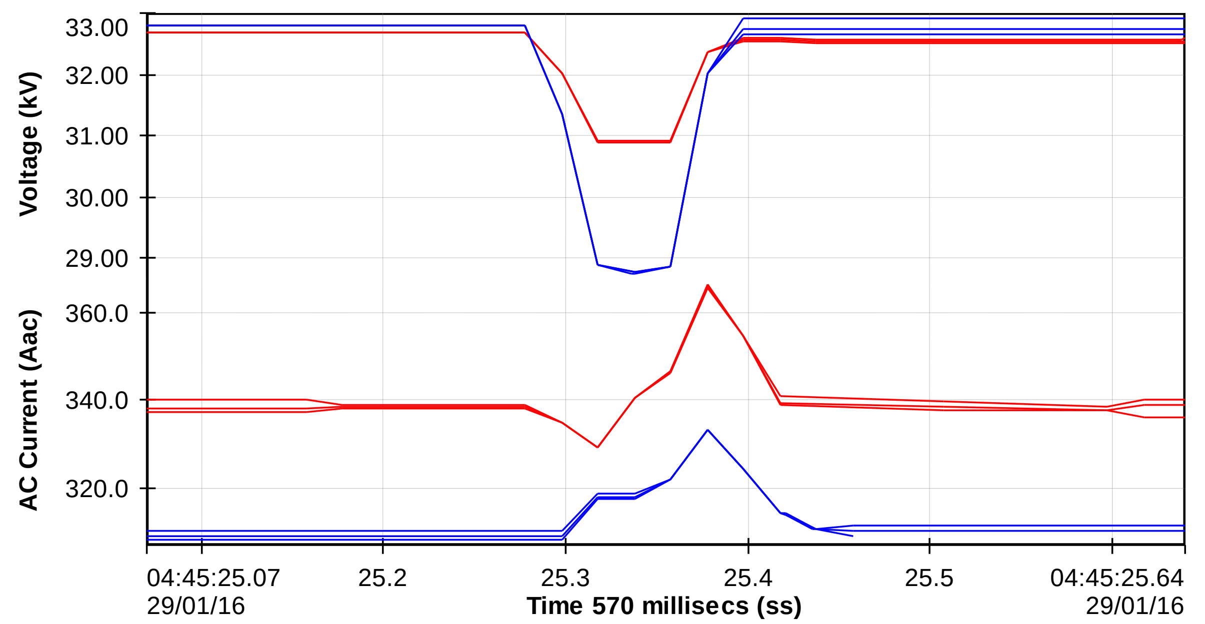


Graph 3. C-B phase voltage disturbance on 10th January 2016.



	Maximum	Minimum	Average
kV RMS of Vab	32.67	30.99	32.39
kV RMS of Vcb	32.80	28.80	32.21
Linear of Aac RMS of Ia	363.1	330.1	338.1
Linear of Aac RMS of Ic	330.1	303.9	308.2

Graph 4. First C-B phase voltage disturbance on 29th January 2016.



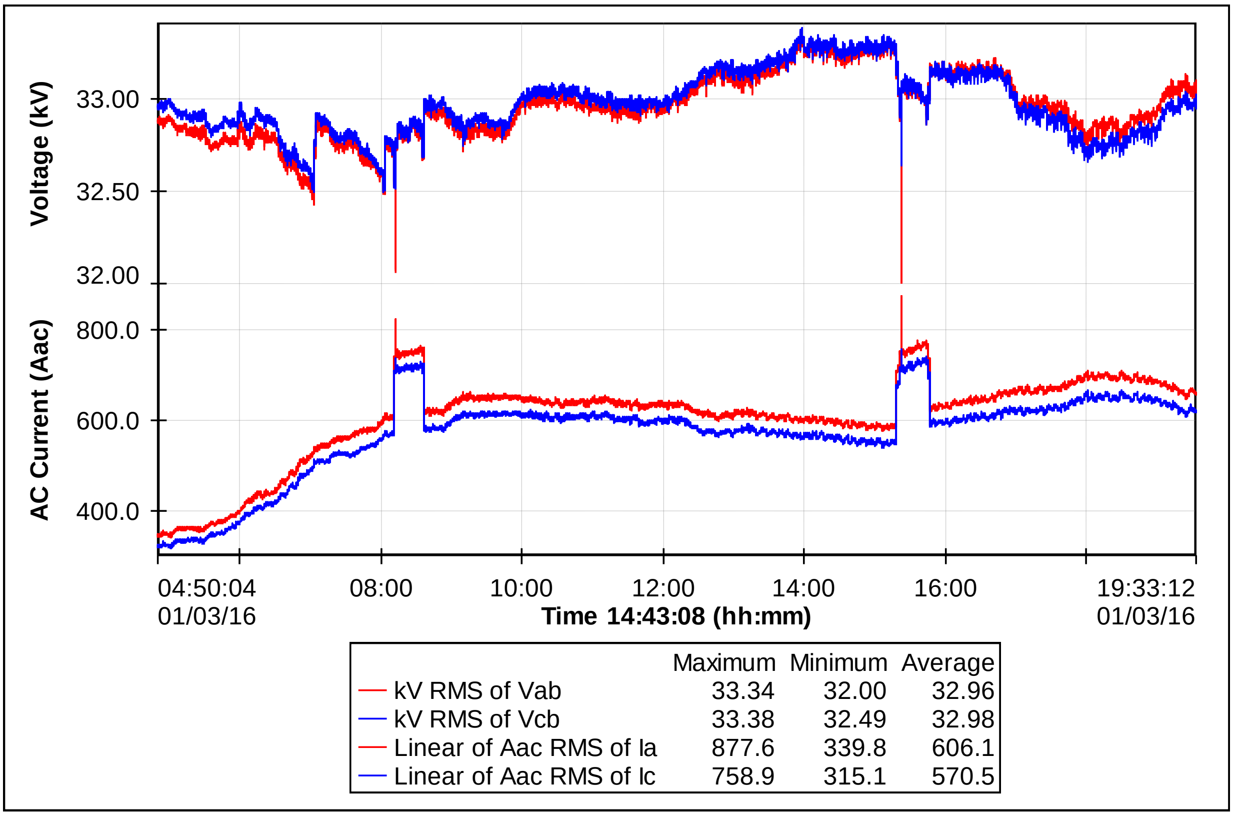
	Maximum	Minimum	Average
kV RMS of Vab	32.69	30.90	32.40
kV RMS of Vcb	32.90	28.76	32.28
Linear of Aac RMS of Ia	366.1	329.4	339.9
Linear of Aac RMS of Ic	333.1	308.5	312.3

Graph 5. Second C-B phase voltage disturbance on 29th January 2016.

Useful Fault Level type disturbances.

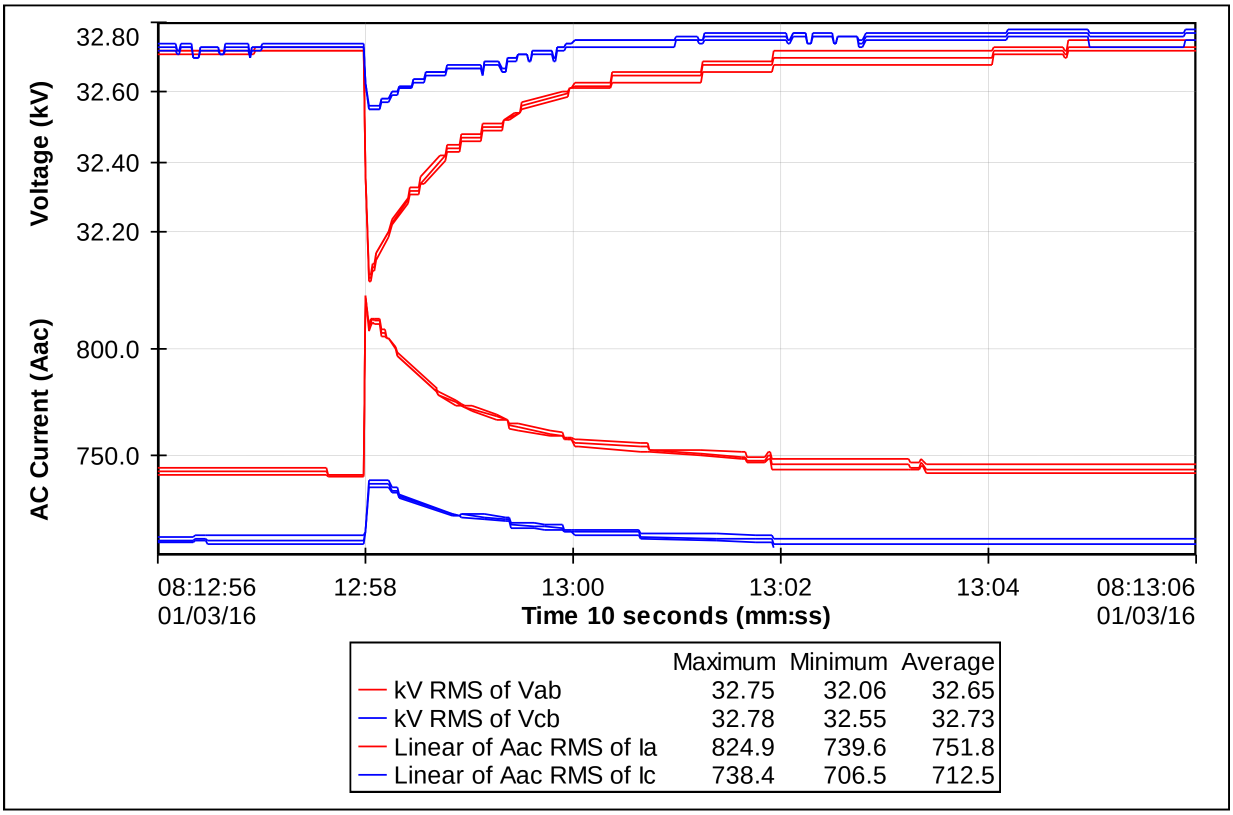
During the bulk of the recording there were few substantial current spikes, but plenty of low level activity.

On 1st March, there were two slightly abnormal load changes as shown below. These may have yielded good Fault Level samples.



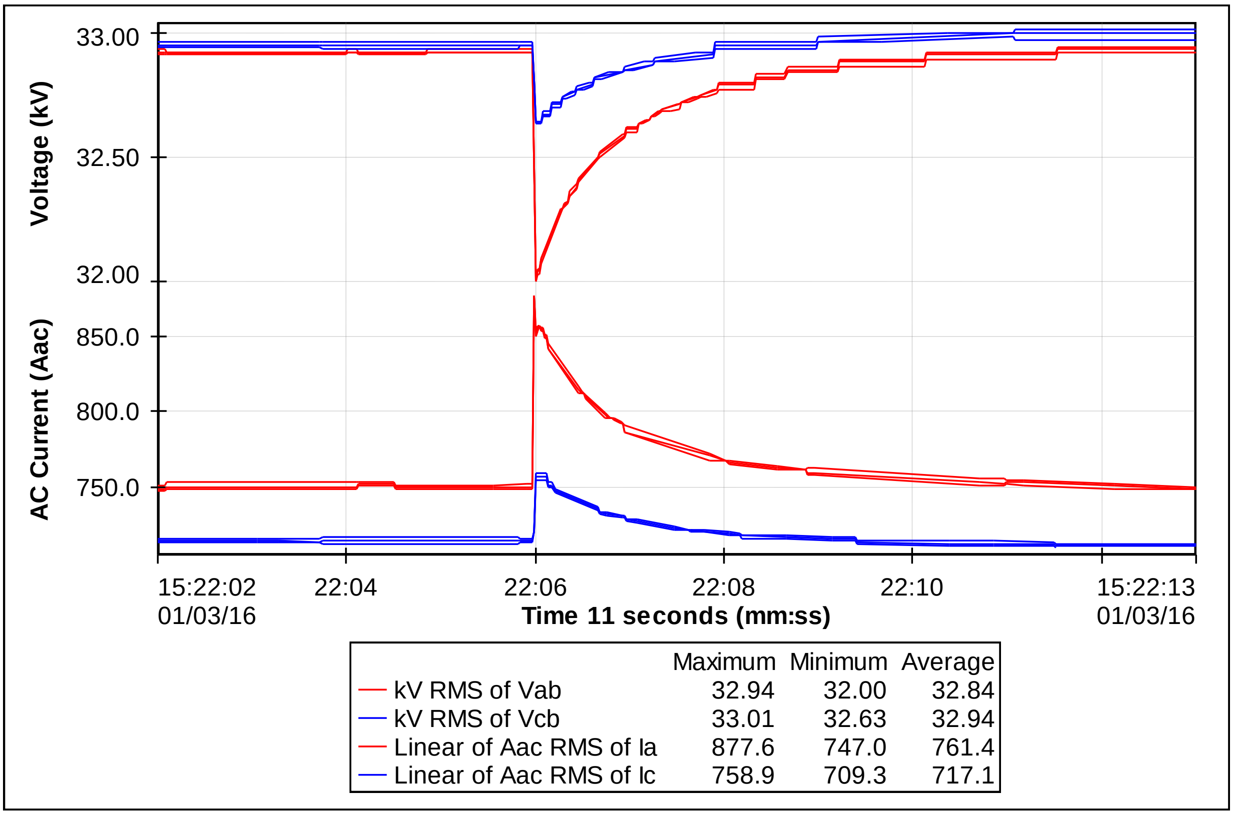
Graph 6. Two load generated disturbances.

The initial large current step would be useful, as would the very short spike, shown below.



Graph 7. Expansion of load generated disturbance on 1st March 2016 at 12:58.

The spike occurs about 3 minutes into the high load current condition. A very similar thing occurs at 15:22, as shown in Graph 8 below

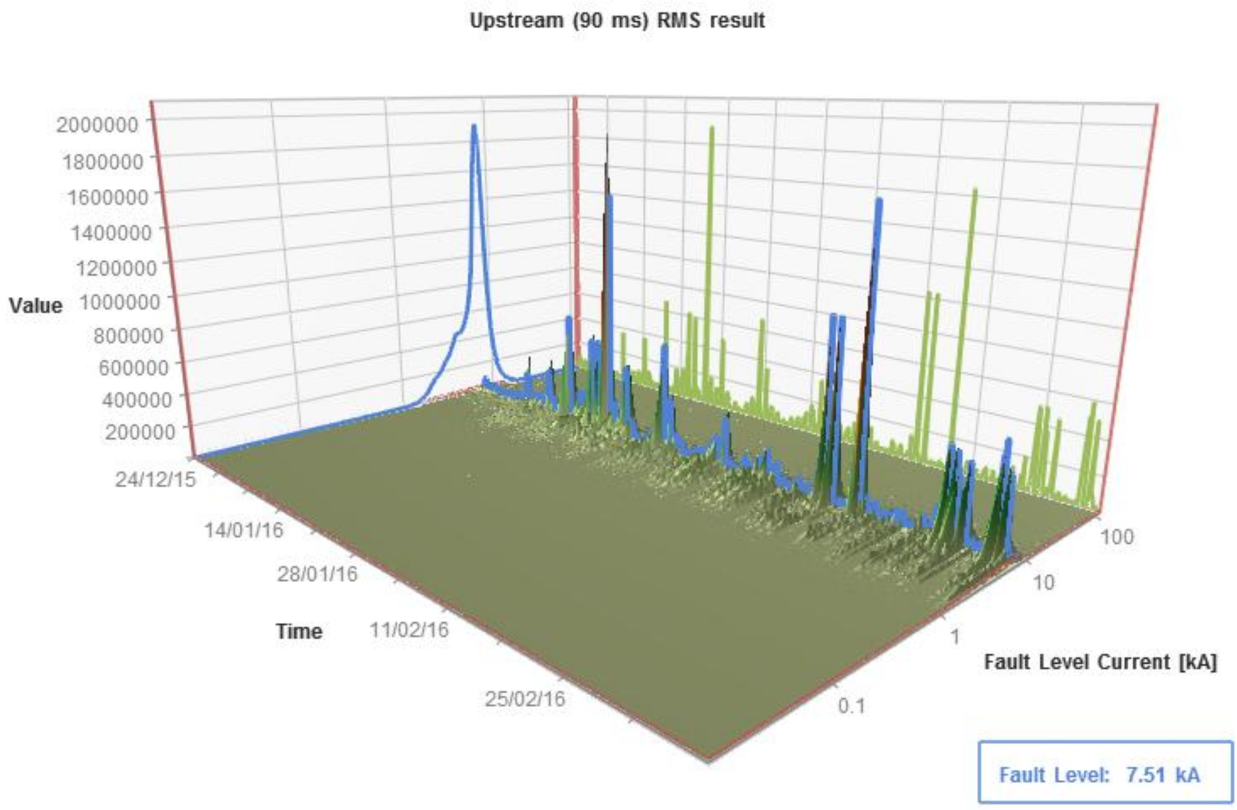


Graph 8. Expansion of load generated disturbance on 1st March 2016 at 15:22.

General Power Quality

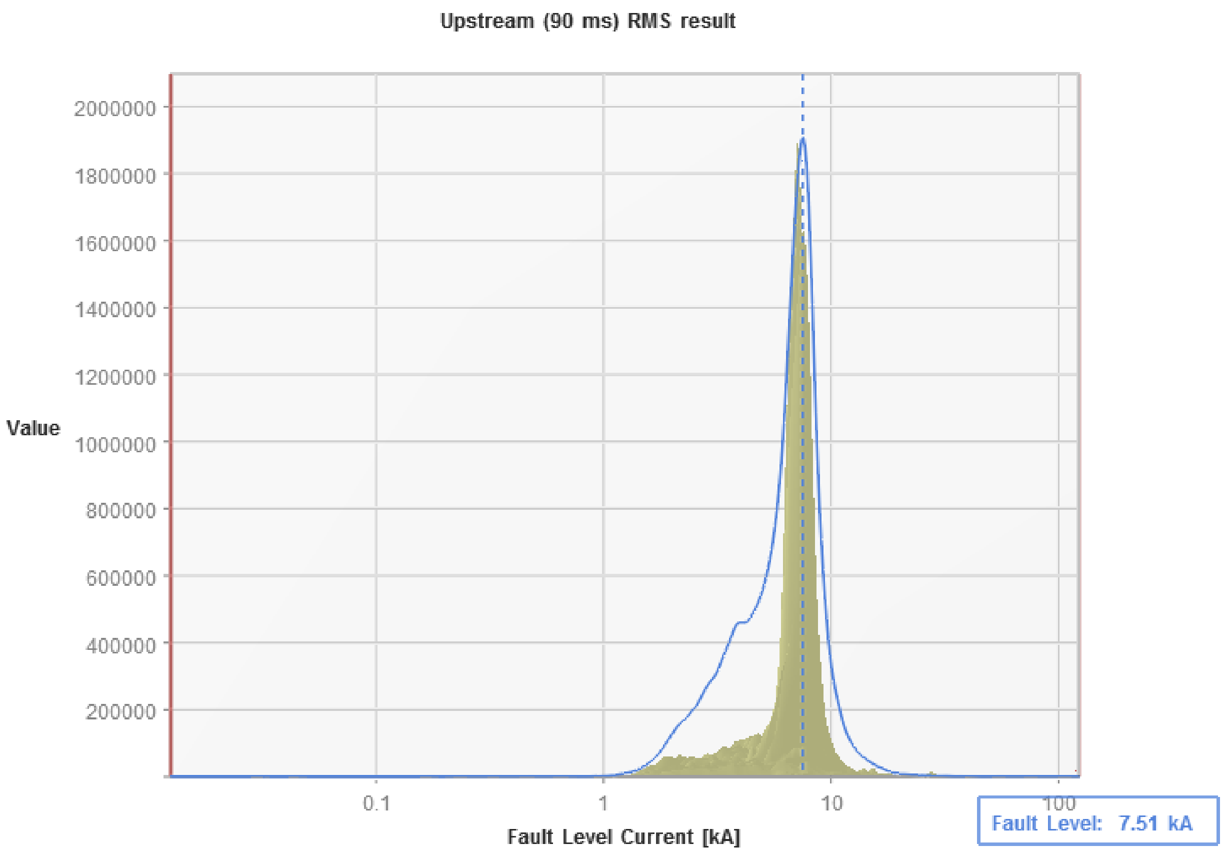
In addition to the spikes observed, there were a number of higher speed or resonance PQ events recorded in waveform snapshots at different times. These can be reported upon if required.

Fault Level Results



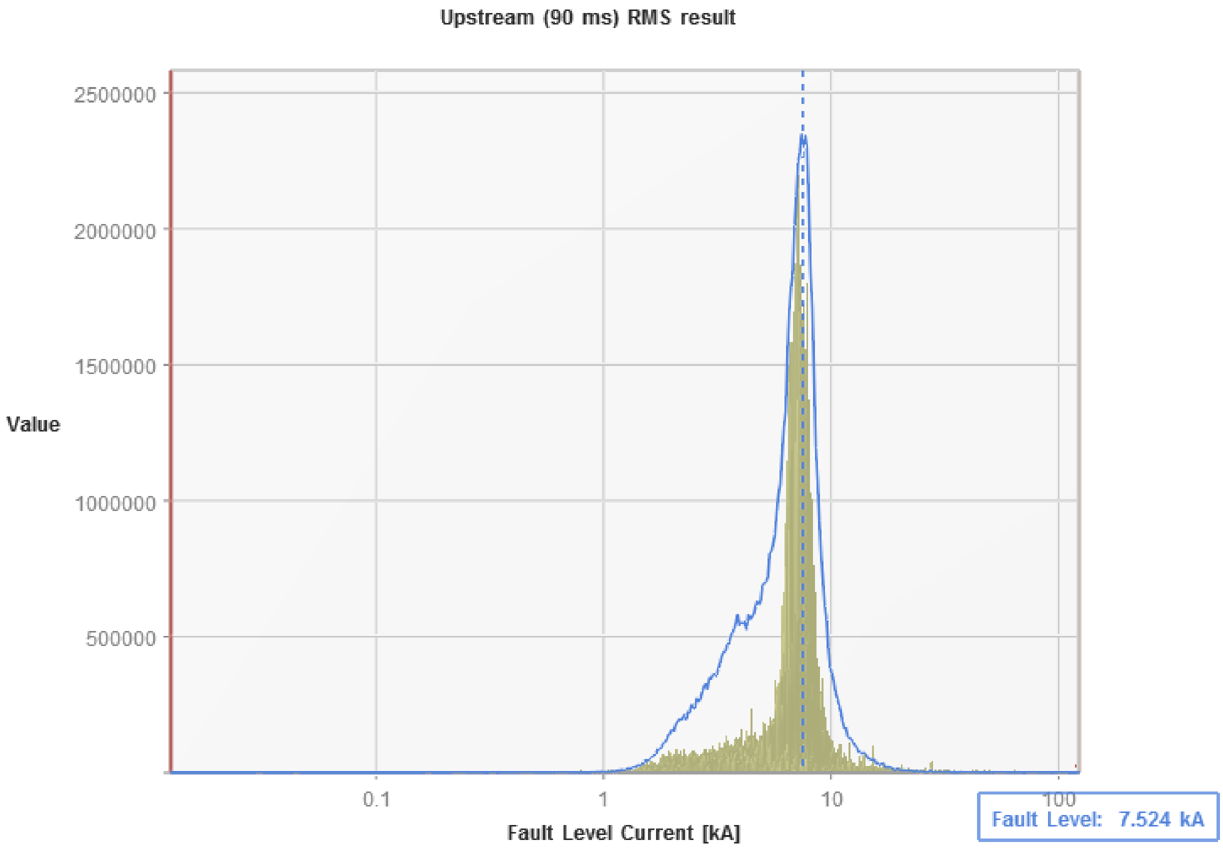
Graph 9. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.

Graph 9 shows that the mean Upstream 90ms RMS Fault Level for the period was 7.51 kA. Graph 10 shows the same thing in 2 dimensions.



Graph 10. Upstream RMS Fault level at 90ms. 2D Distribution shown with 2% filtering.

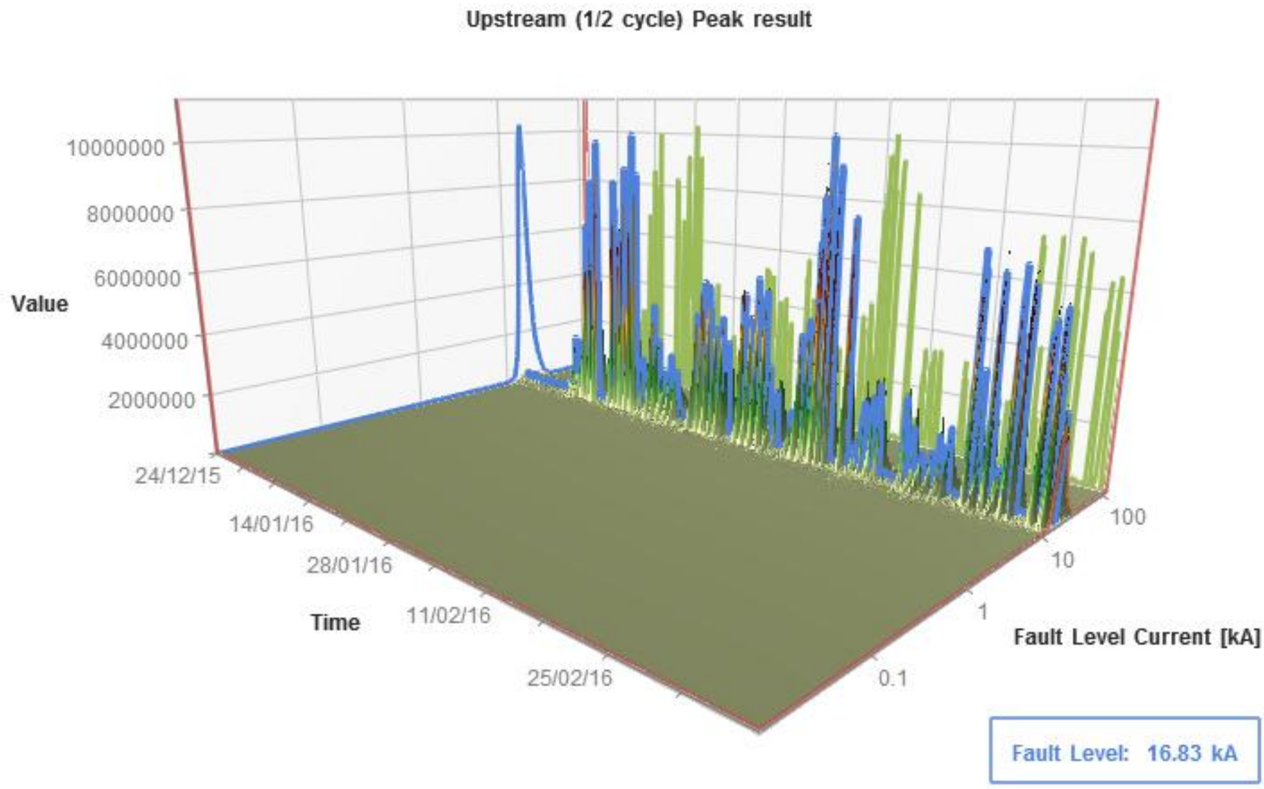
A modest degree of filtering was used to extract this peak, as without it, the nose of the distribution is slightly biased high, as shown in Graph 11 below.



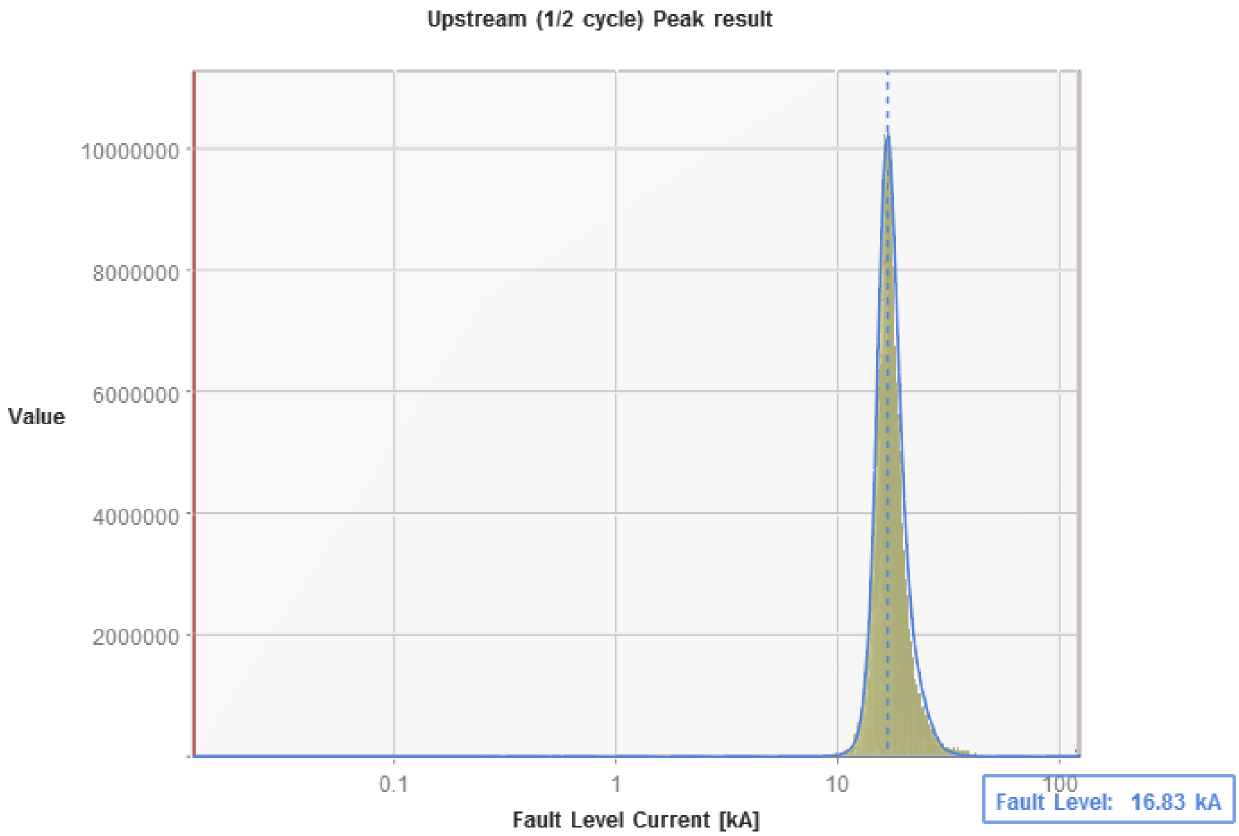
Graph 11. Upstream RMS Fault level at 90ms. 2D Distribution shown with no filtering.

In fact the distribution is relatively narrow so that there is very little variation between the two. As can be seen on all three graphs, there is quite a lot of "grass", low energy samples, giving results below the main peak. This is typical of the low level disturbance energy left behind at 90ms after a fast disturbance such as motor start-up. The energy seen at half-cycle rather than 90ms is generally higher, and consequently the peak and the RMS evaluated at 10ms are more symmetrical.

Graphs 12 and 13 show the Peak Upstream Fault Level for the whole period.

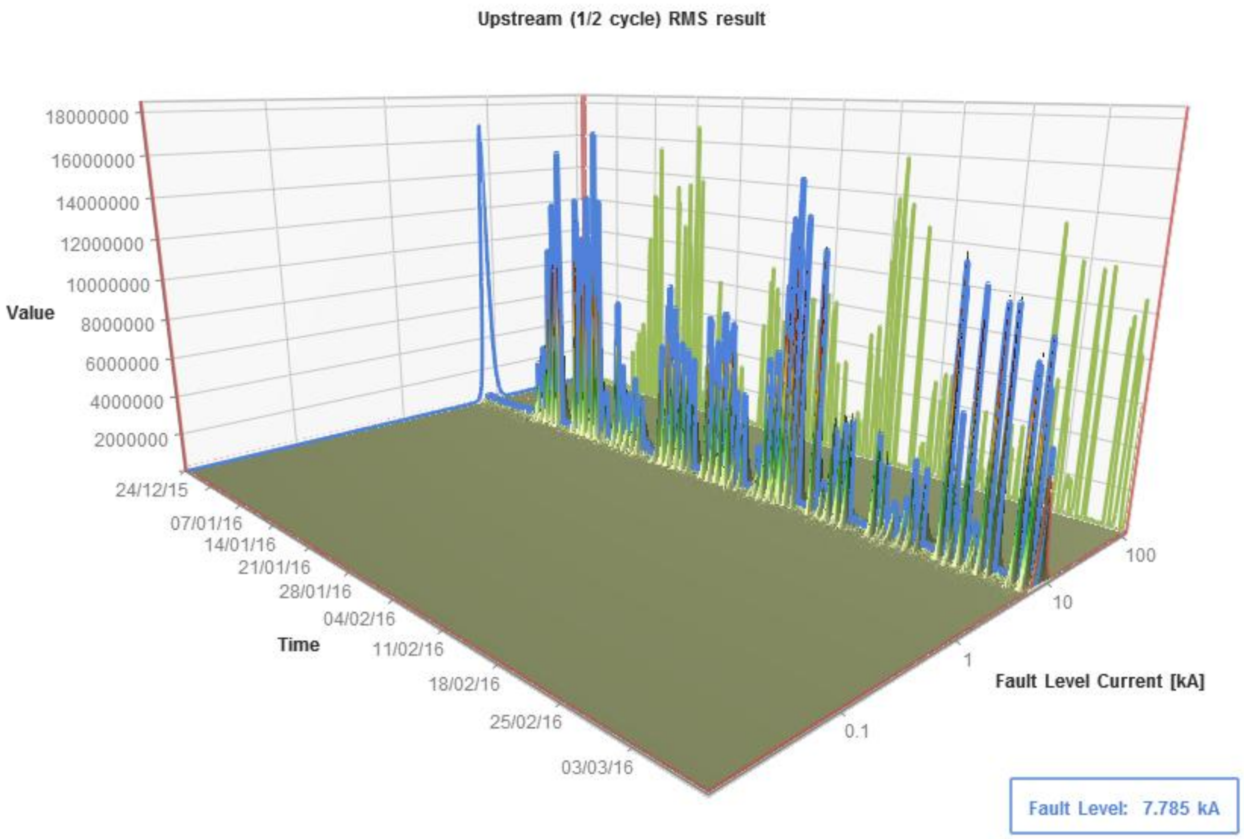


Graph 12. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with no filtering.

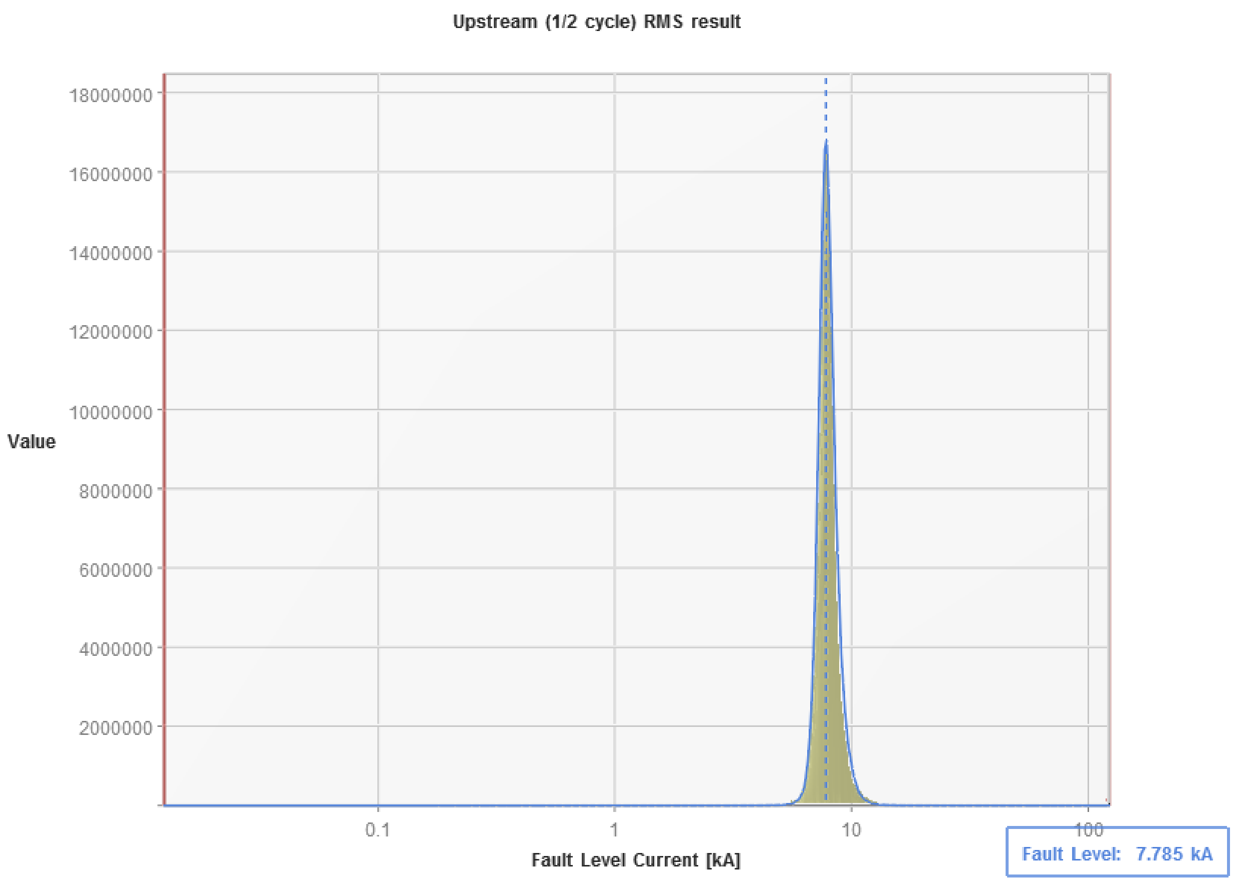


Graph 13 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with no filtering.

Graphs 14 and 15 show the Upstream RMS result at half-cycle.



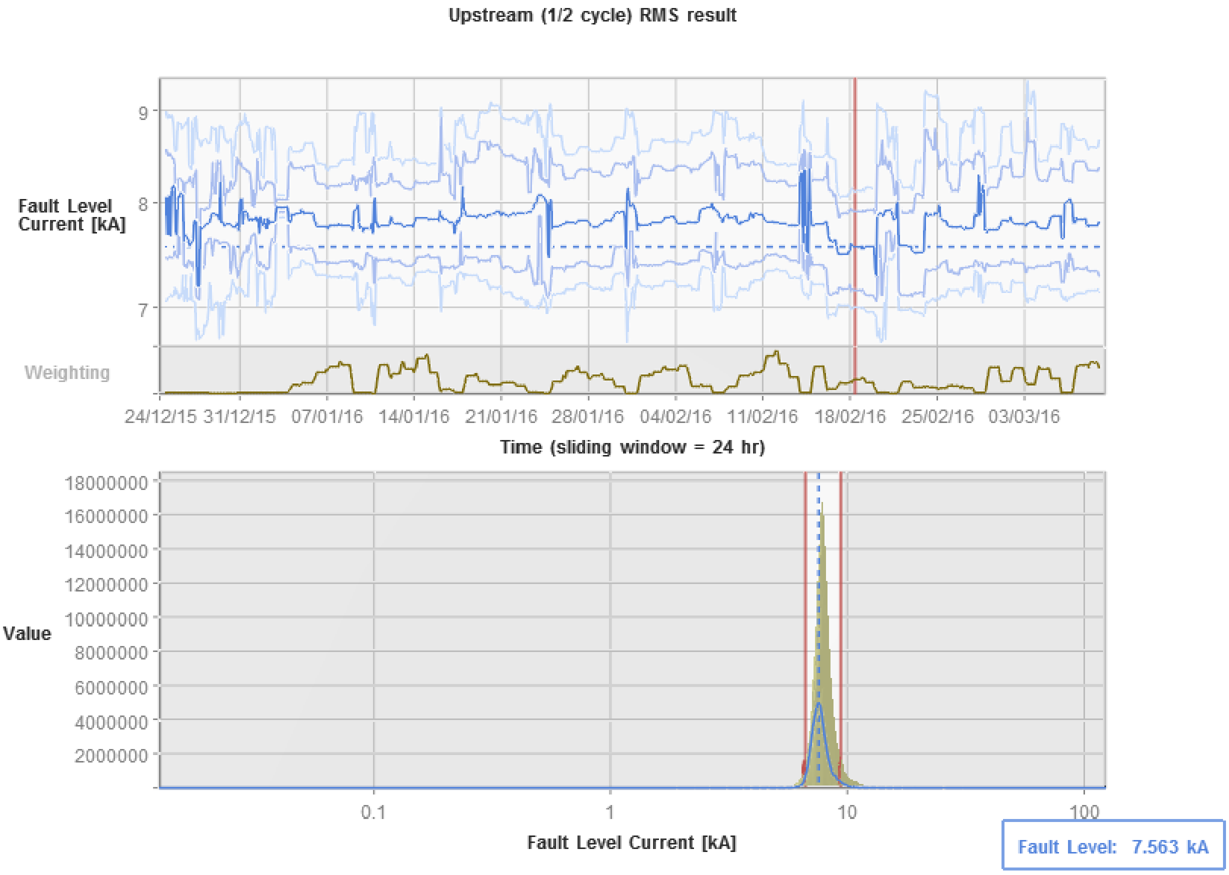
Graph 14. Upstream RMS Fault level at ½ cycle. 3D Distribution shown with no filtering.



Graph 15. Upstream RMS Fault level at ½ cycle. 2D Distribution shown with no filtering.

These distributions are some of the best that have been seen. It is rare that no filtering is required, but this may be because the installation has been monitored for longer than has typically been the case. The above graph 15 is narrower still than the Peak graph 13. They are both derived from the same data, but whereas the RMS depends on the absolute value of impedance, the Peak also depends on the phase, so it is generally noisier (and the distribution broader) than the RMS result.

Looking at these results over much shorter times, we can observe short term variation. Graph 16 below shows the cleanest of the above (the ½ cycle RMS result) averaged over 24 hours.

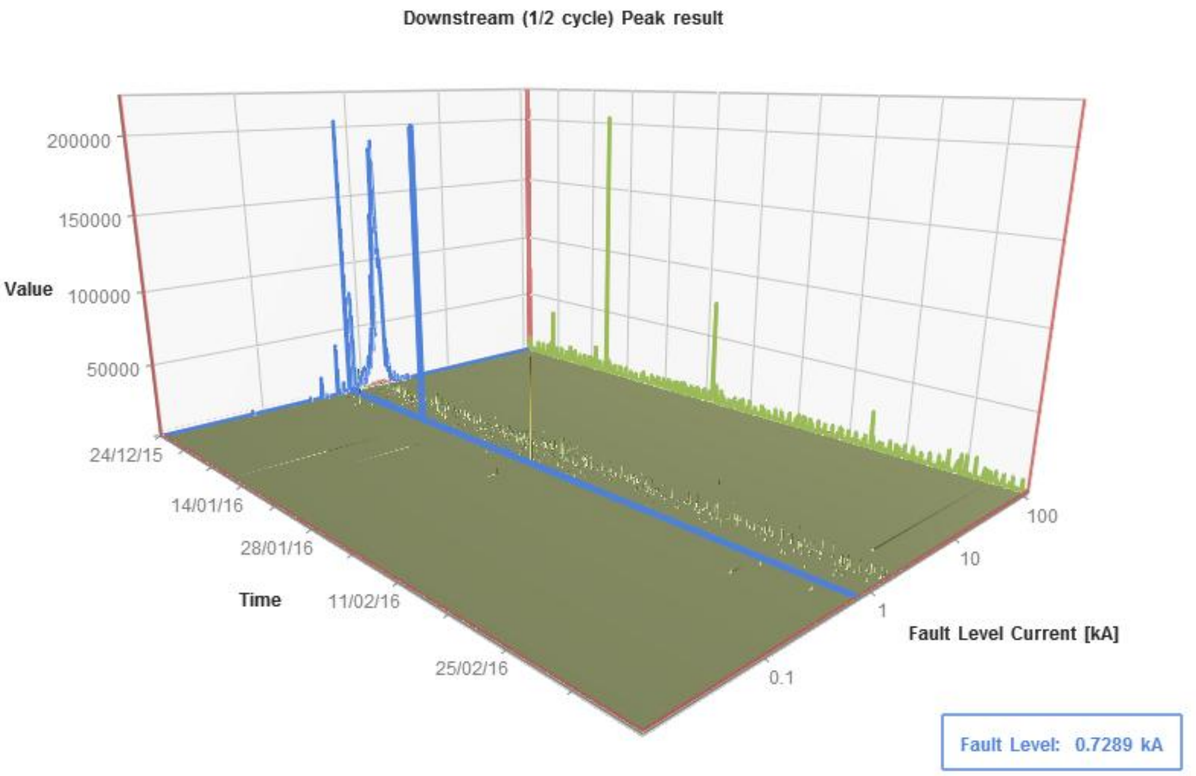


Graph 16. Upstream RMS Fault level at ½ cycle. 24 hr Time varying result shown with no filtering.

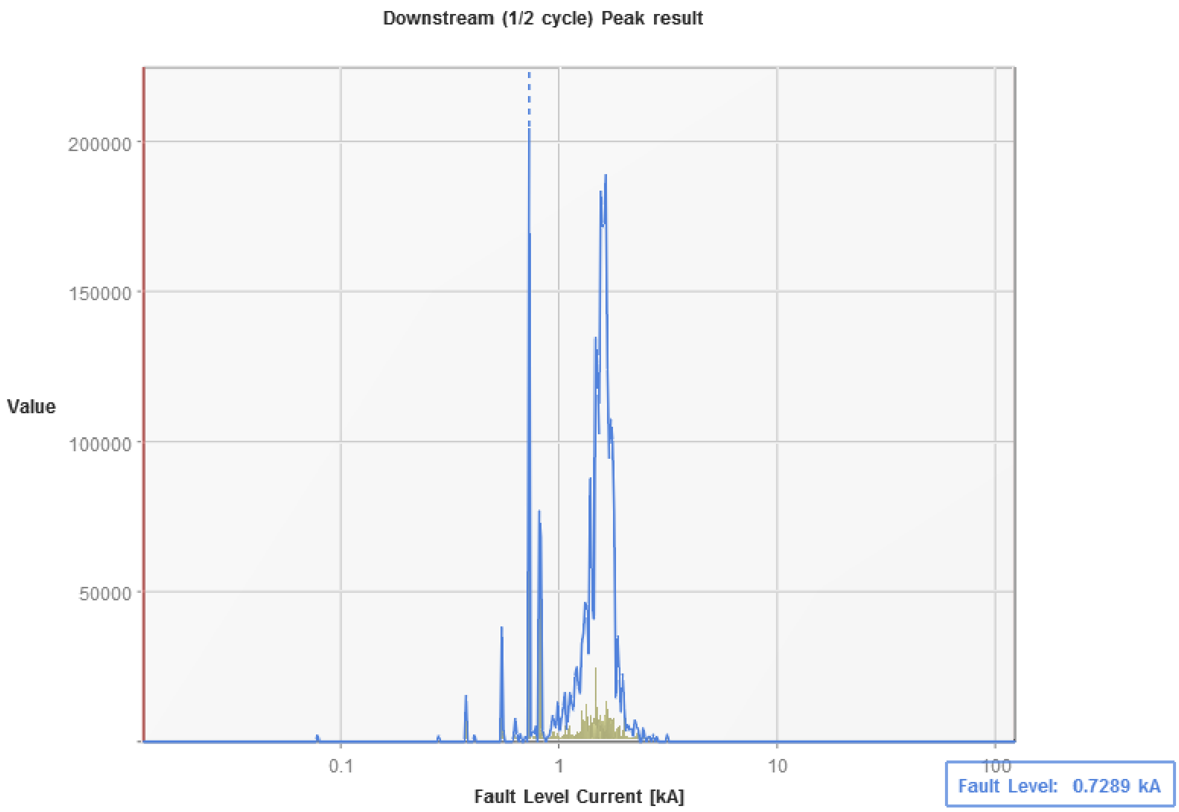
The vertical red lines in the lower graph are the lower and upper Fault Level bounds used for the upper graph. The weighting section of the upper graph shows the disturbance energy used to produce the Fault Level result. The weekends are evident in the lower weighting and increased FL noise. ENWL would know from their operation records whether any variations in Fault Level might be expected during this period. From these results, the only period when variation does seem to have crept in is around the 16th to 24th February, when it may have dropped by 2-3%. (Note the raised result during the weekend (20-21st Feb) should be ignored as there is almost no disturbance energy). The cursor in the upper graph is shown lying on Thursday 18th Feb, yielding a 24 hour result of 7.56kA. This figure rises slightly with increased filtering to 7.68kA (maximum 10% filtering)

Downstream Fault Level contribution

Graphs 17 and 18 show the Peak half cycle Fault Level detected for downstream contribution. Without any filtering, this is dominated by a single spike (discussed/shown in Graphs 1 and 3) detected on 10th January at 5:40 am, whose Fault Level contribution is 0.73kA.



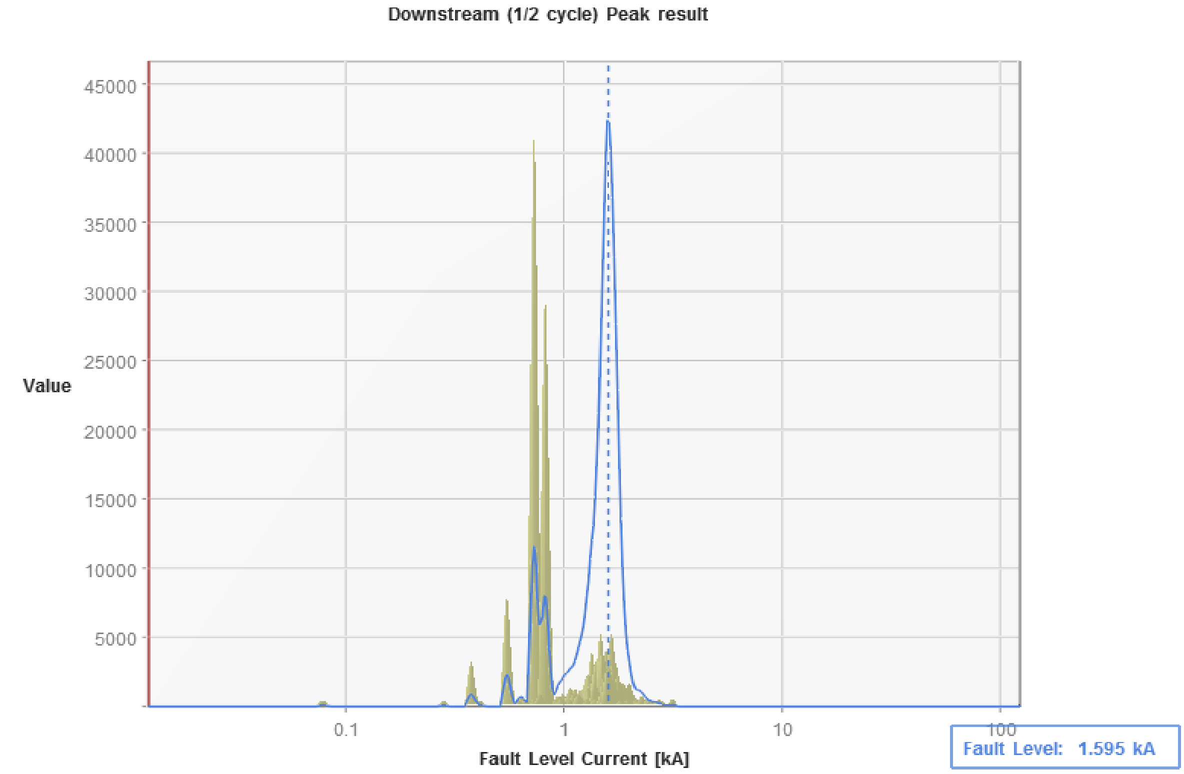
Graph 17. Downstream Peak Fault Level contribution at ½ cycle. 3D representation with no filtering.



Graph 18. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with no filtering.

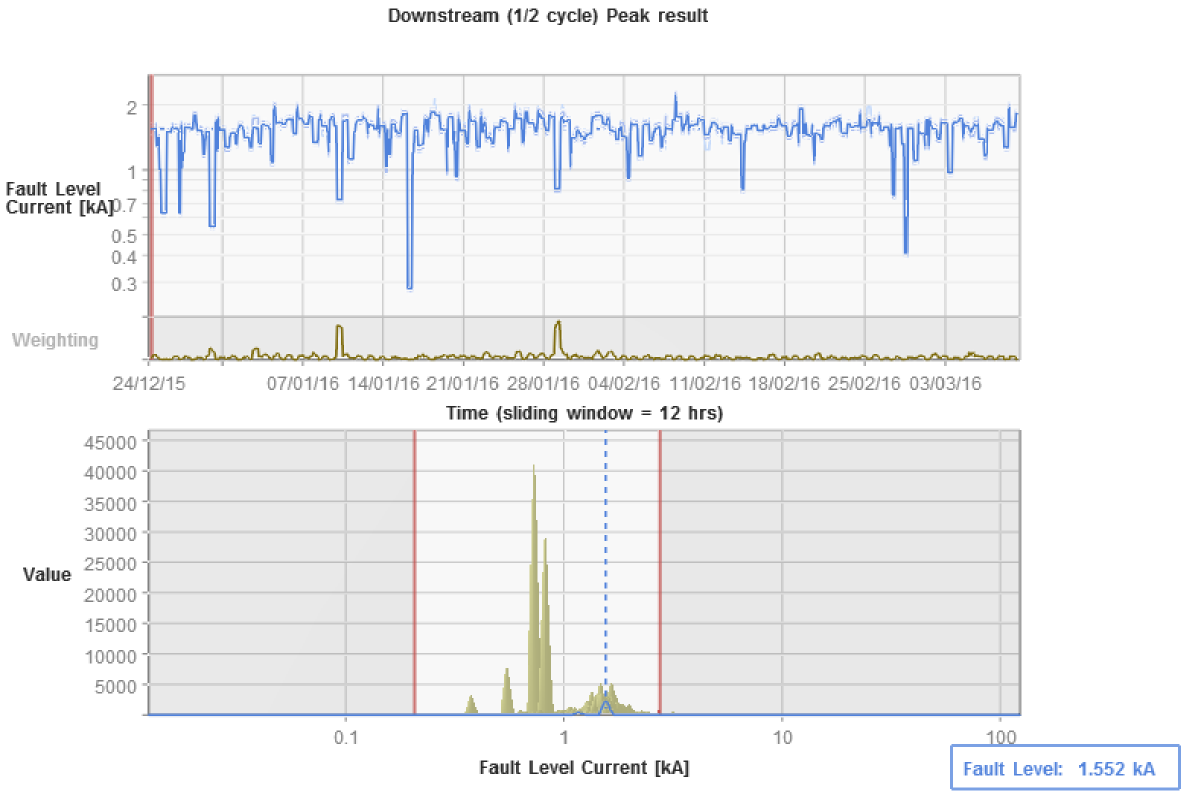
This may not be a representative time for motor contribution, so a more realistic figure can perhaps be obtained by ignoring the spike result, and concentrating on the main distribution.

In fact by adding even modest filtering, the accrued data at more representative Fault Levels rapidly overtakes the single spike results Graph 19 shows the result with 2% filtering.



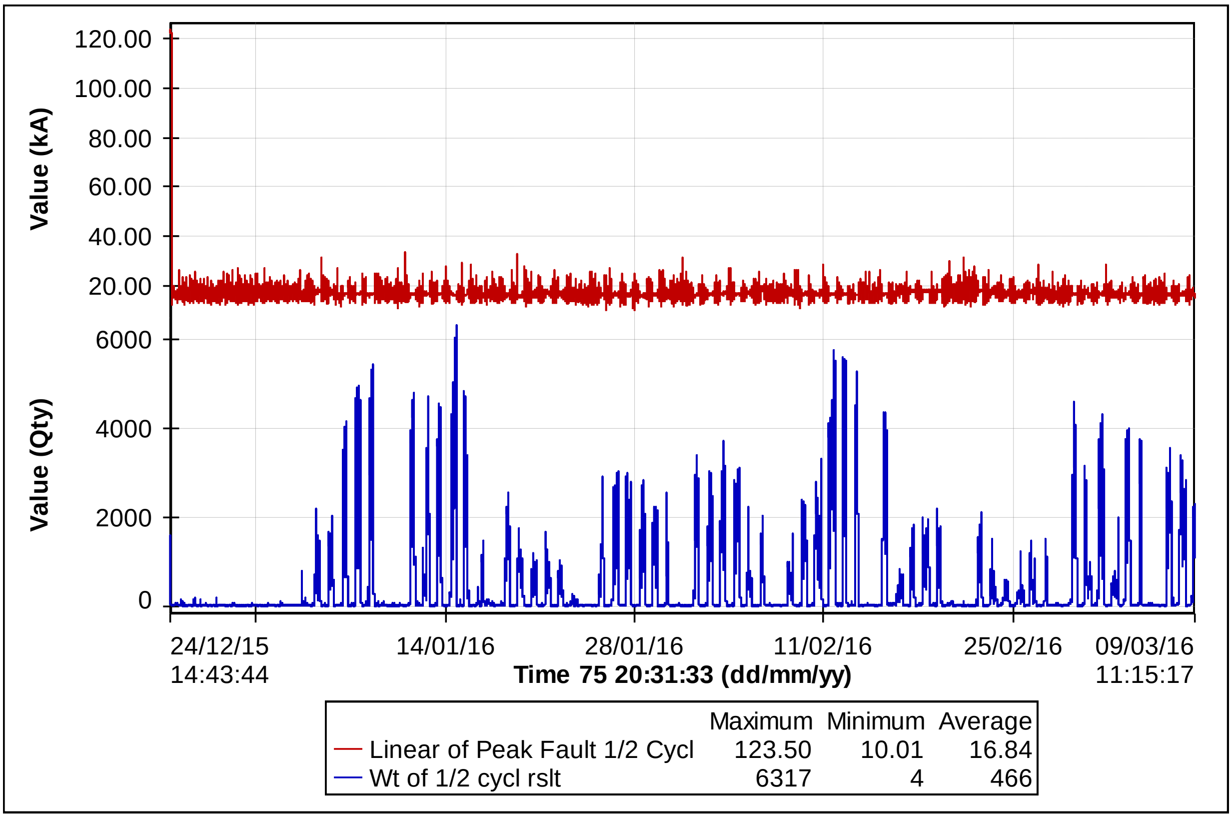
Graph 19. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 2% filtering.

Graph 20 below shows a 12 hour sliding window applied, again with 2% filtering. The downstream contribution is again relatively consistent. Note that the main Upstream disturbances contributing to these results, (tap changes?) appear to occur late in the evening or during the night.

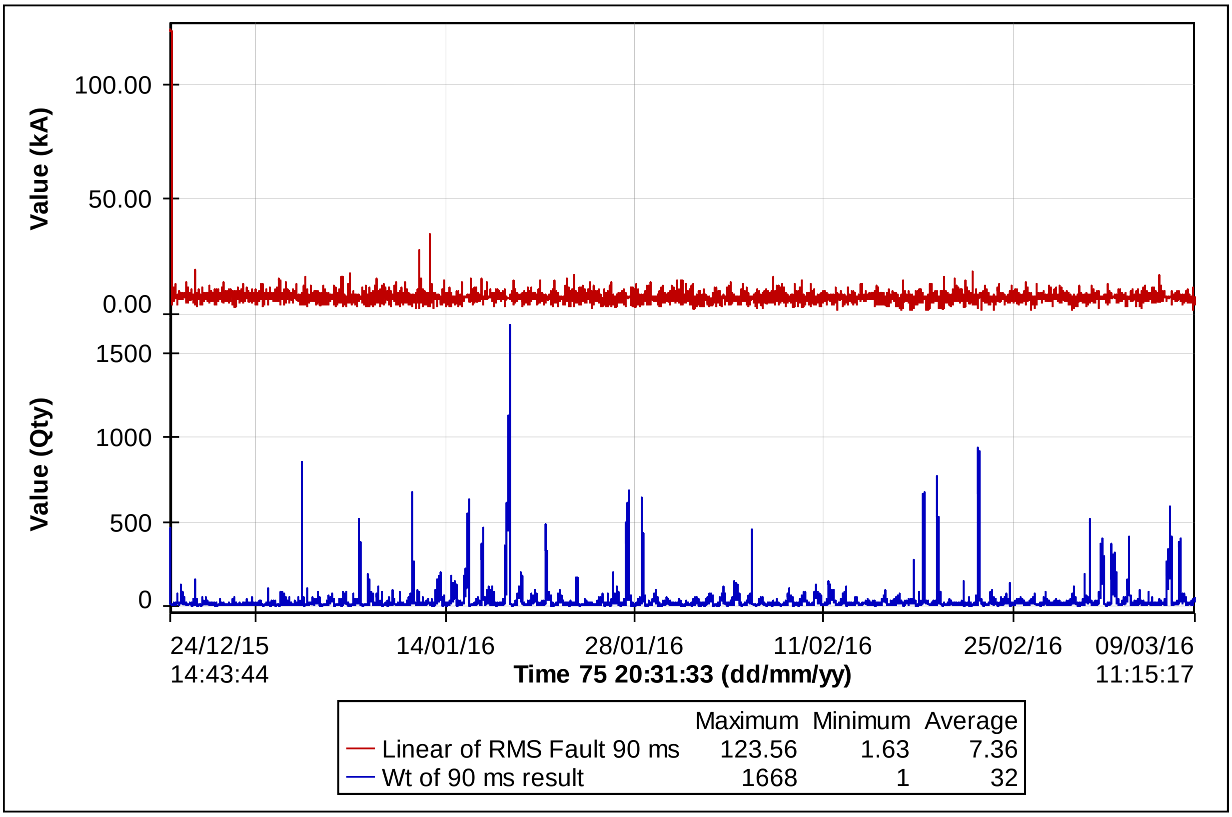


Graph 20. Downstream Peak Fault level at ½ cycle. 12 hr Time varying result shown with 2% filtering.

The following graphs 21 and 22 show the detail results and weighting applied at ½ cycle and 90 ms respectively.



Graph 21. Peak upstream results and weighting present at ½ cycle.



Graph 22. RMS upstream results and weighting present at 90ms.

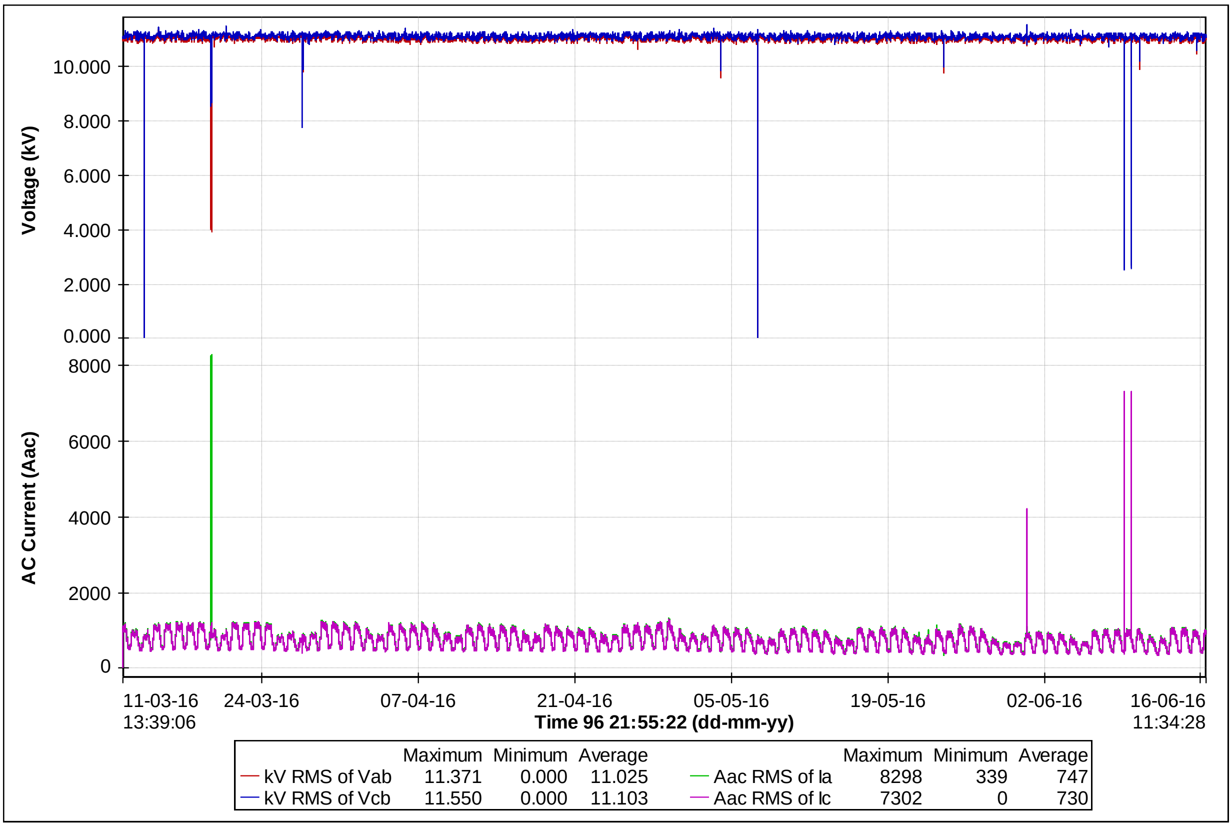
Appendix 2. Broadheath. FLM Serial No 888

Sources of error

The overall results for Peak and ½ cycle RMS Fault Level at Broadheath over the 14 week period are reasonably unambiguous in spite of modest disturbance energy. There is some room for interpretation for the RMS 90ms result. Again sources of error are principally the systematic ones of incorrect assumptions, wrong CT settings, faulty sensors, cables etc. If the current and voltage results recorded by the PM7000 and shown below match the independent measurements reported by the ENWL SCADA or other systems, then it is unlikely that these results are wrong (but see comment on interruptions below).

Broadheath results, General observations

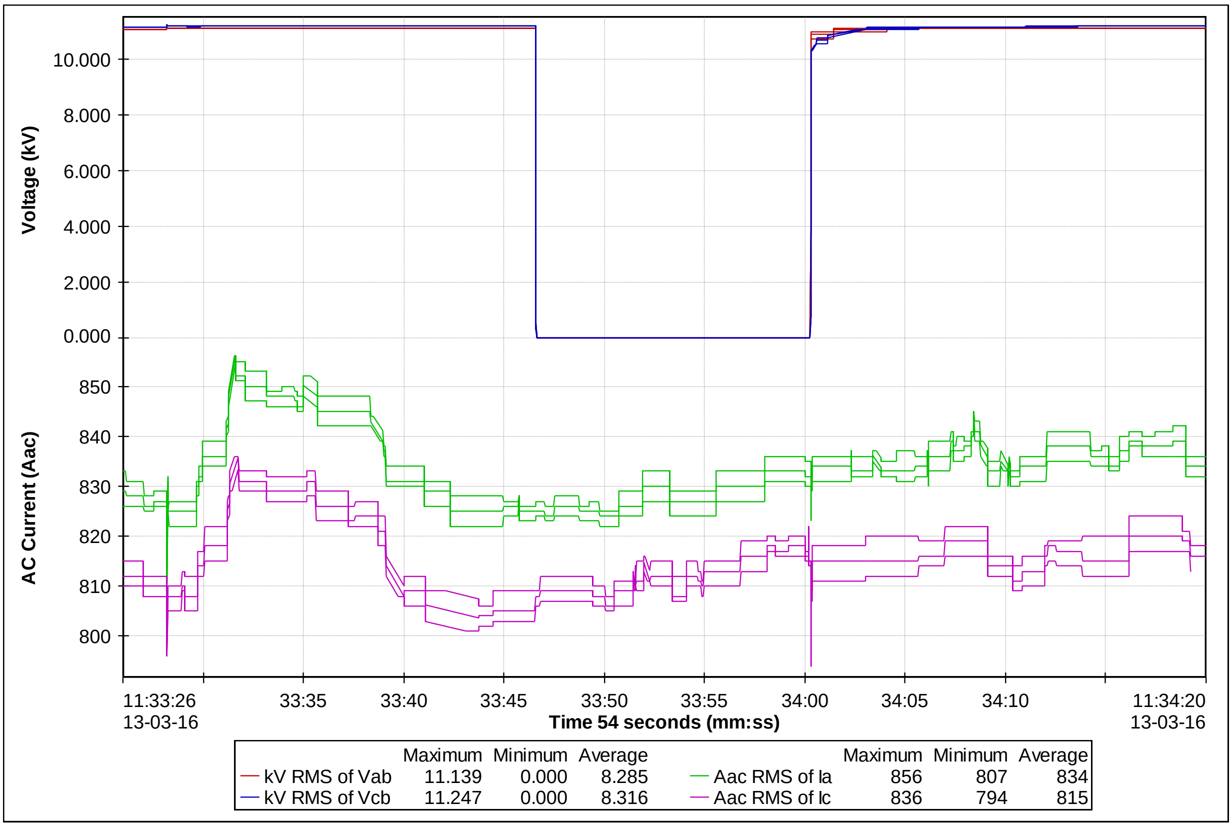
Graph 1 shows the voltage and current for the full recording period.



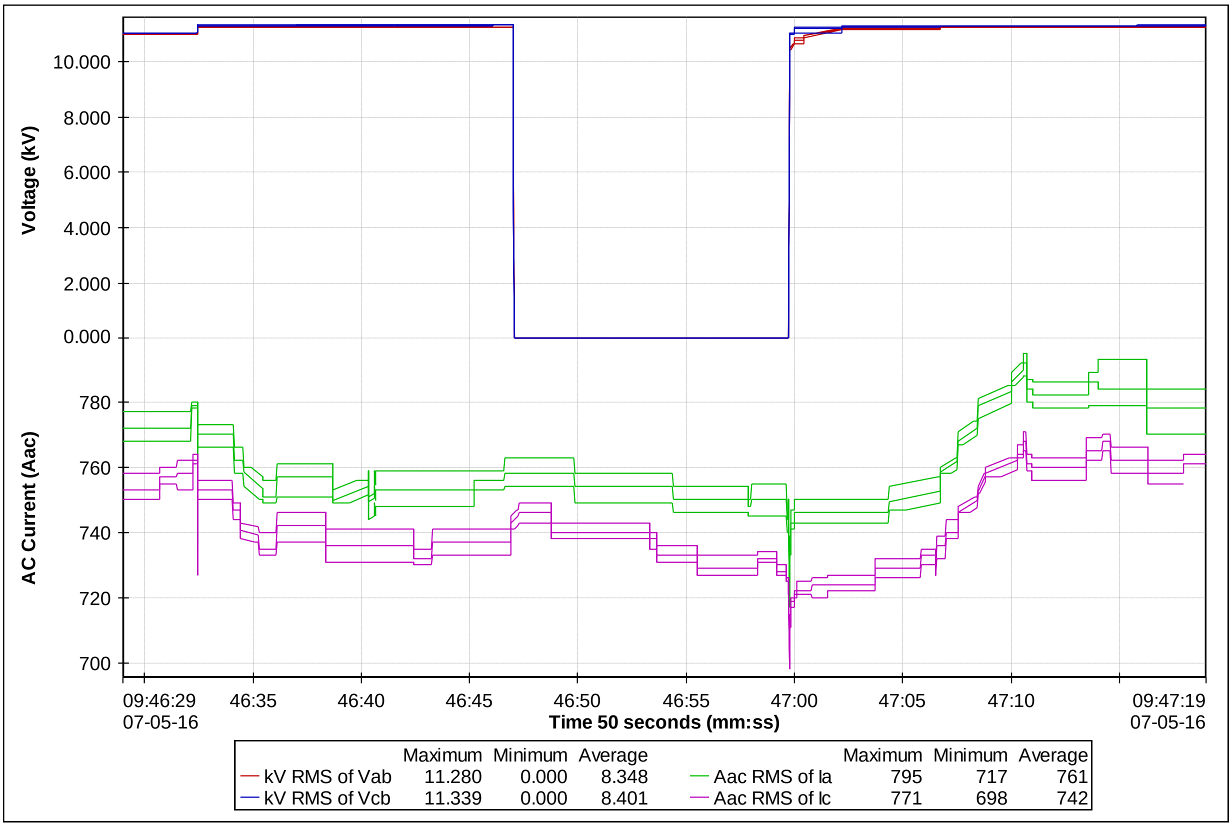
Graph 1. Volts and Current for the full recorded period.

There appear to have been several power quality events during the period. A 14 second interruption occurred on 13th March, and another on 7th May for approx. 12 seconds, though in both cases, current appears unaffected (needs explanation). A pair of 70% dips on Vab due to current on Ia occurred on 19th March a little over an hour apart (~200 & ~300ms secs wide respectively). On 31st May there was a large Ic current spike, and on 9th June, current spikes on Ic twice produced a ~80% dip on Vcb for ~100ms.

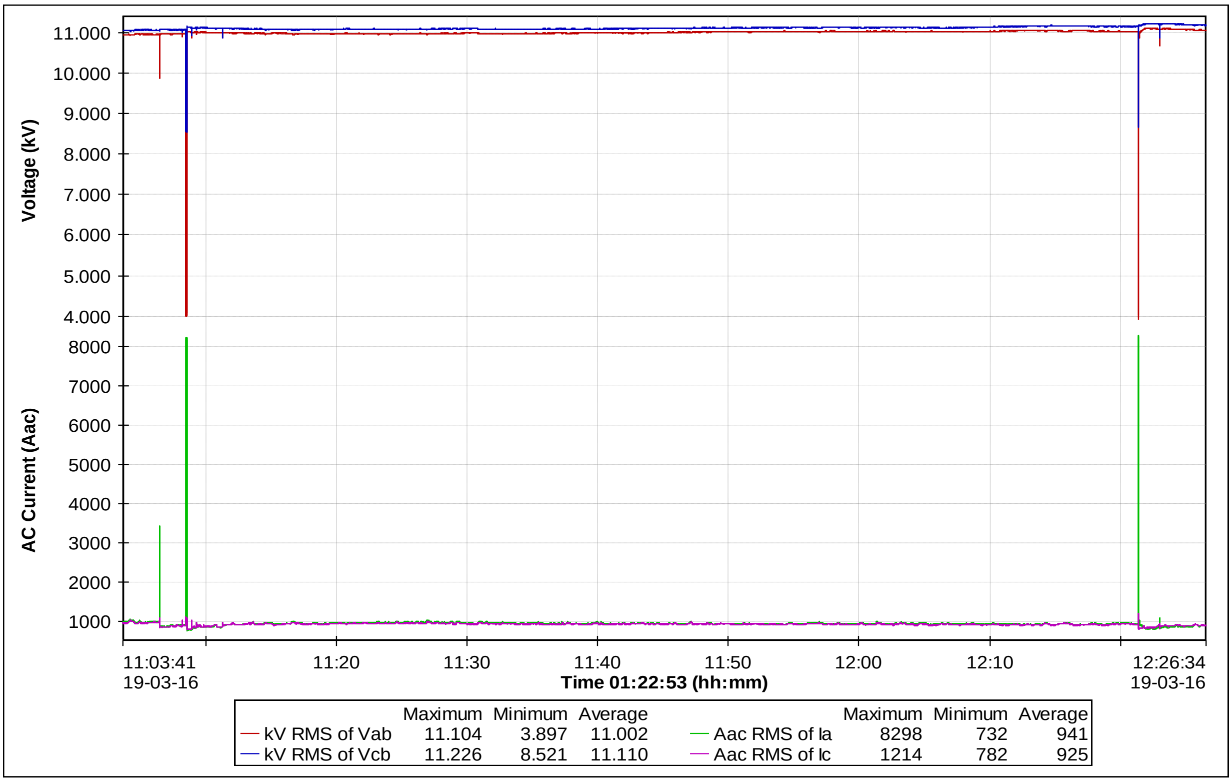
Graphs 2-9 show the RMS detail.



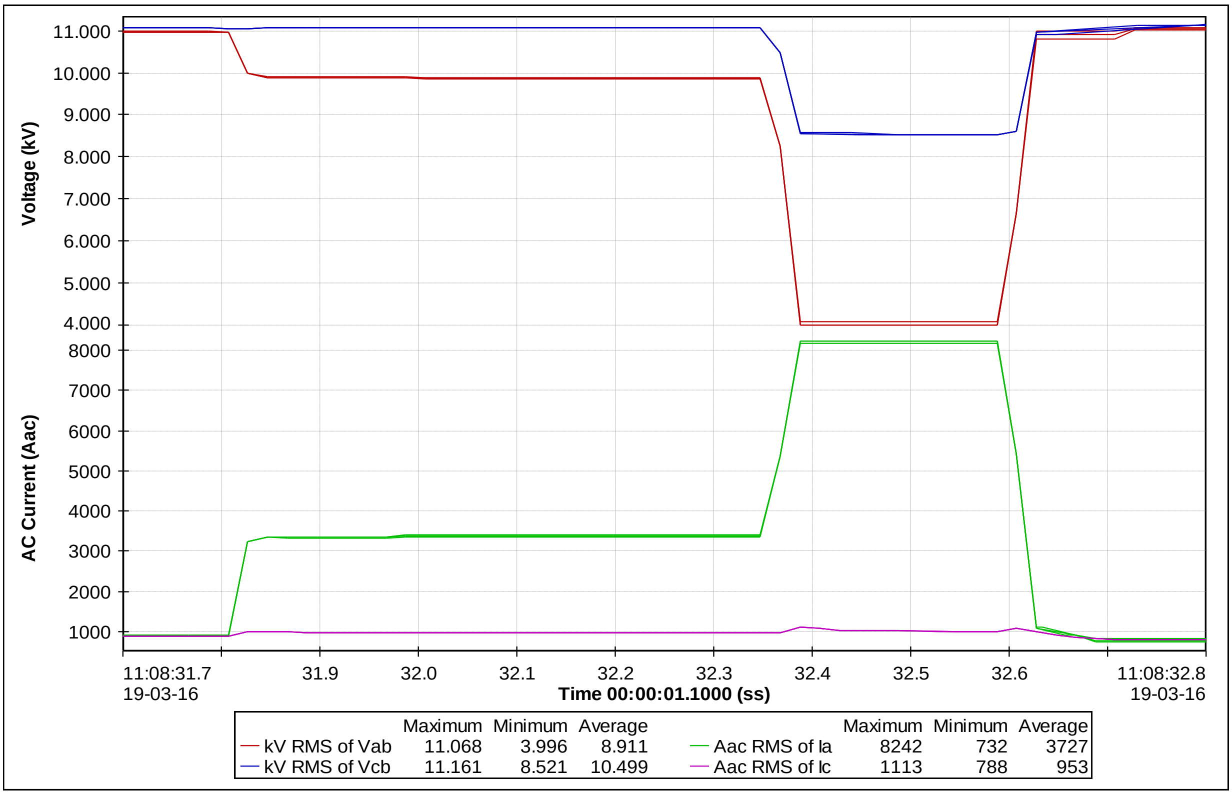
Graph 2. Interruption on Voltage, 13 March 2016.



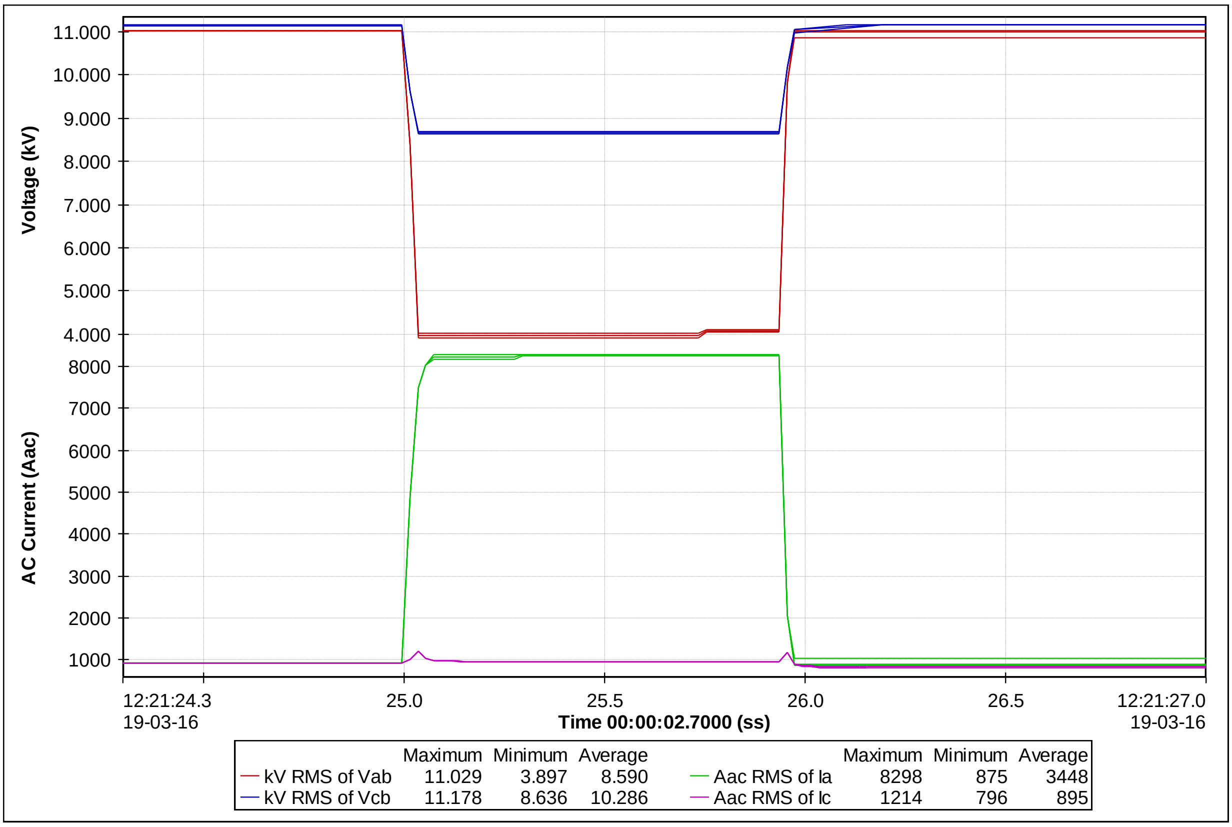
Graph 3. Interruption on Voltage, 7th May 2016.



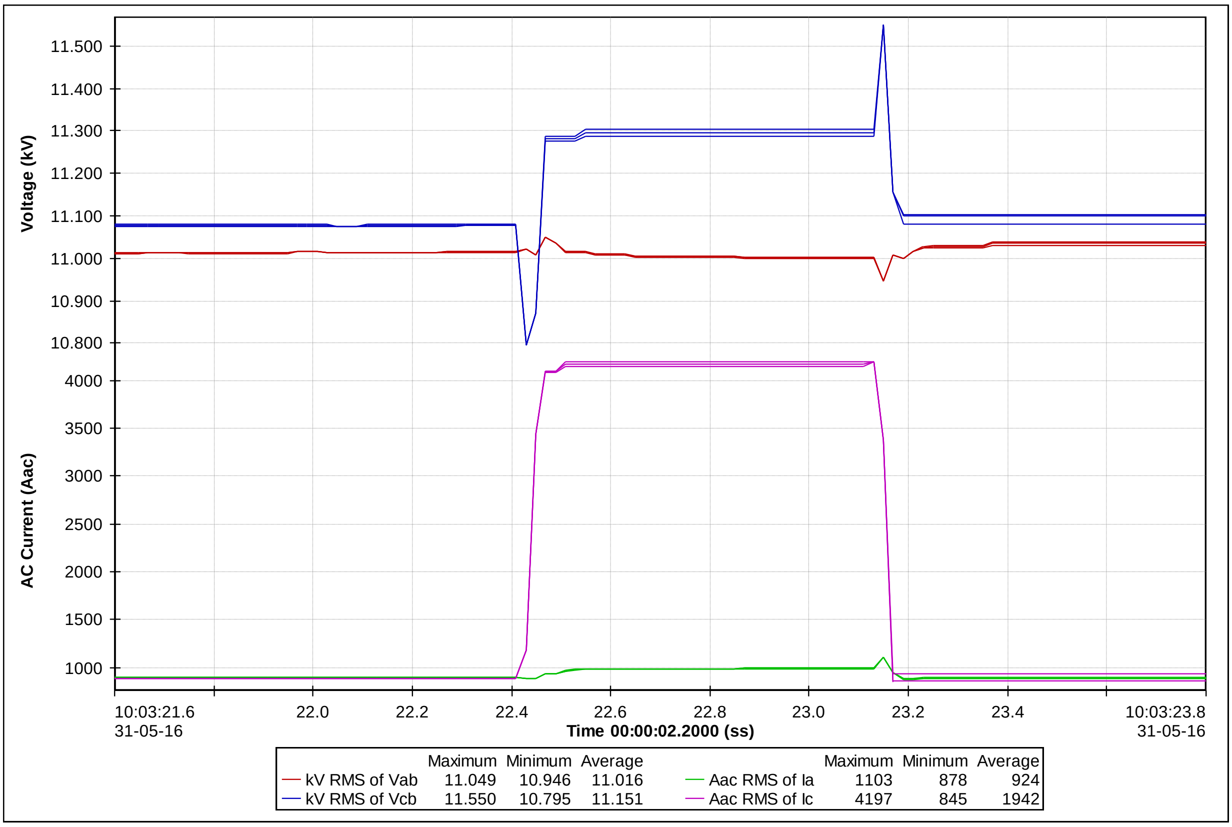
Graph 4. Pair of A phase current disturbances on 19th March 2016.



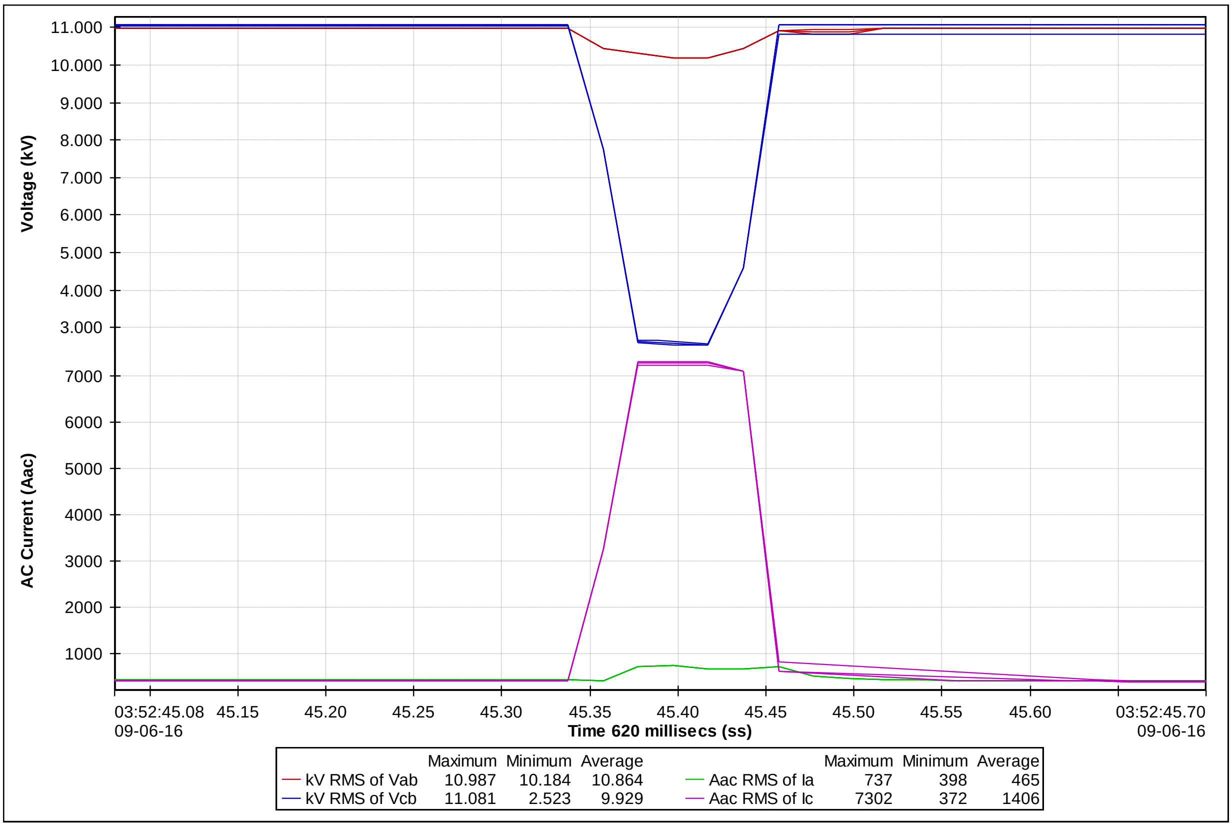
Graph 5. First A phase current disturbance on 19th March 2016.



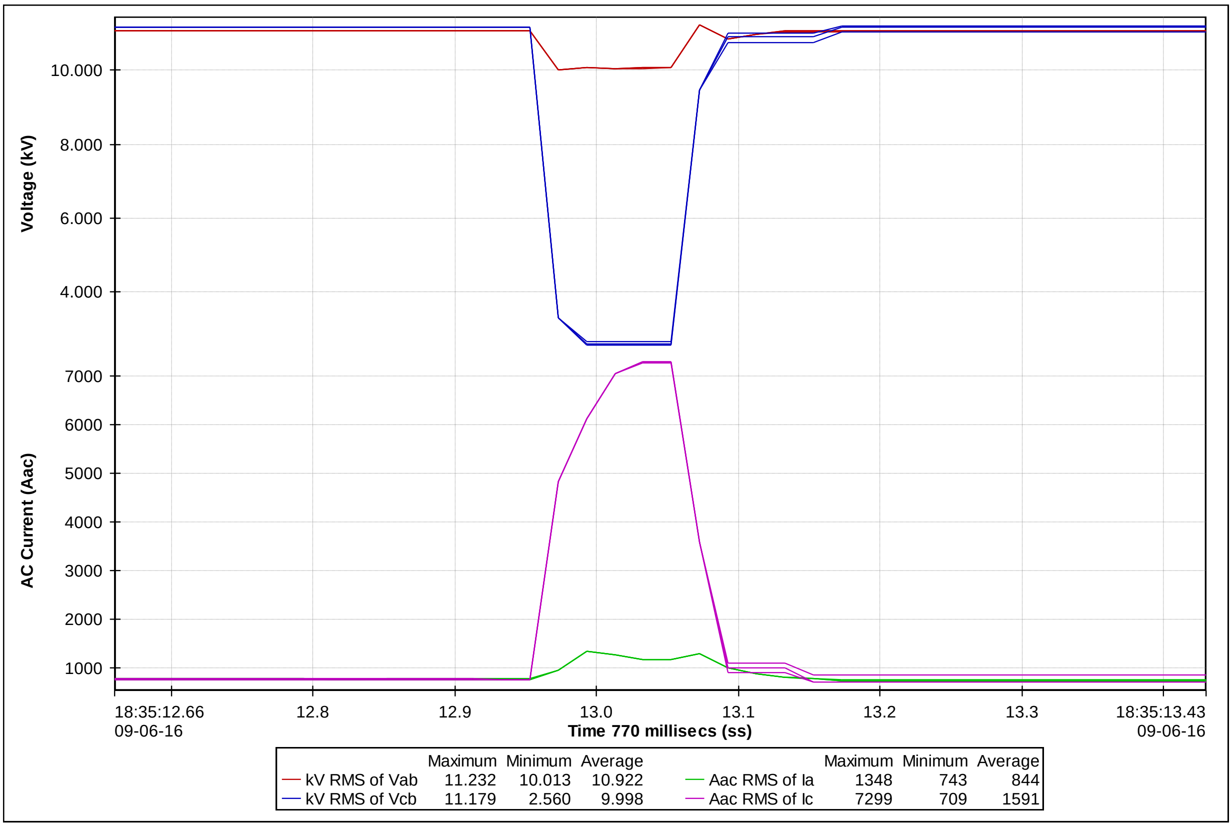
Graph 6. Second A phase current disturbance on 19th March 2016.



Graph 7. C phase current disturbance on 31st May 2016.



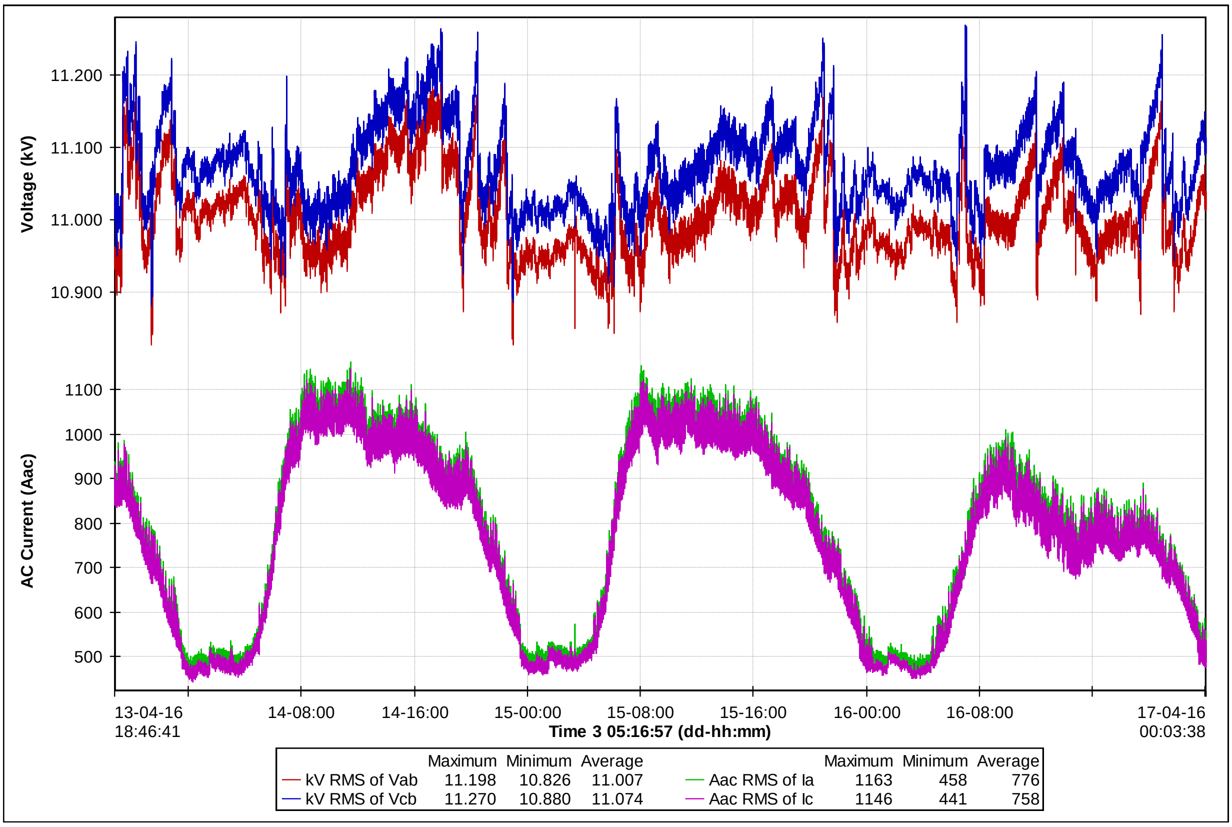
Graph 8. C phase current disturbance on 9th June 2016.



Graph 9. C phase current disturbance on 9th June 2016.

Useful Fault Level type disturbances.

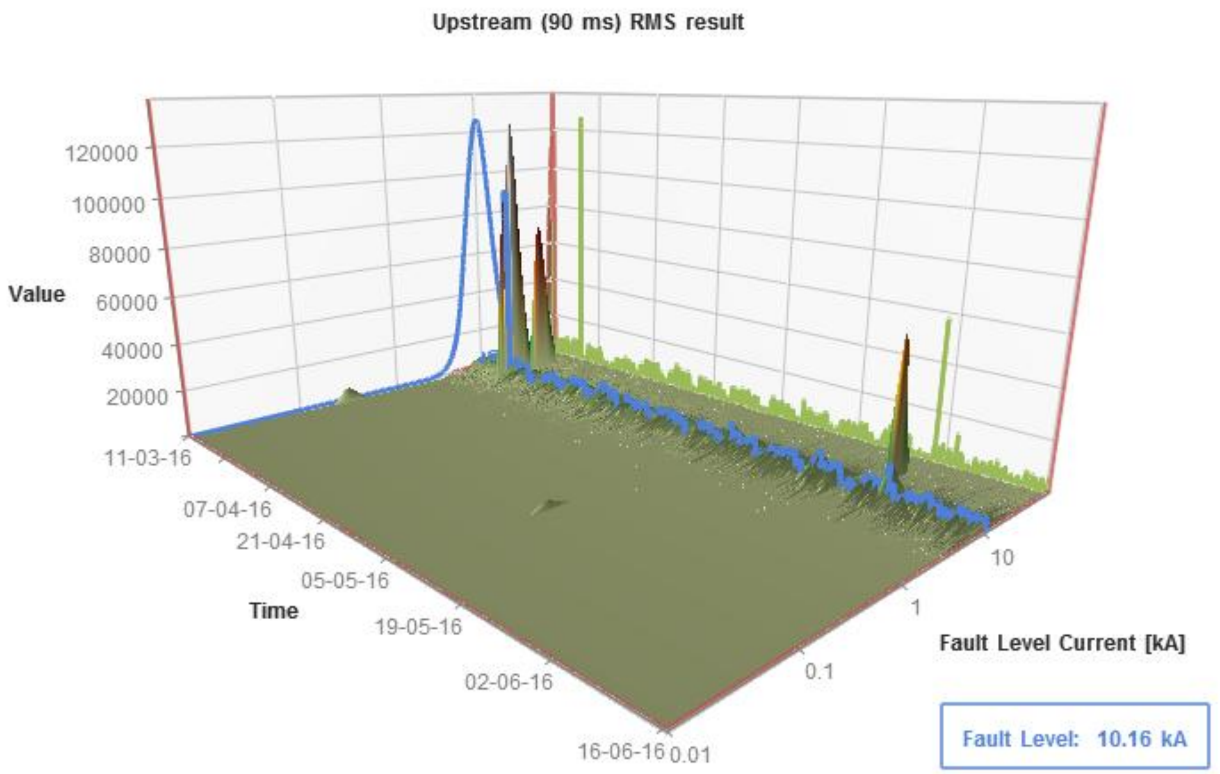
In addition to the few very large disturbances noted above, there was an underlying pattern of daytime current disturbances which should yield reasonable Fault Level results. Graph 10 shows a typical 3 day section of the recording.



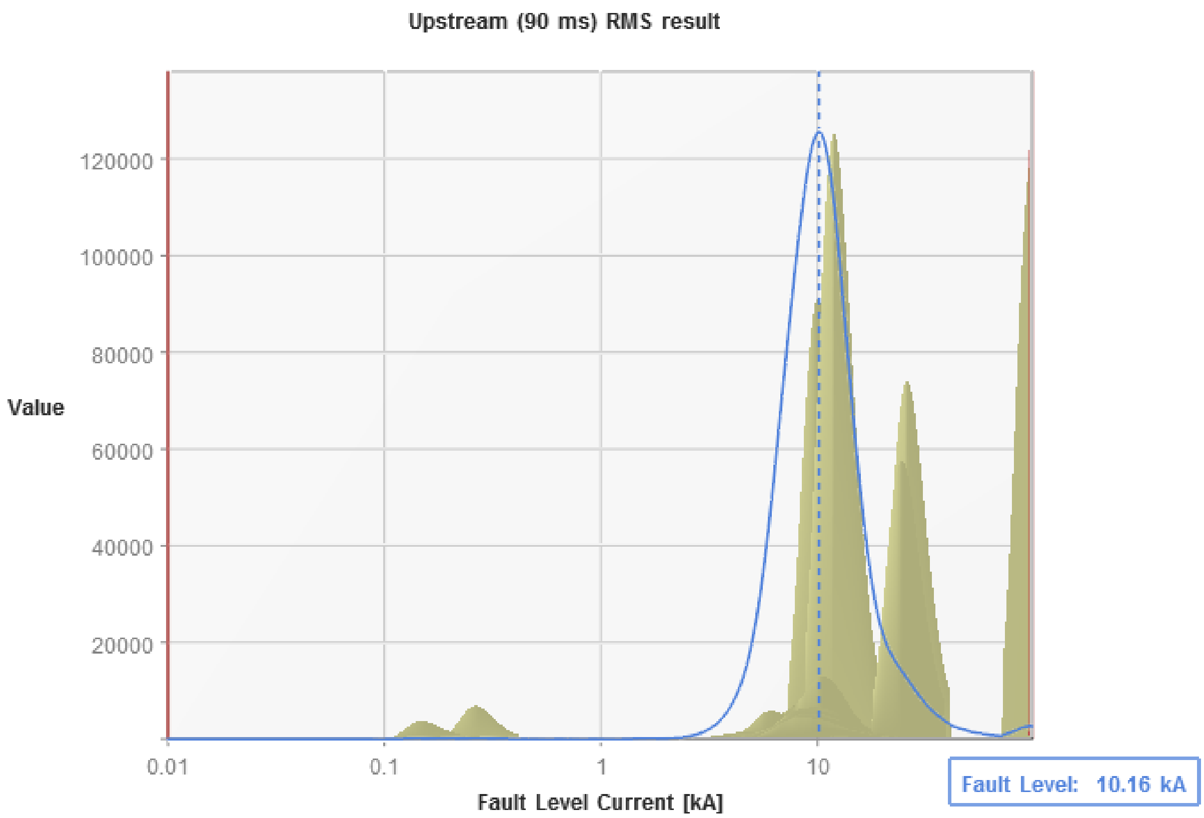
Graph 10. Typical disturbance activity.

Fault Level Results

There is some scope for interpretation here. A reasonable bell-shaped curve requires more filtering than usual. Graph 11 shows that with 10% filtering the mean Upstream 90ms RMS Fault Level for the period was 10.16 kA. Graph 12 shows the same thing in 2 dimensions.

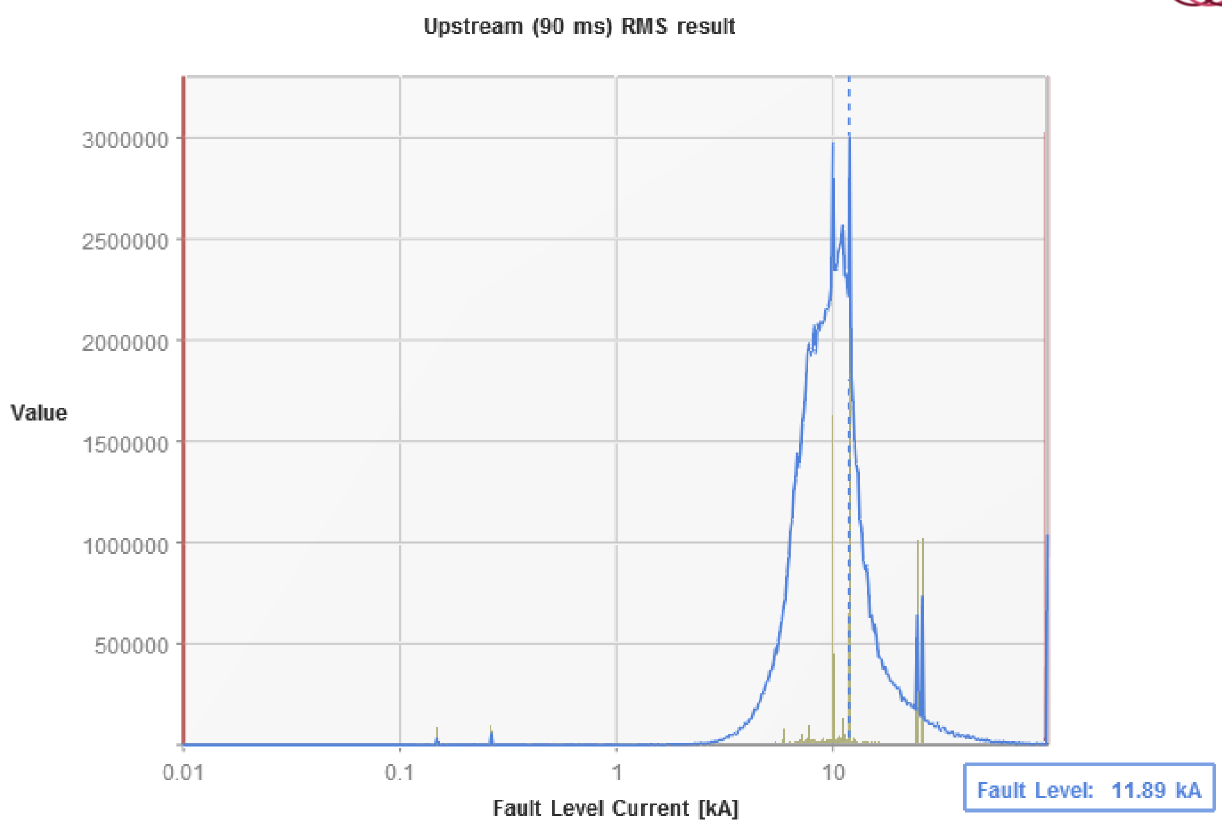


Graph 11. Upstream RMS Fault level at 90ms. 3D Distribution shown with 10% filtering.



Graph 12. Upstream RMS Fault level at 90ms. 2D Distribution shown with 10% filtering.

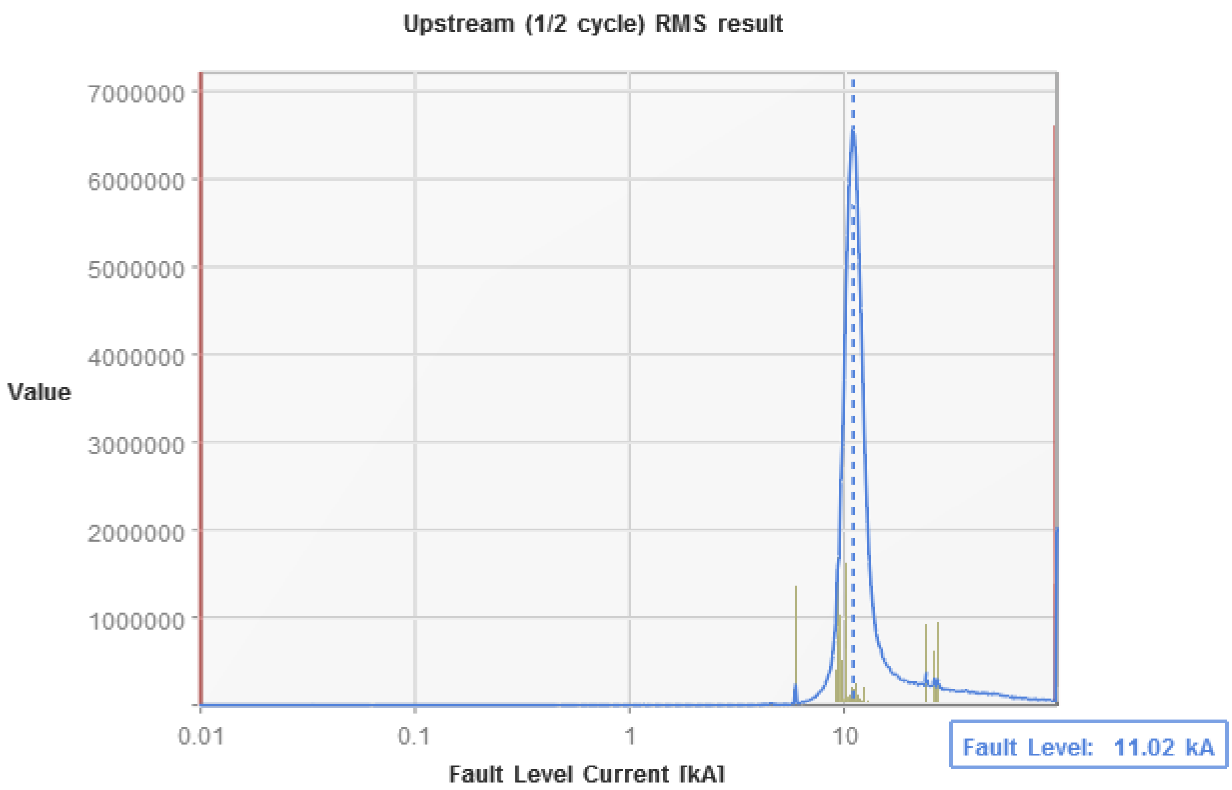
Without the filtering, the peak of the distribution is biased high, as shown in Graph 13 below.



Graph 13. Upstream RMS Fault level at 90ms. 2D Distribution shown with no filtering.

As filtering is raised from 0 up to 10%, the peak moves from spike to spike, dropping back to 10.06kA (at 1%) climbing to 10.85kA (3%), before settling below 10.57 (5%). As shown later, there does not appear to be any definite change in Fault Level during the period, so the population may be considered as one, though there are the very large disturbances which may be received in distorted form.

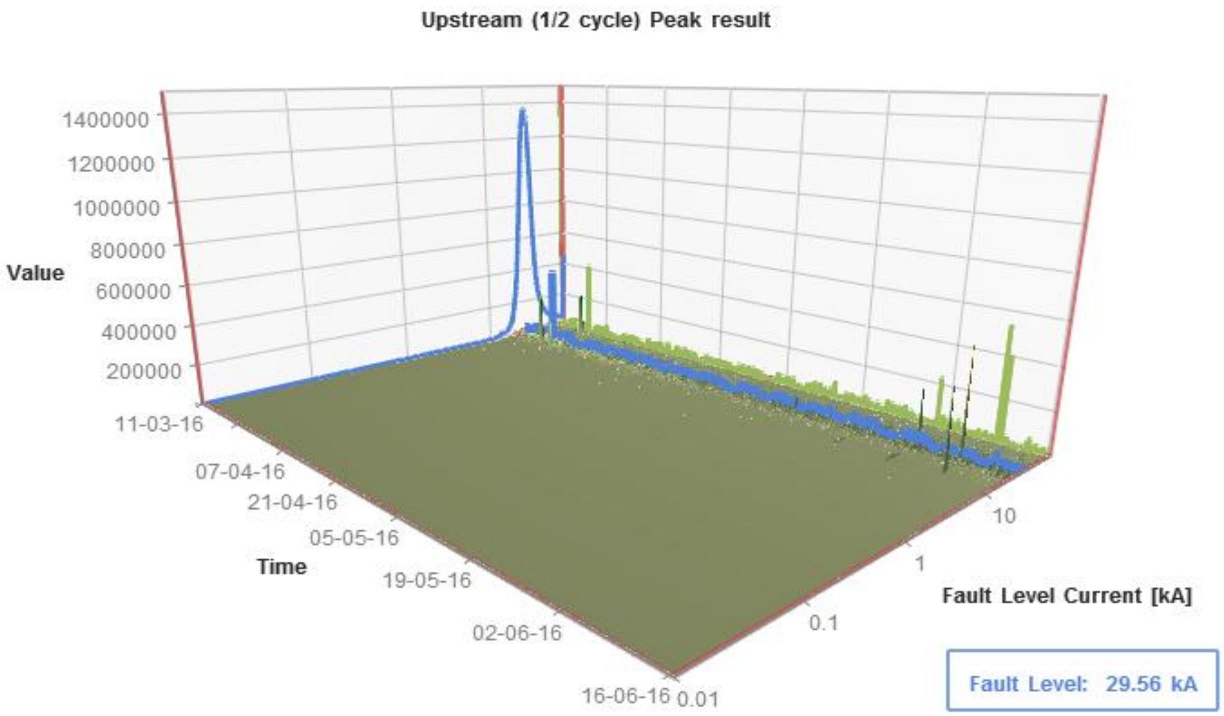
This is a case where examination of the 10ms RMS result can give an insight.



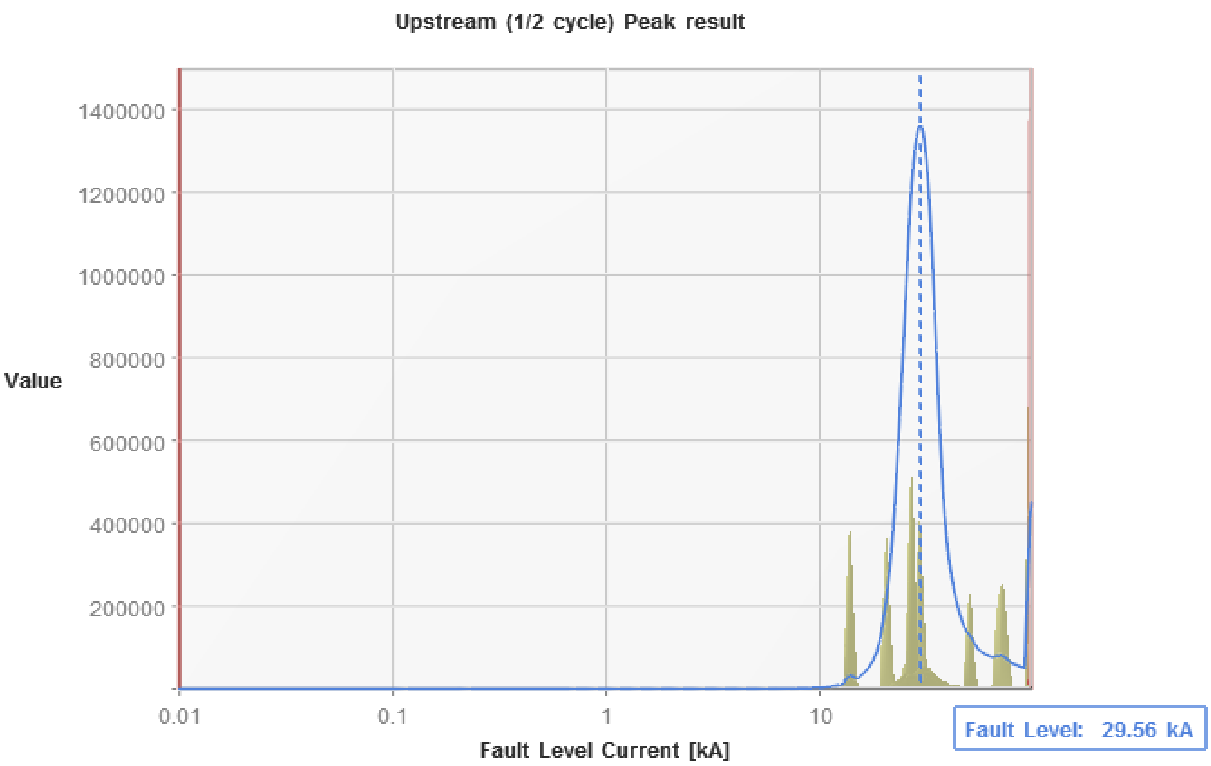
Graph 14. Upstream RMS result at half cycle, no filtering.

As can be seen on graph 14, even without any filtering, the result is unambiguous. This suggests that there is only one population, therefore it is reasonable to apply full length integration and high filtering to the 90ms result.

Graphs 15 and 16 show the Peak Upstream Fault Level for the whole period.

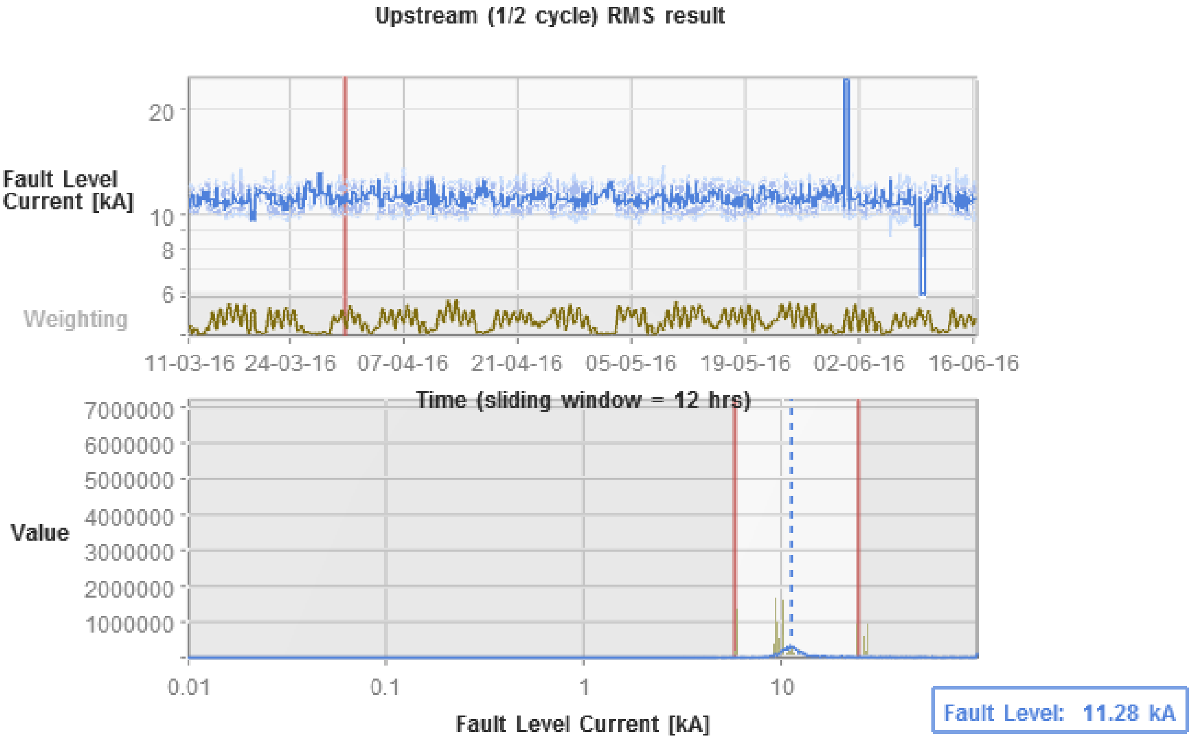


Graph 15. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 2% filtering.



Graph 16. Upstream Peak Fault level at ½ cycle. 2D Distribution shown with 2% filtering.

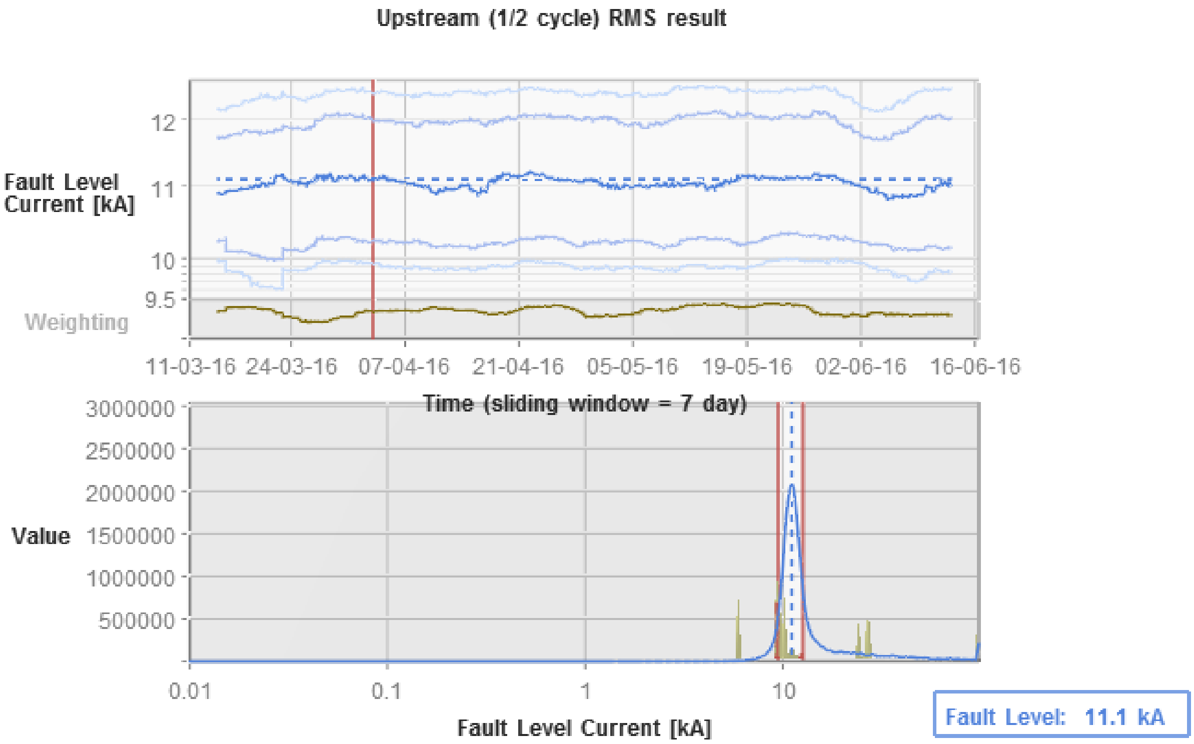
Looking at these results over much shorter times, we can observe short term variation associated with the some of the gross events. Graph 17 below shows the cleanest of the above (the ½ cycle RMS result) averaged over 12 hours.



Graph 17. Upstream RMS Fault level at ½ cycle. 12 hr Time varying result shown with no filtering.

The vertical red lines in the lower graph are the lower and upper Fault Level bounds used for the upper graph. The weighting section of the upper graph shows the disturbance energy used to produce the Fault Level result. The daily weighting variation is clearly visible.

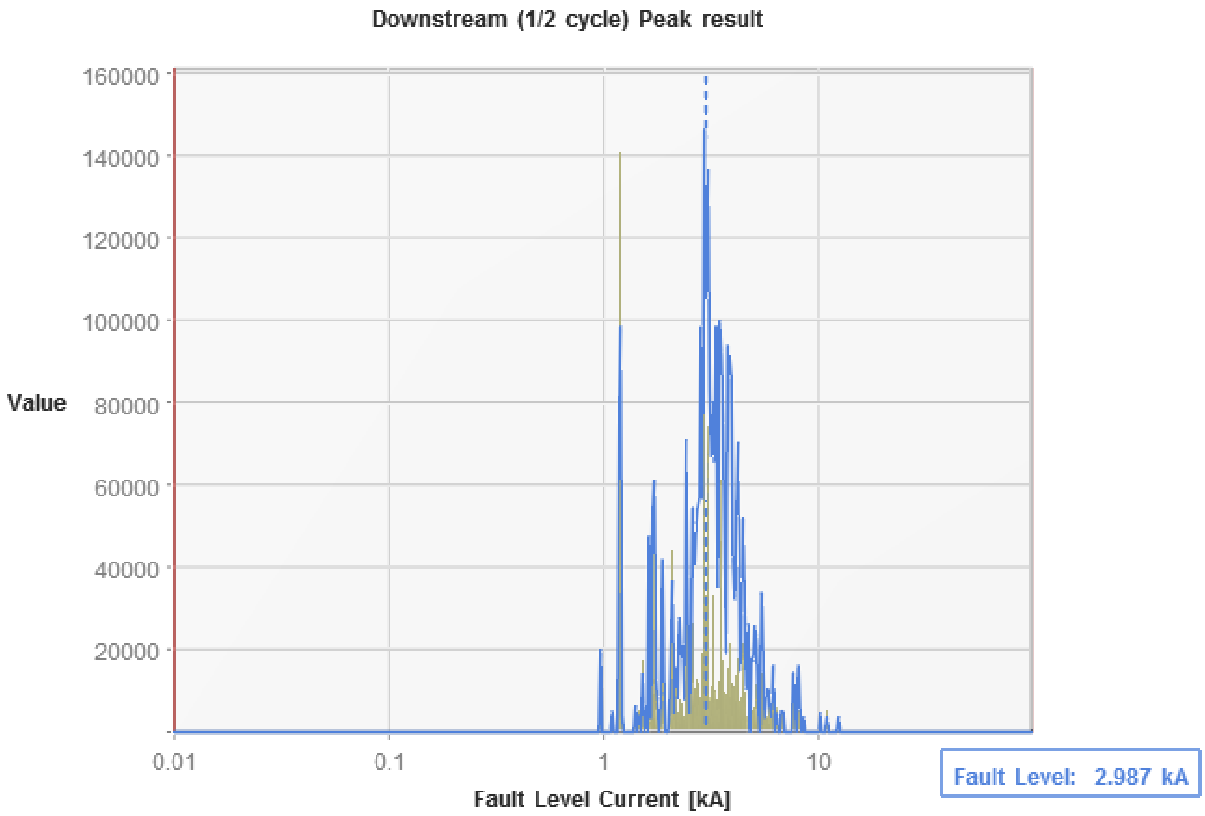
Extending the averaging period out to 7 days and adding 1% filtering, there does not appear to be much variation over the recording. See graph 18.



Graph 18. Upstream RMS Fault level at ½ cycle. 7 day Time varying result shown with 1% filtering.

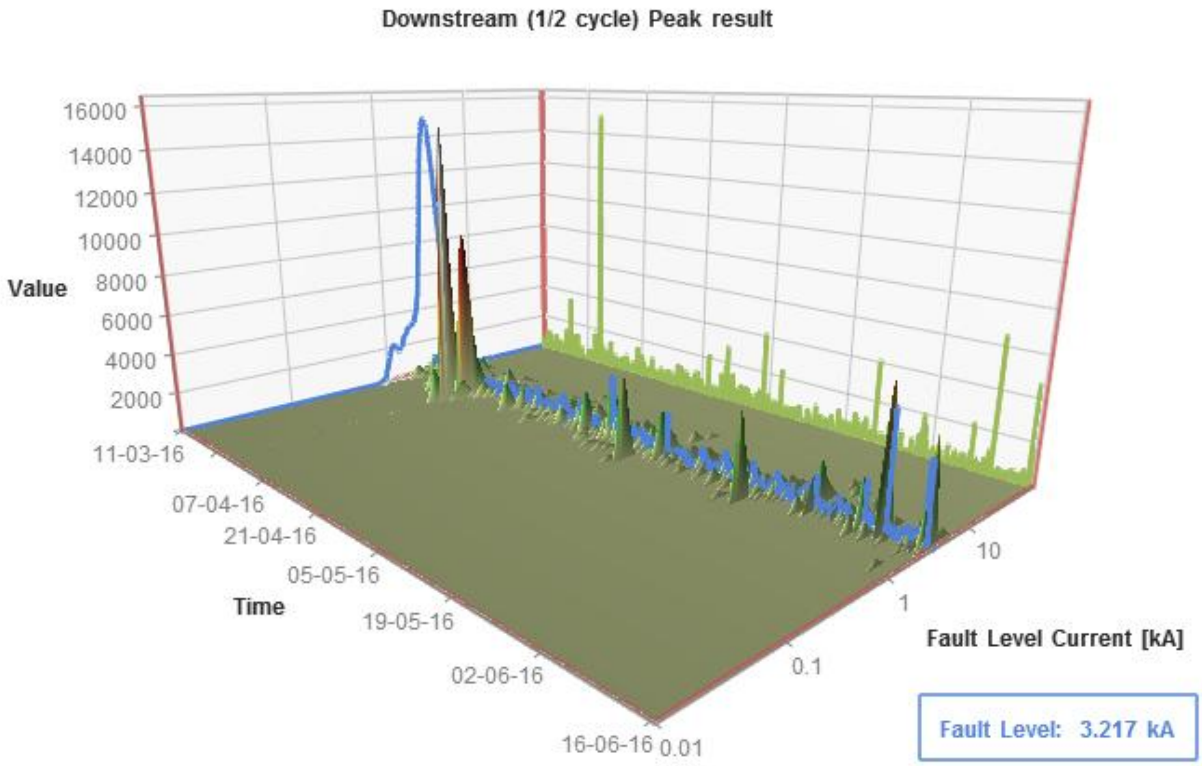
Downstream Fault Level contribution

Graph 19 shows the Peak half cycle Fault Level detected for downstream contribution without any filtering.

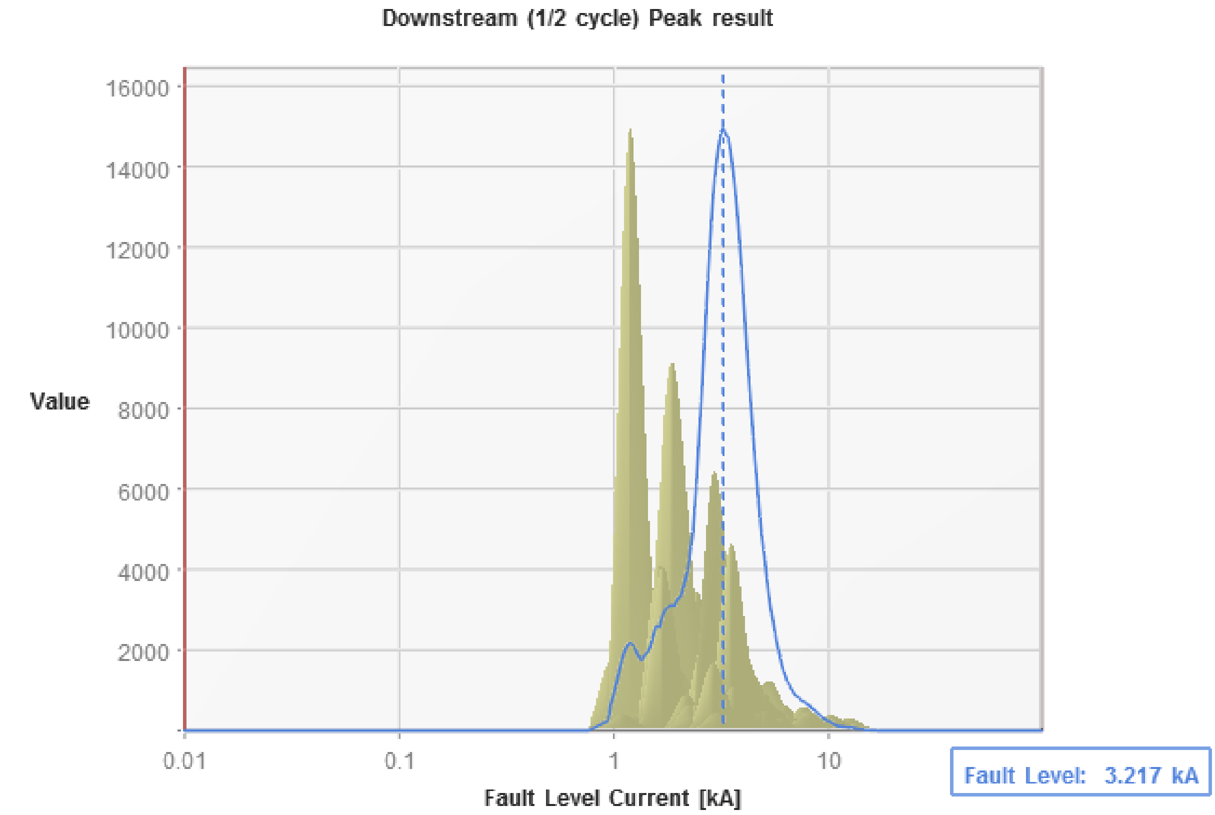


Graph 19. Downstream Peak Fault Level contribution at ½ cycle. 2D representation without filtering.

With 7% filtering, this population becomes reasonably bell-like around the centre. See graphs 20 and 21.

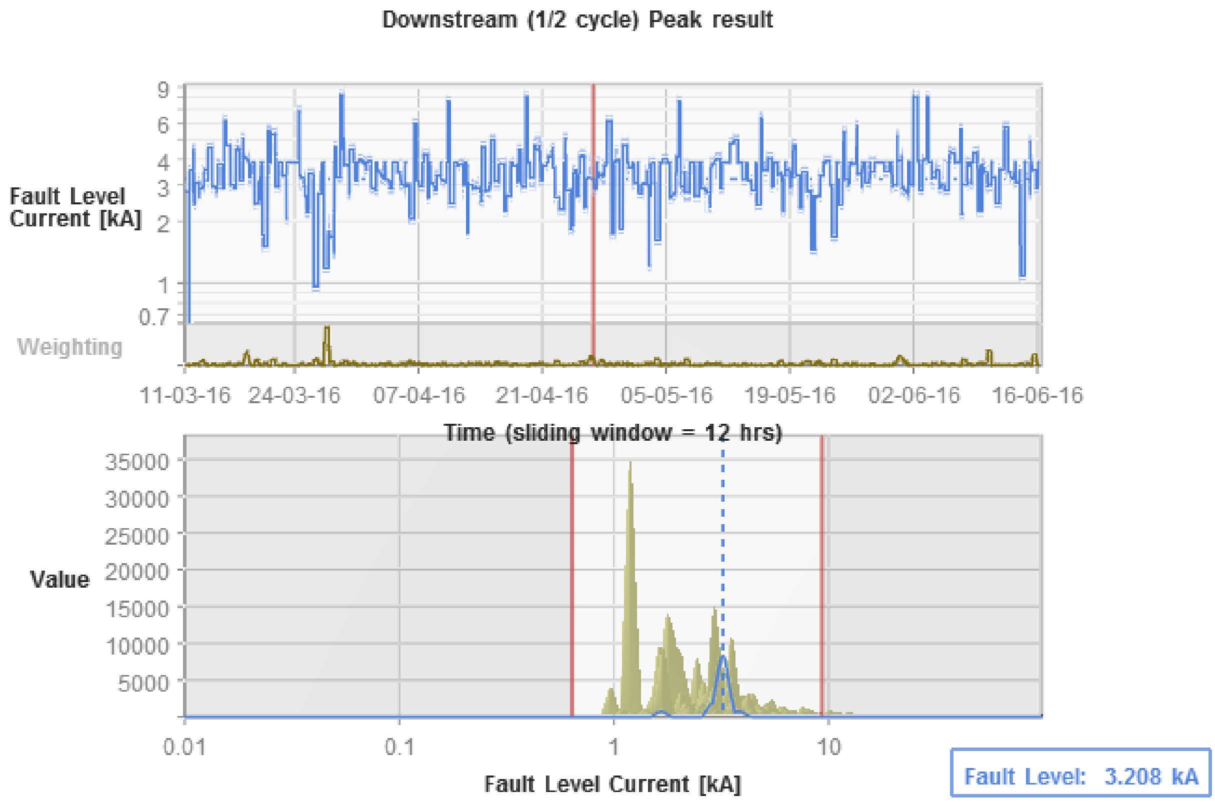


Graph 20. Downstream Peak Fault Level contribution at ½ cycle. 3D representation with 7% filtering.



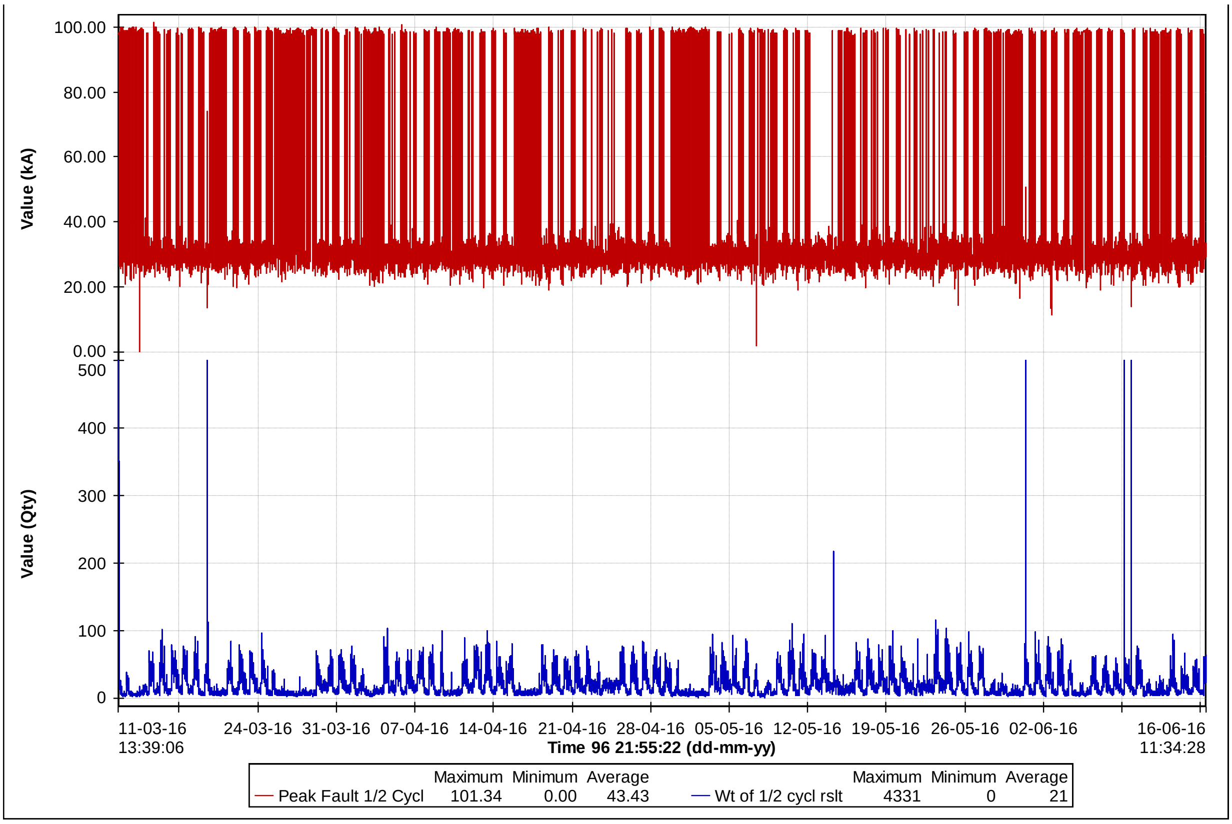
Graph 21. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 7% filtering.

Graph 22 below shows a 12 hour sliding window applied, with 3% filtering. The downstream contribution is again relatively consistent.

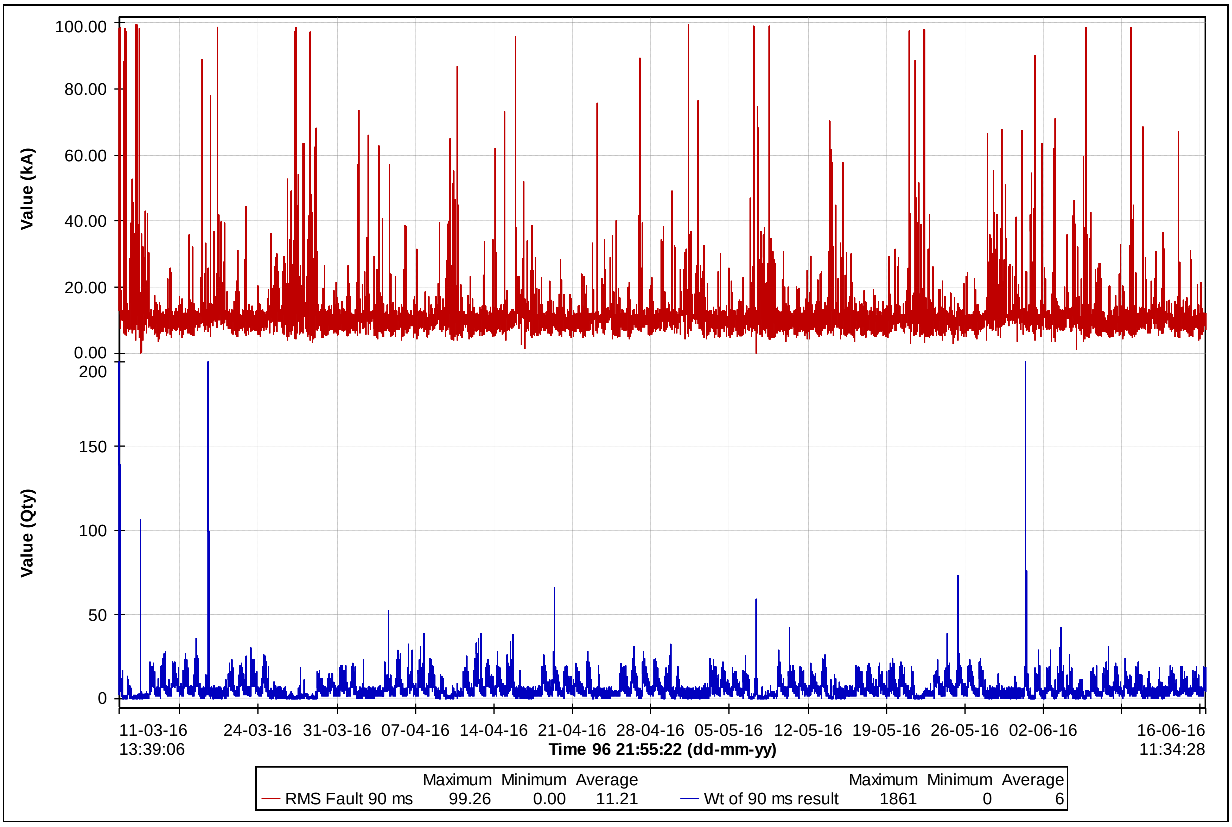


Graph 22. Downstream Peak Fault level at ½ cycle. 12 hr Time varying result shown with 3% filtering.

The following graphs 23 and 24 show the detail results and weighting applied at ½ cycle and 90 ms respectively. The excessive fault level values shown in Graph 23 are associated with NO weight, and strictly speaking should be suppressed. See “Fault Level Graphing. Two and three dimensional distribution surface plots versus using standard Pronto graphing against time” at the start of this document.



Graph 23. Peak upstream results and weighting present at ½ cycle.



Graph 24. RMS upstream results and weighting present at 90ms.

Appendix 3. Irlam Primary. FLM Serial No 0889

Sources of error

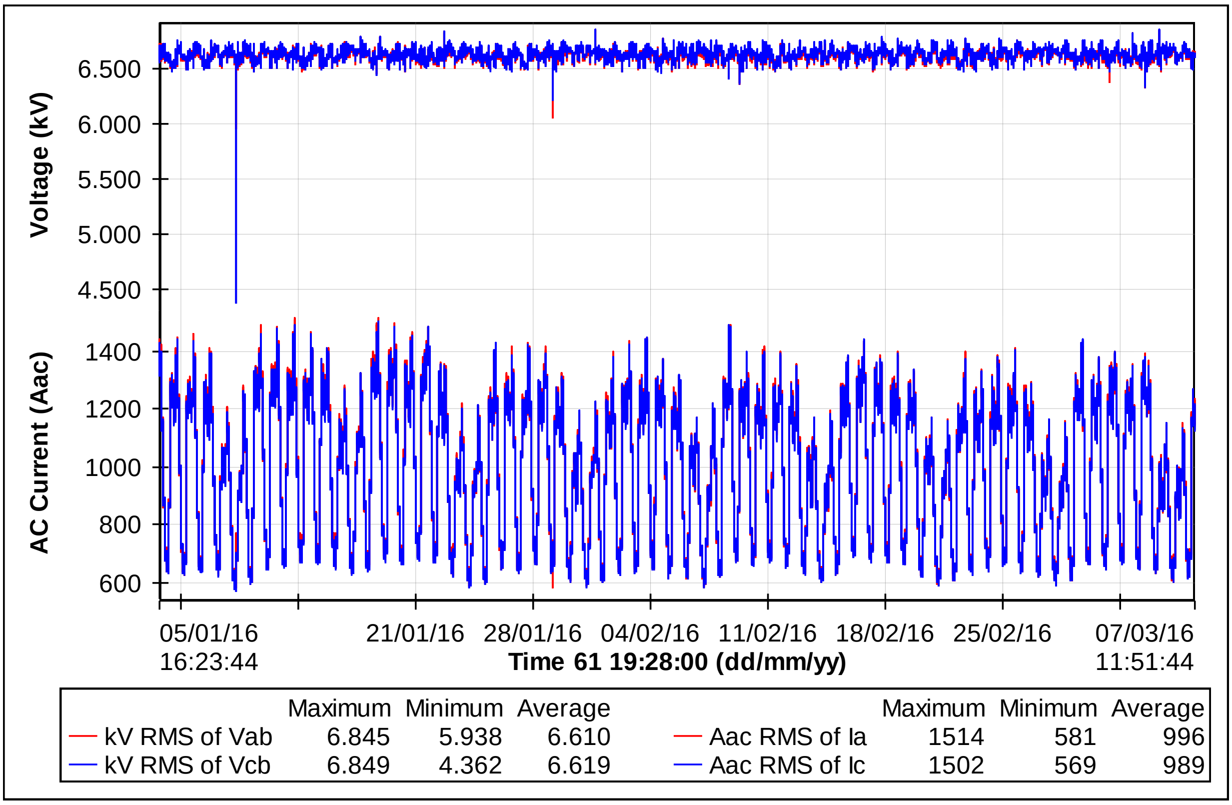
The overall results for Irlam Primary over the 9 week period are not as uniformly good as at Wigan, but are nevertheless strong. As with Wigan, there is little room for manipulation of these results, so sources of error are principally the systematic ones of incorrect assumptions, wrong CT settings, faulty sensors, cables etc. If the current and voltage results recorded by the PM7000 and shown below match the independent measurements reported by the ENWL SCADA or other systems, then it is very unlikely that these results are wrong.

The spread of results on the 90ms RMS result from no filtering to maximum (10% of span) is just 1%. For the ½ cycle Peak, the spread is 7.2%. In both cases, 10% filtering is far more than is needed, and since the higher filter values include more of the (potentially anomalous) outliers, if they can be avoided, i.e. if the shape of the distribution is bell-shaped and clean at low filter values, then the low filter values are likely to give the most accurate results. Filter variation from 2% to 5% on the ½ cycle Peak result gives a spread of 3.3% (2% is about the minimum filtering needed to get a clean distribution).

As the total accrual period for assessment is reduced from the total 9 weeks, the noise can become more significant. Graphs 12 and 13 below show 12 and 24 hour sliding windows applied to the raw data.

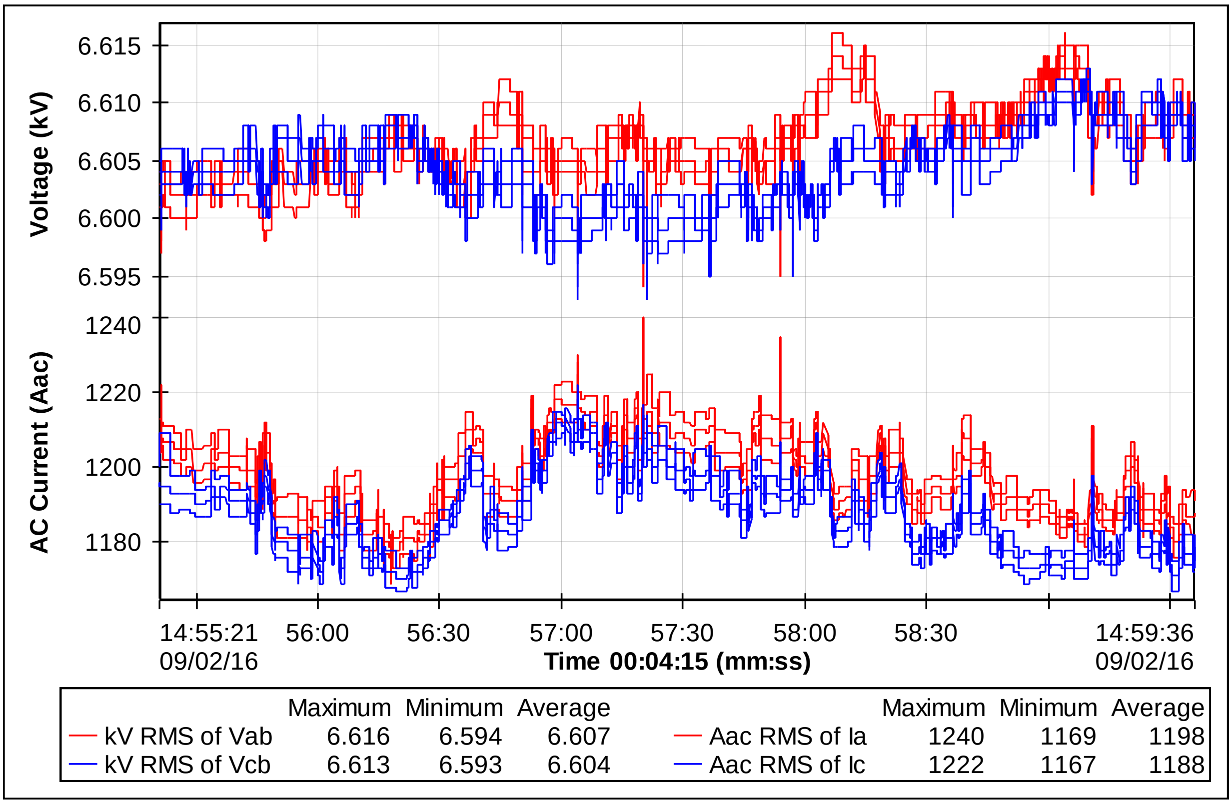
Irlam Primary results, General observations.

Graph 1 shows the voltage and current for the full recording period. The voltage spikes reported for Wigan BSP and Broadheath are also visible here.

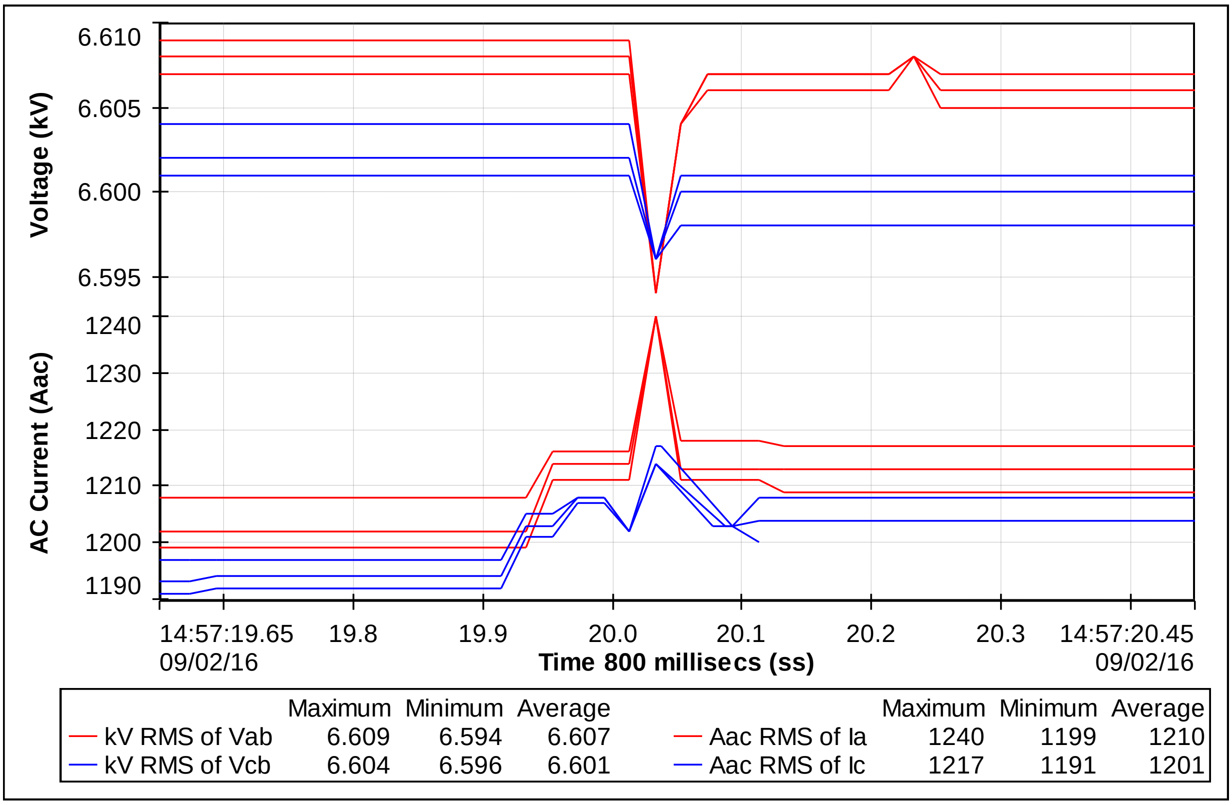


Graph 1. Volts and Current for the full recorded period.

Searching for useful disturbances of any size reveals very little. Graphs 2 and 3 show some typical disturbances.

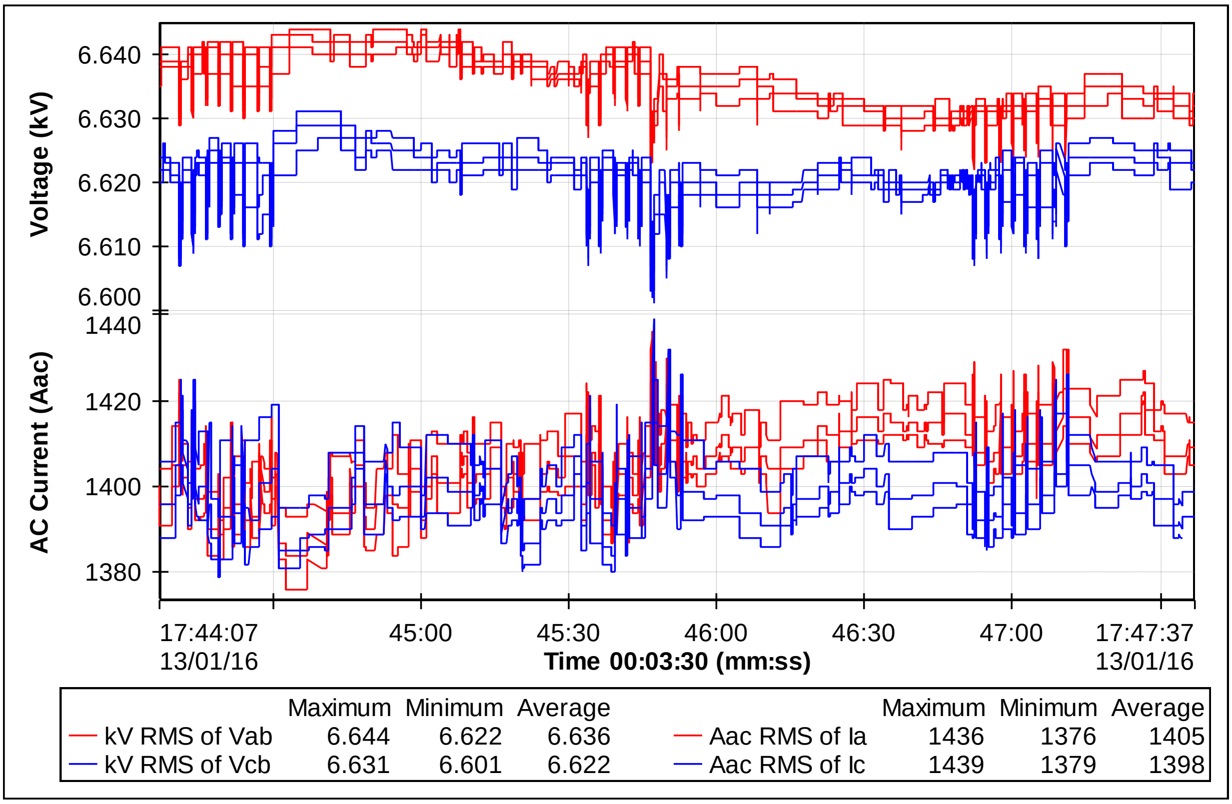


Graph 2. Possibly useful disturbances.



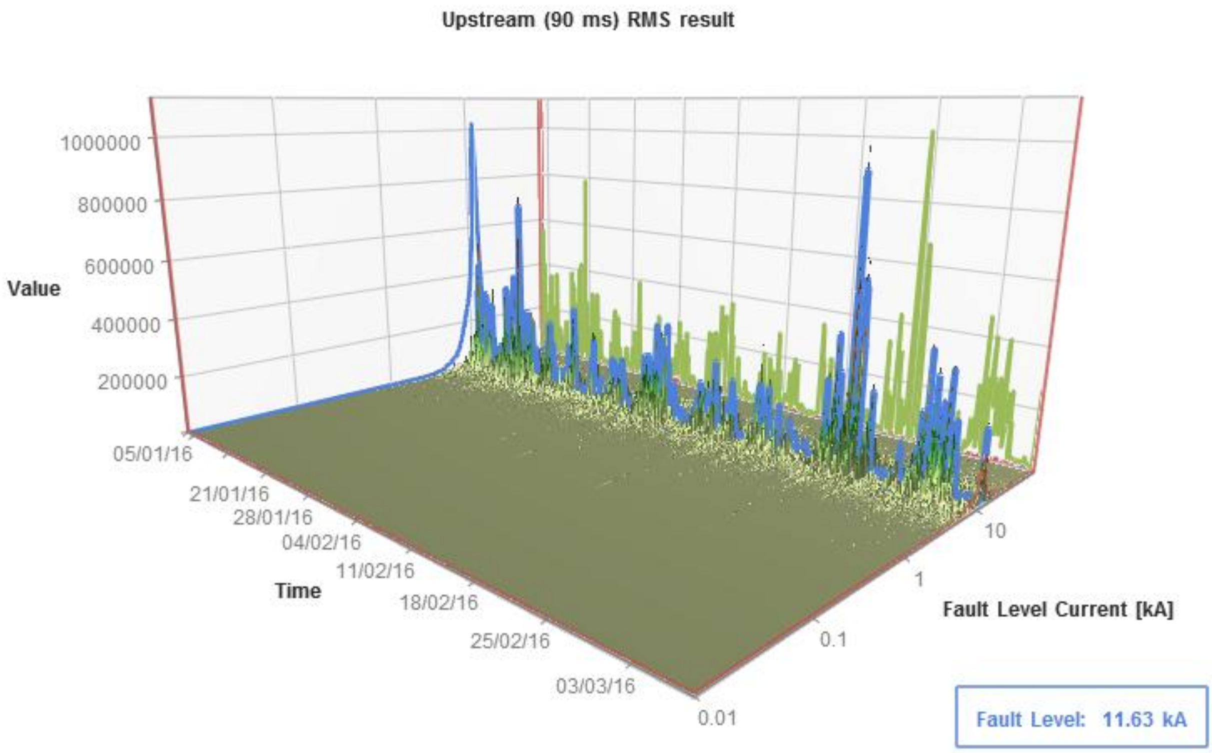
Graph 3. Small current and voltage spikes at 14:57:20 on 9th February, expanded.

Although there does not appear to be anything much bigger than this, there are patterns of disturbances running through parts of the recording, as shown in Graph 4 below. These do seem to be load related so may be useful as downstream disturbances.



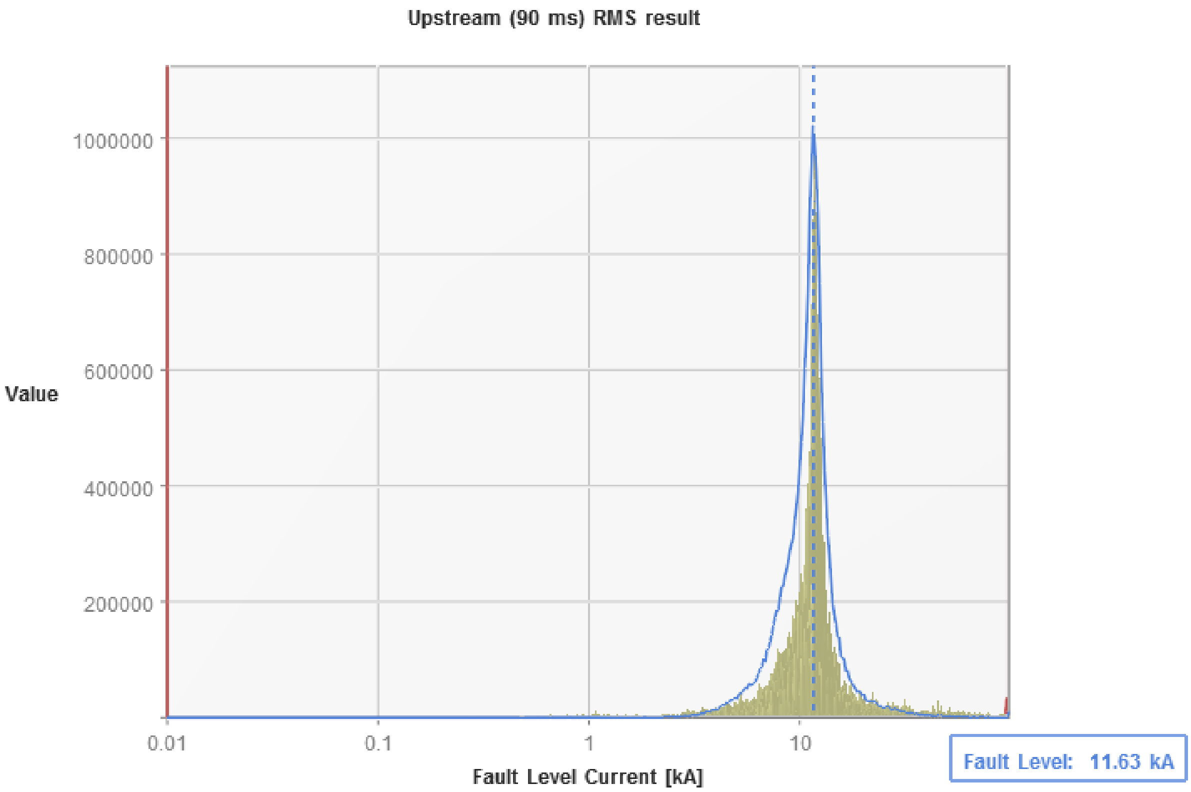
Graph 4. Patterns of small disturbances which may be useful for Fault Level extraction.

Fault Level Results



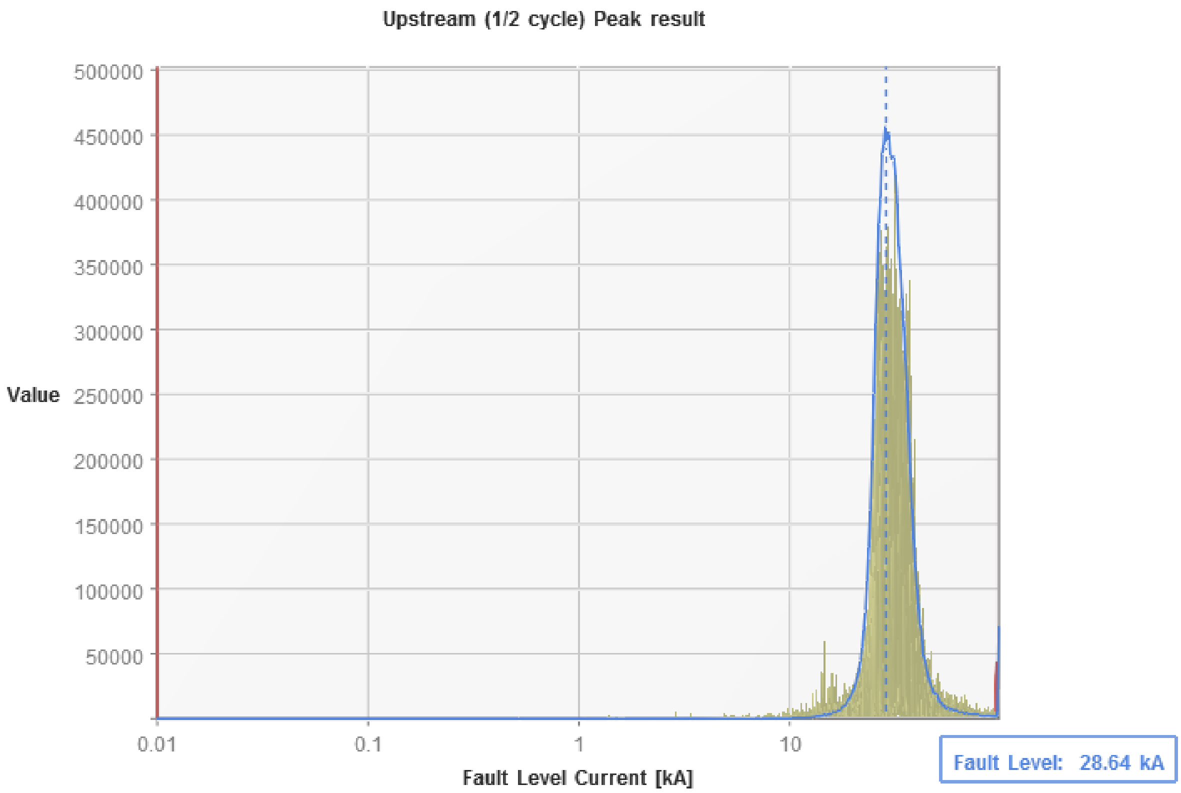
Graph 5. Upstream RMS Fault level at 90ms. 3D Distribution shown with no filtering.

Graph 5 shows that the mean Upstream 90ms RMS Fault Level for the period was 11.63 kA. Graph 6 shows the same thing in 2 dimensions.



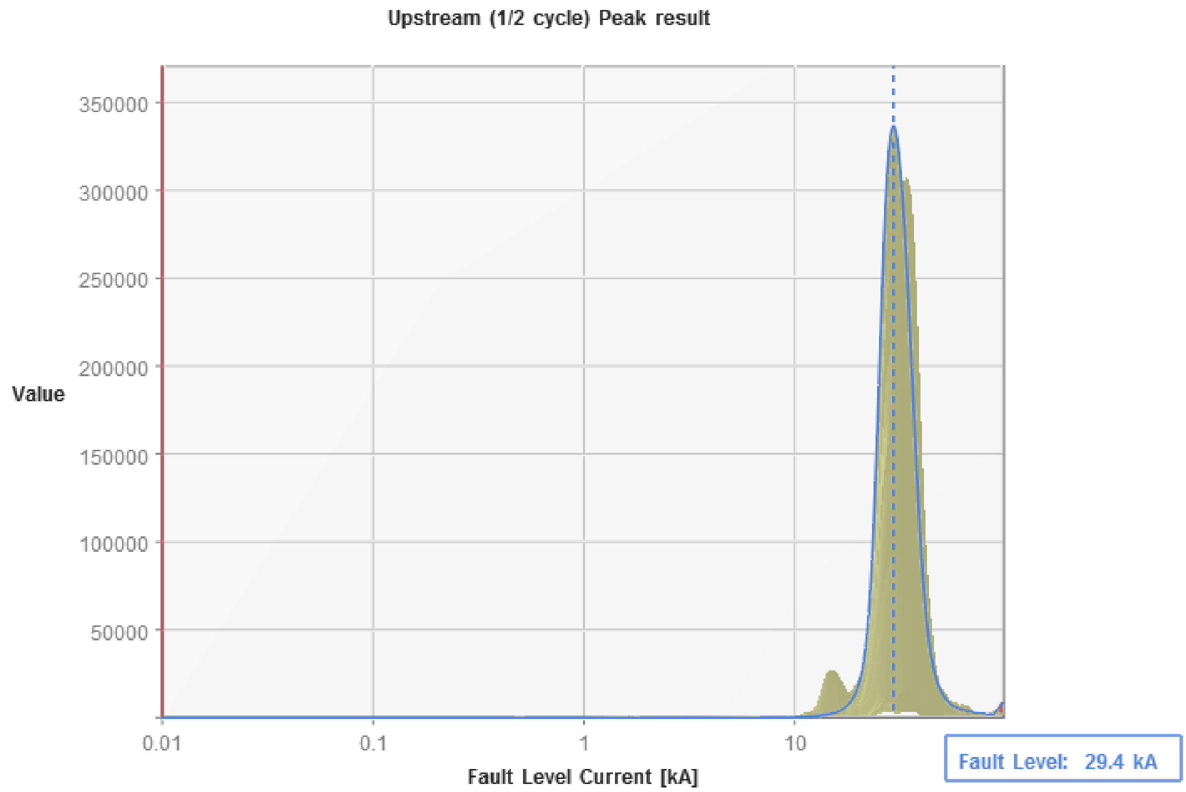
Graph 6. Upstream RMS Fault level at 90ms. 2D Distribution shown with no filtering.

Graph 7 below shows the Peak Fault Level at ½ cycle in 2D with no filtering. This could benefit from some filtering because the peak is clearly biased slightly down.



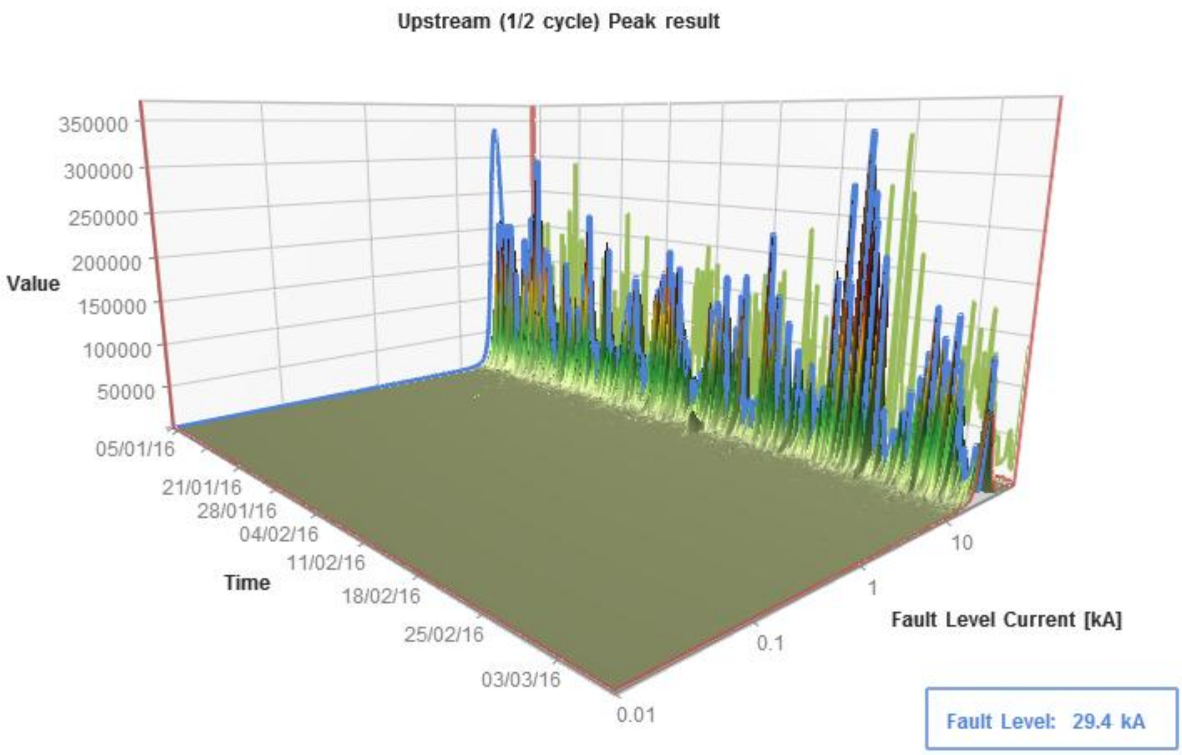
Graph 7 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with no filtering.

Graph 8 below shows the same data with 3% filtering.

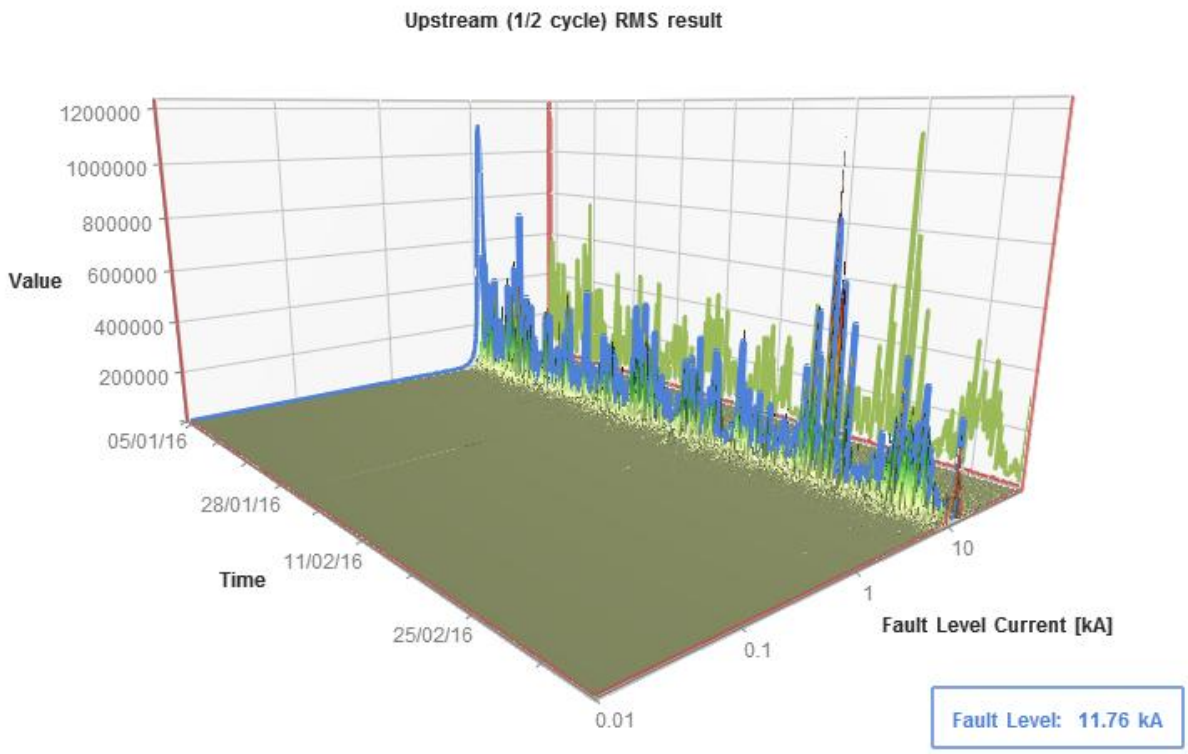


Graph 8 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with 3% filtering.

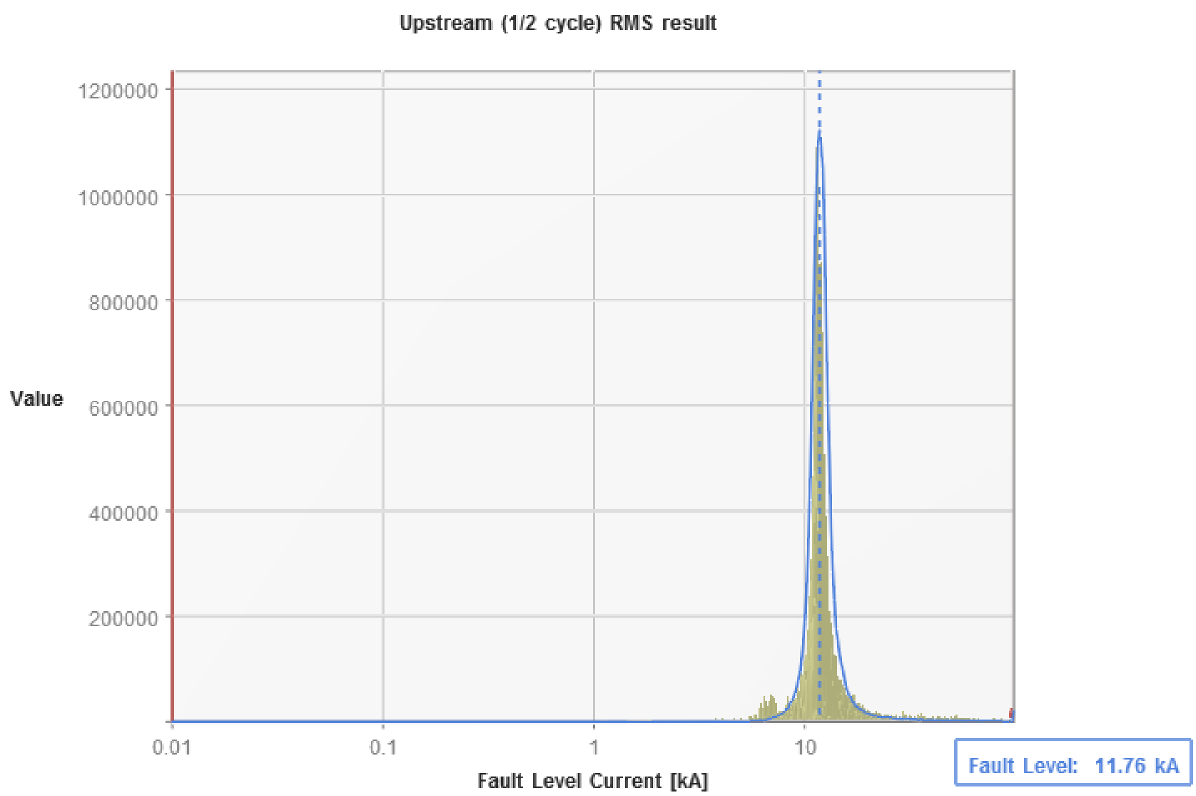
The peak of the distribution is now detected at 29.4kA. Graph 9 is the 3D version, showing the distribution of disturbance energy over time.



Graph 9 Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 3% filtering.

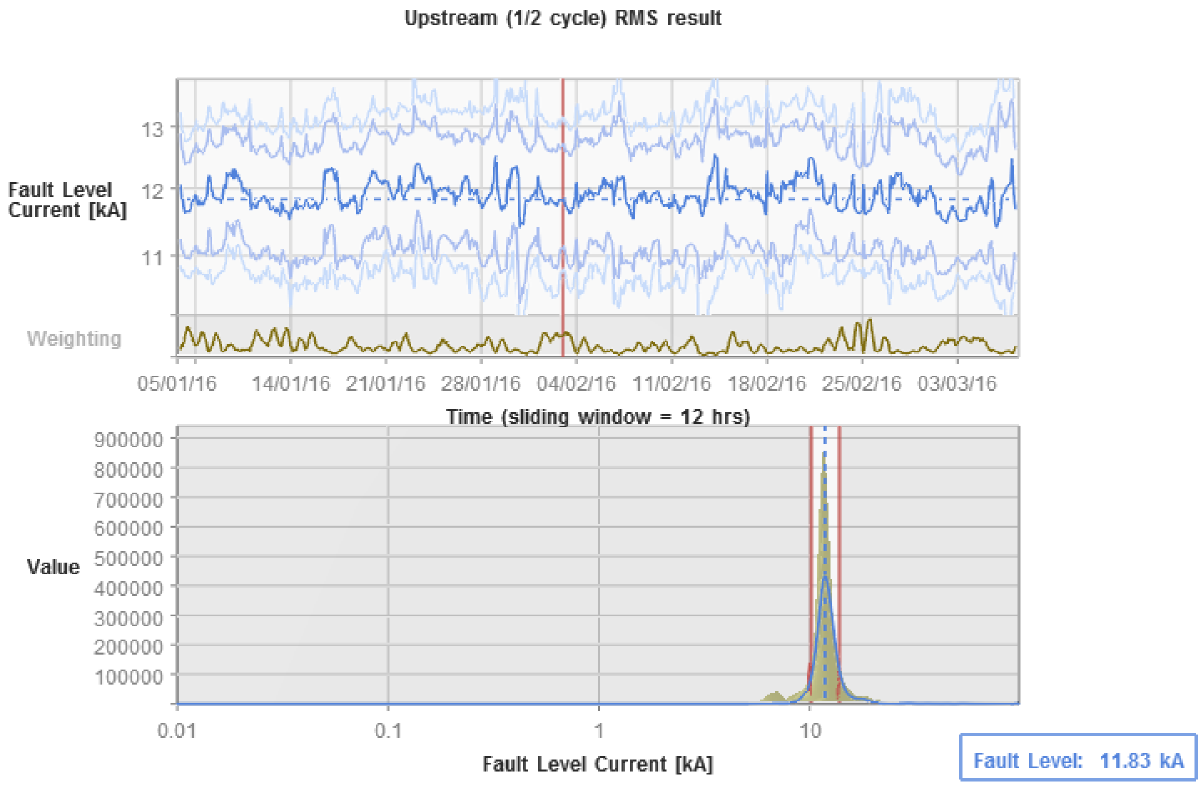


Graph 10. Upstream RMS Fault level at ½ cycle. 3D Distribution shown with no filtering.

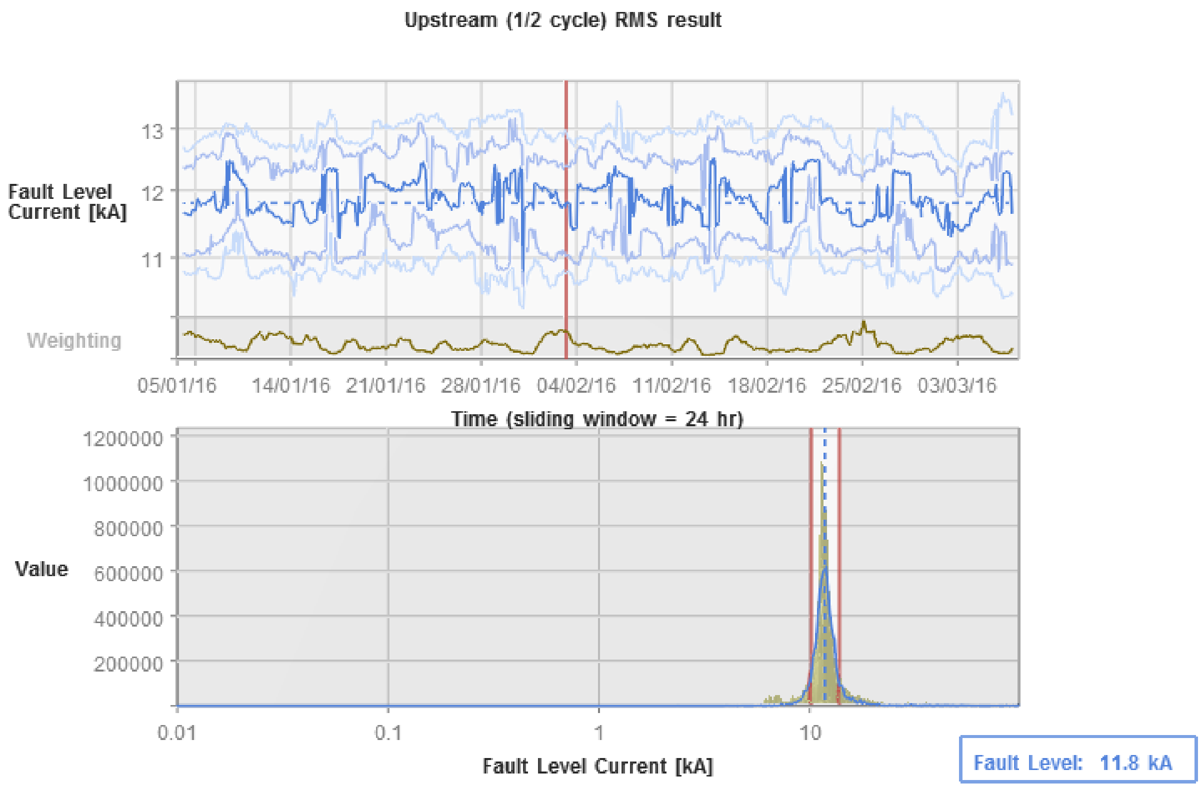


Graph 11. Upstream RMS Fault level at ½ cycle. 2D Distribution shown with no filtering.

The RMS result also at ½ cycle is shown in Graphs 10 and 11. The cleanliness of this distribution suggests it is a good basis for searching for significant changes in Fault Level during the period such as due to switching operations. Graph 12 shows a sliding window of 12 hours applied with a filter of 2%.



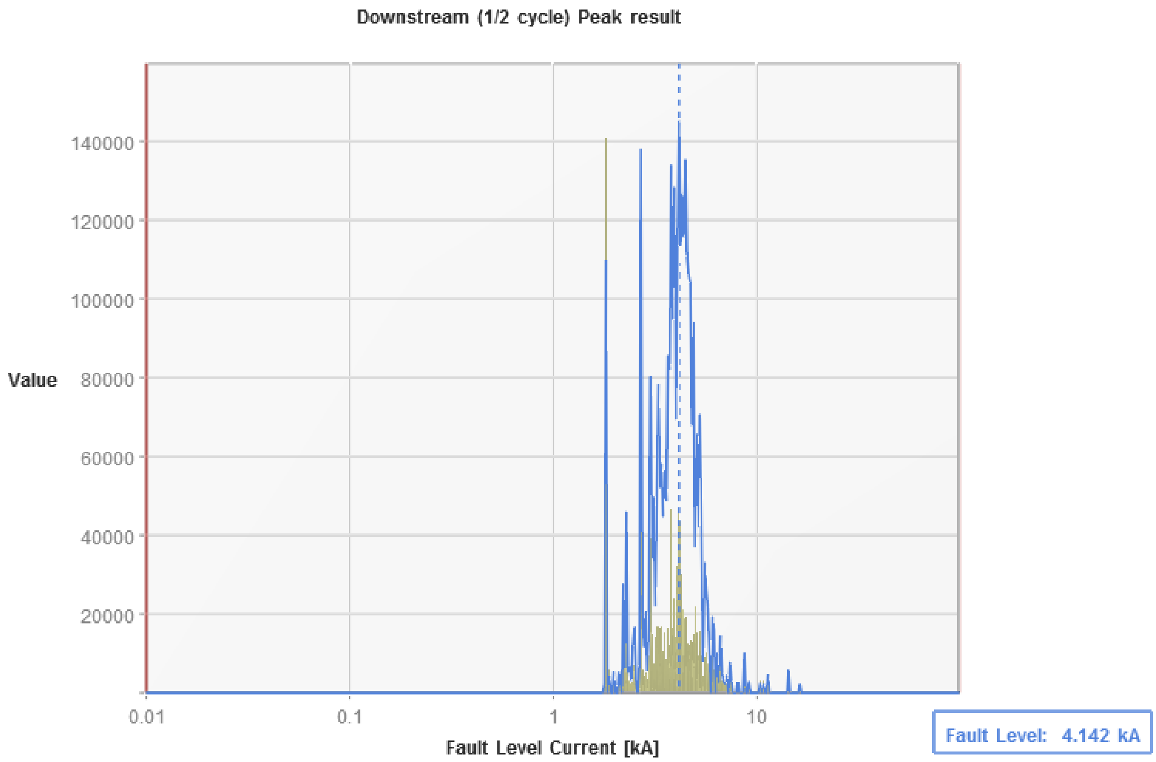
Graph 12. Upstream RMS Fault level at ½ cycle. 12 hr Time varying result shown with 2% filtering.



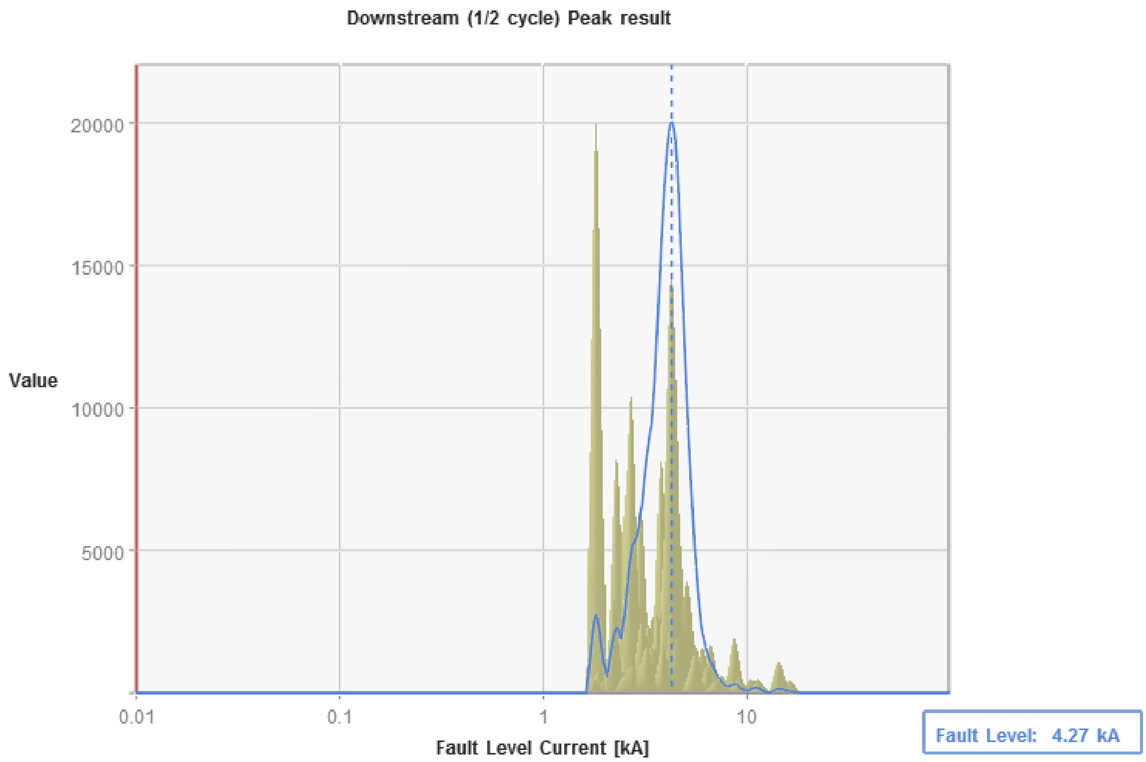
Graph 13. Upstream RMS Fault level at ½ cycle. 24 hr Time varying result shown with no filtering.

Downstream Fault Level contribution

Graphs 14 and 15 show the Peak half cycle Fault Level detected for downstream contribution. Graph 14 is with no filtering, and Graph 15 with 3%.

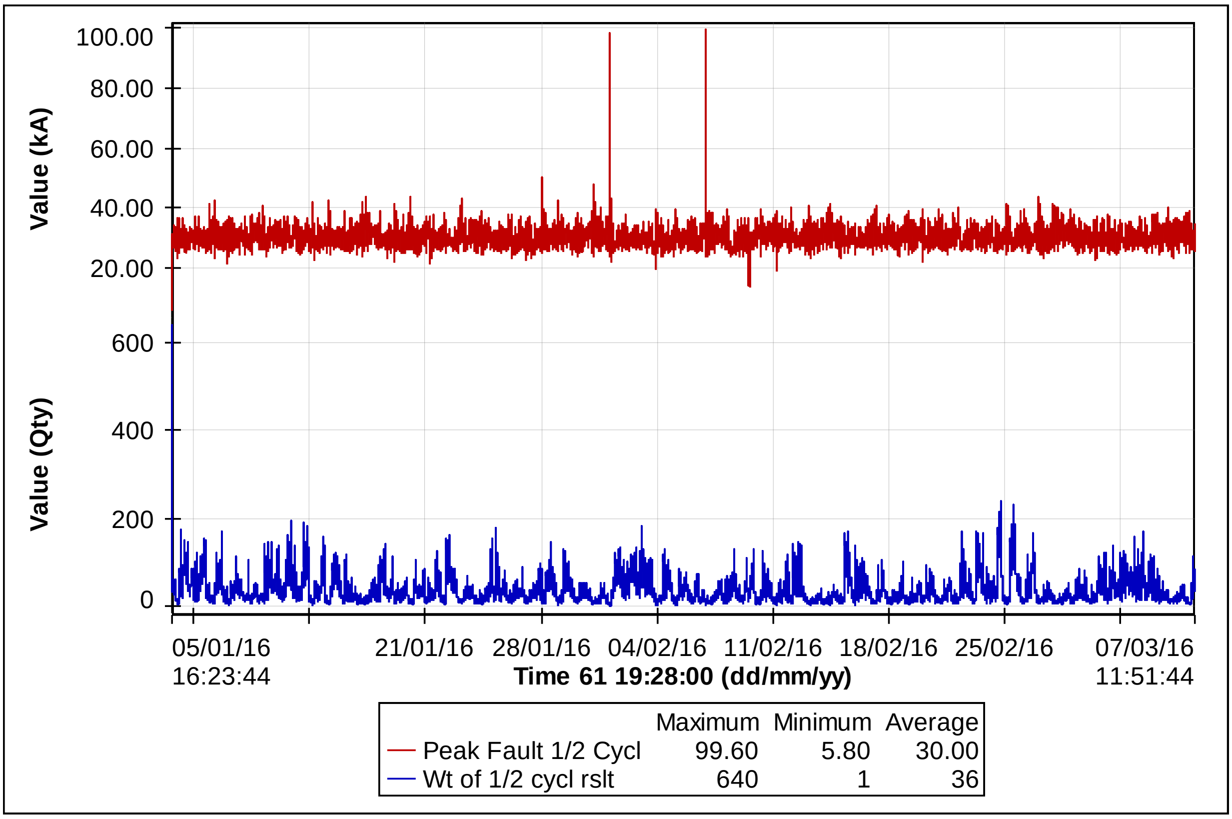


Graph 14. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with no filtering.

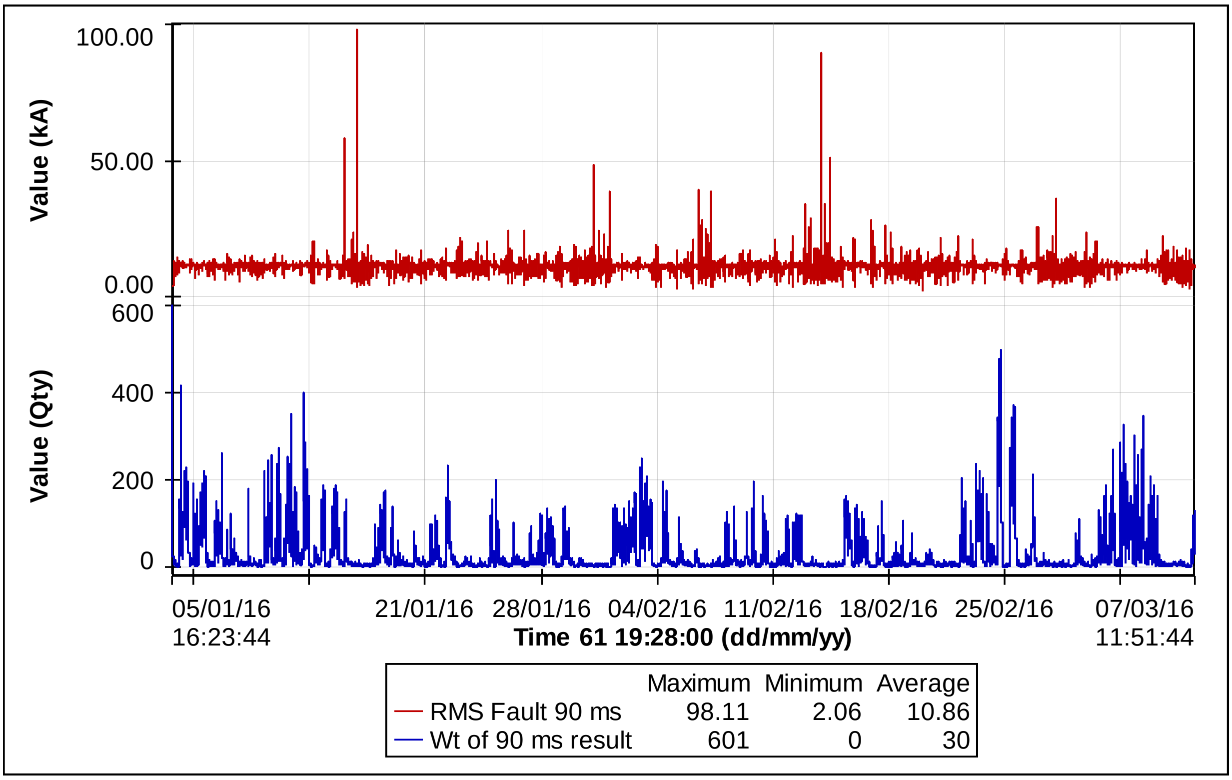


Graph 15. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 3% filtering. The best peak appears to be around 4.27kA.

The following graphs 16 and 17 show the detail results and weighting applied at ½ cycle and 90 ms respectively.



Graph 16. Peak upstream results and weighting present at ½ cycle.



Graph 17. RMS upstream results and weighting present at 90ms.

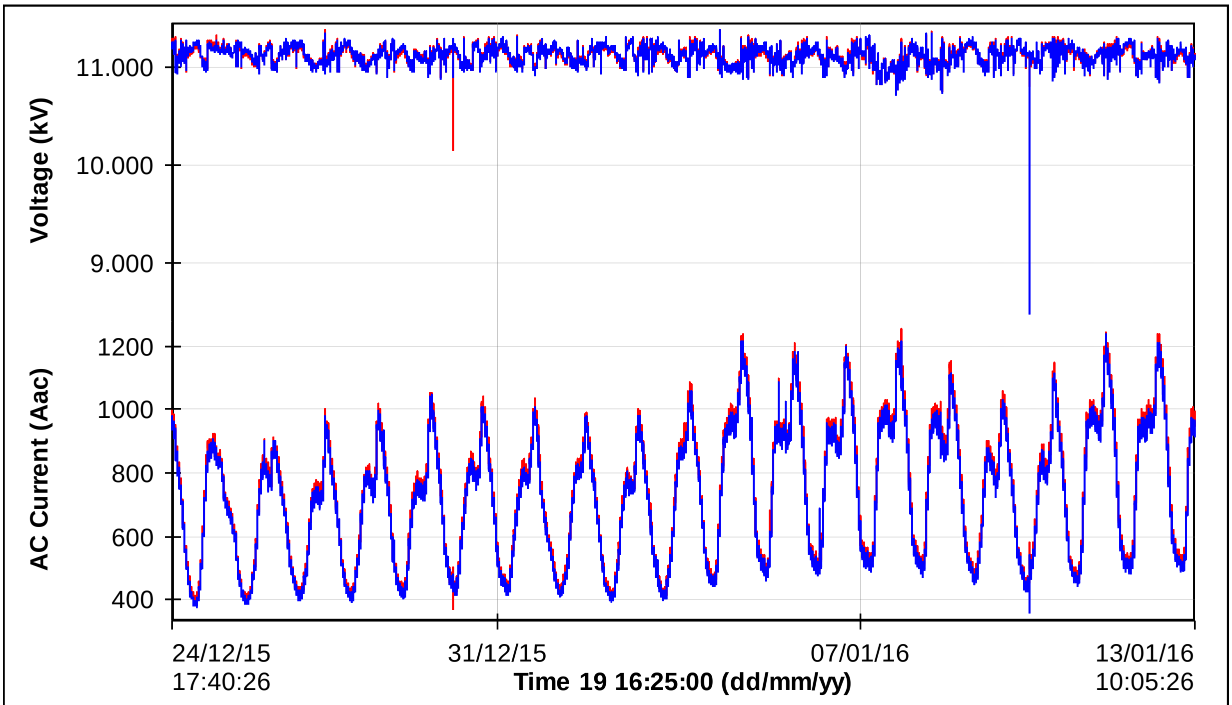
Appendix 4. Hindley Green. FLM Serial No 0890

Sources of error

The overall results for Hindley Green over the 3 week period are again quite strong. As with Wigan, there is little room for manipulation of these results, so sources of error are principally the systematic ones of incorrect assumptions, wrong CT settings, faulty sensors, cables etc. If the current and voltage results recorded by the PM7000 and shown below match the independent measurements reported by the ENWL SCADA or other systems, then it is unlikely that these results are wrong.

Hindley Green results, General observations

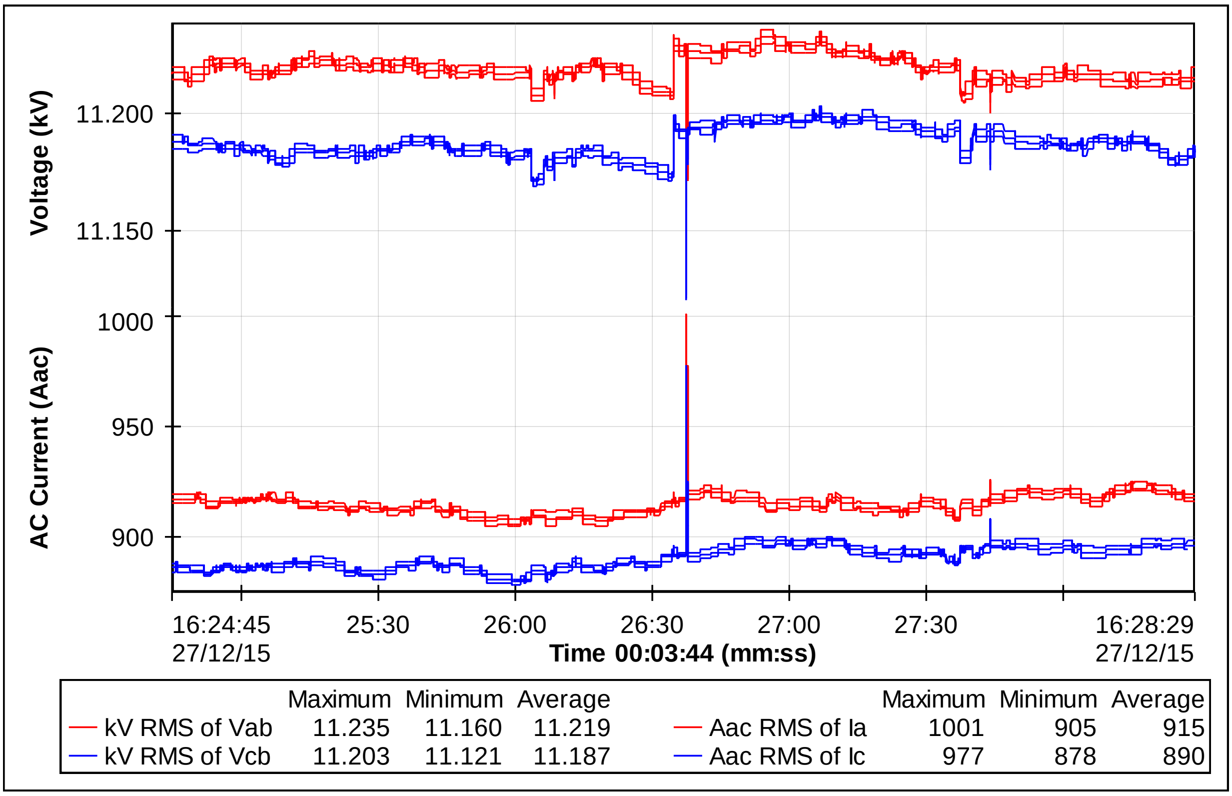
Graph 1 shows the voltage and current for (almost) the full recording period. The voltage spikes reported for Wigan BSP and Broadheath are also visible here. (The final few minutes of the recording have been truncated as the voltage connections to the FLM were removed before the unit stopped recording.)



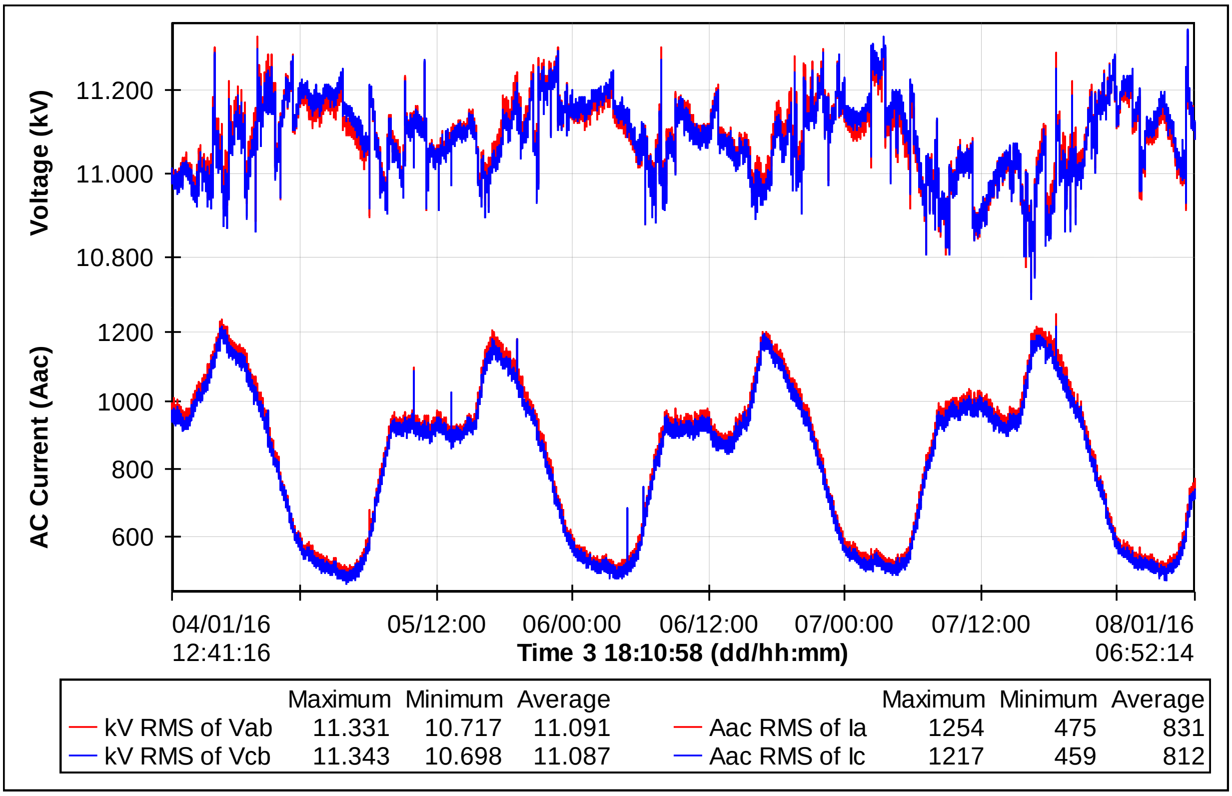
	Maximum	Minimum	Average		Maximum	Minimum	Average
kV RMS of Vab	11.374	10.139	11.118	Aac RMS of Ia	1254	369	740
kV RMS of Vcb	11.375	8.476	11.116	Aac RMS of Ic	1237	356	723

Graph 1. Volts and Current for the full recorded period.

There are a few big disturbances on the 27th December, and again around the 5th January. Graphs 2 and 3 show examples.

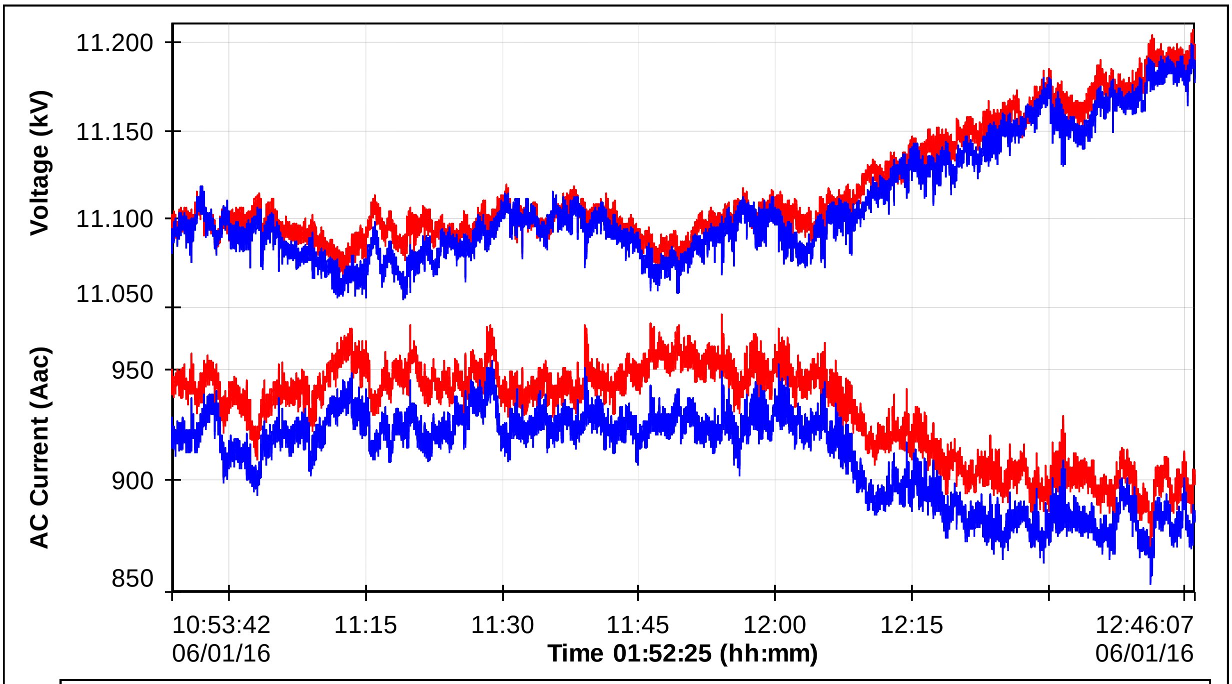


Graph 2. Possibly useful disturbance.



Graph 3. Some useful load disturbances around 5th January.

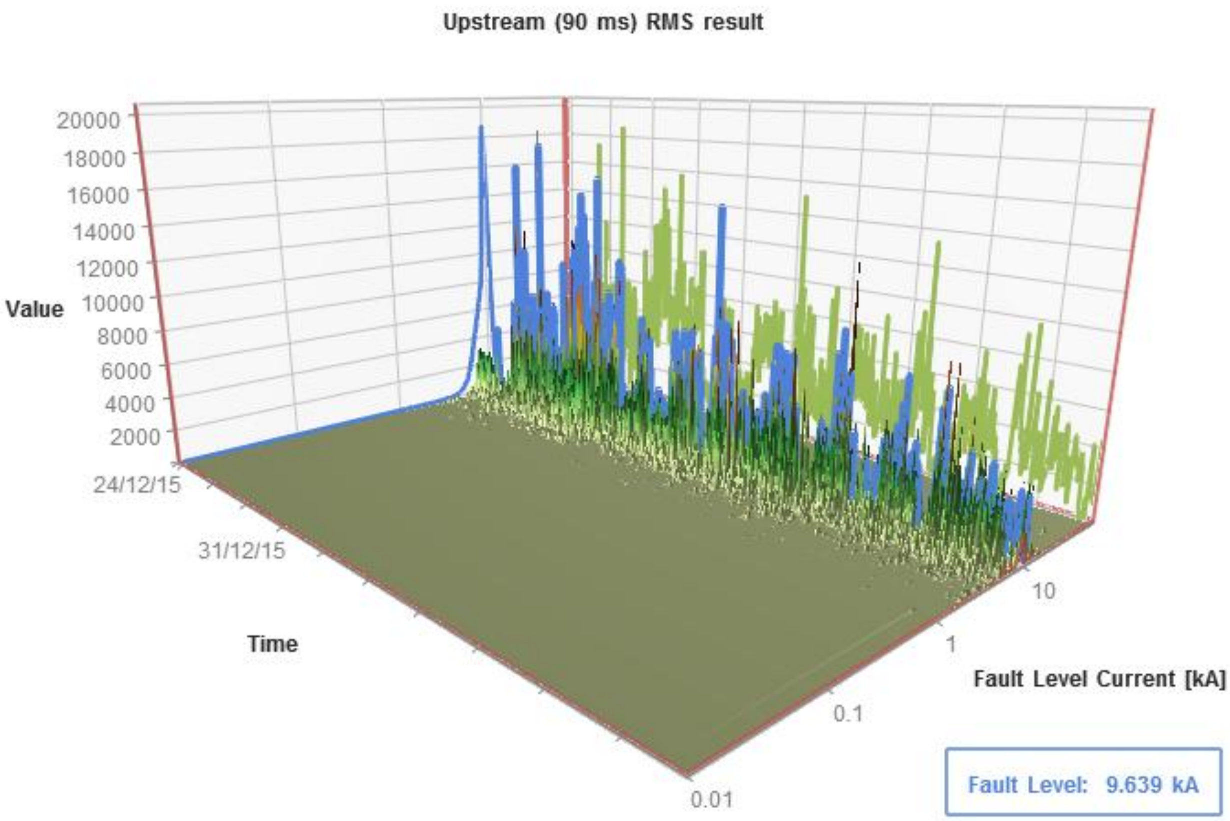
Although there does not appear to be anything much bigger than this, there are little disturbances of about 0.2% voltage variation more frequently throughout the recording. Graph 4 shows examples.



	Maximum	Minimum	Average		Maximum	Minimum	Average
kV RMS of Vab	11.207	11.062	11.117	Aac RMS of Ia	975	869	931
kV RMS of Vcb	11.199	11.054	11.109	Aac RMS of Ic	954	853	910

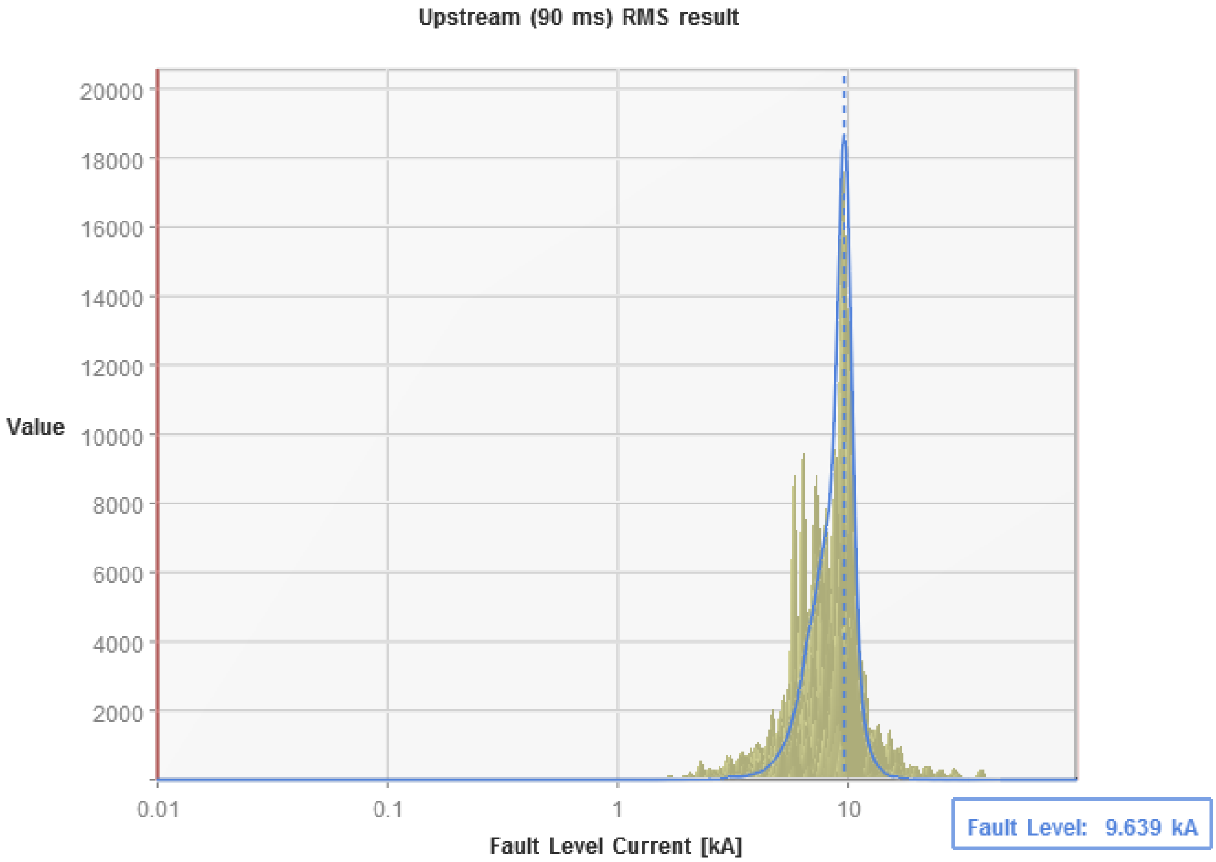
Graph 4. Patterns of small disturbances which may be useful for Fault Level extraction.

Fault Level Results



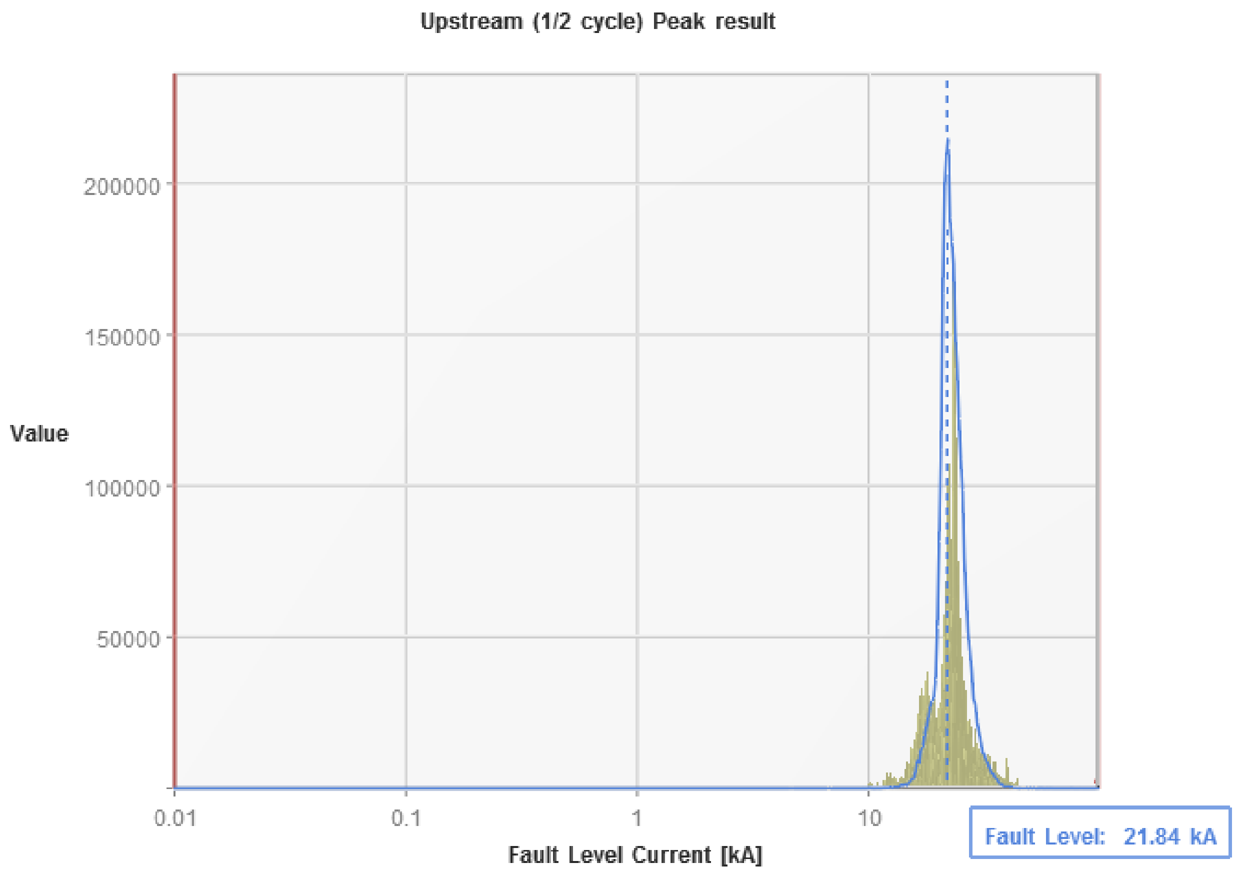
Graph 5. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.

Graph 5 shows that the mean Upstream 90ms RMS Fault Level for the period was 9.639 kA. Graph 6 shows the same thing in 2 dimensions.



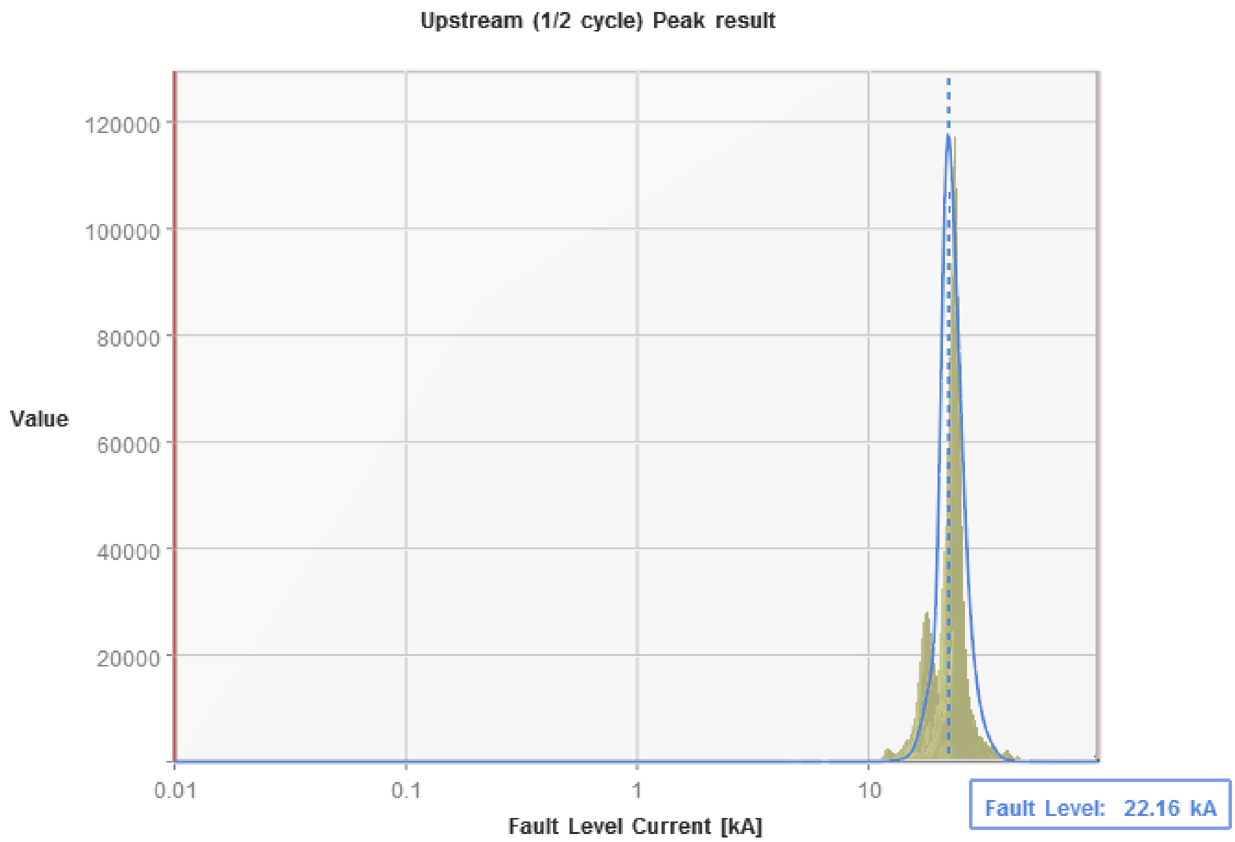
Graph 6. Upstream RMS Fault level at 90ms. 2D Distribution shown with 2% filtering.

Graph 7 below shows the Peak Fault Level at ½ cycle in 2D with no filtering. This could benefit from some filtering because the peak is not quite symmetrical.



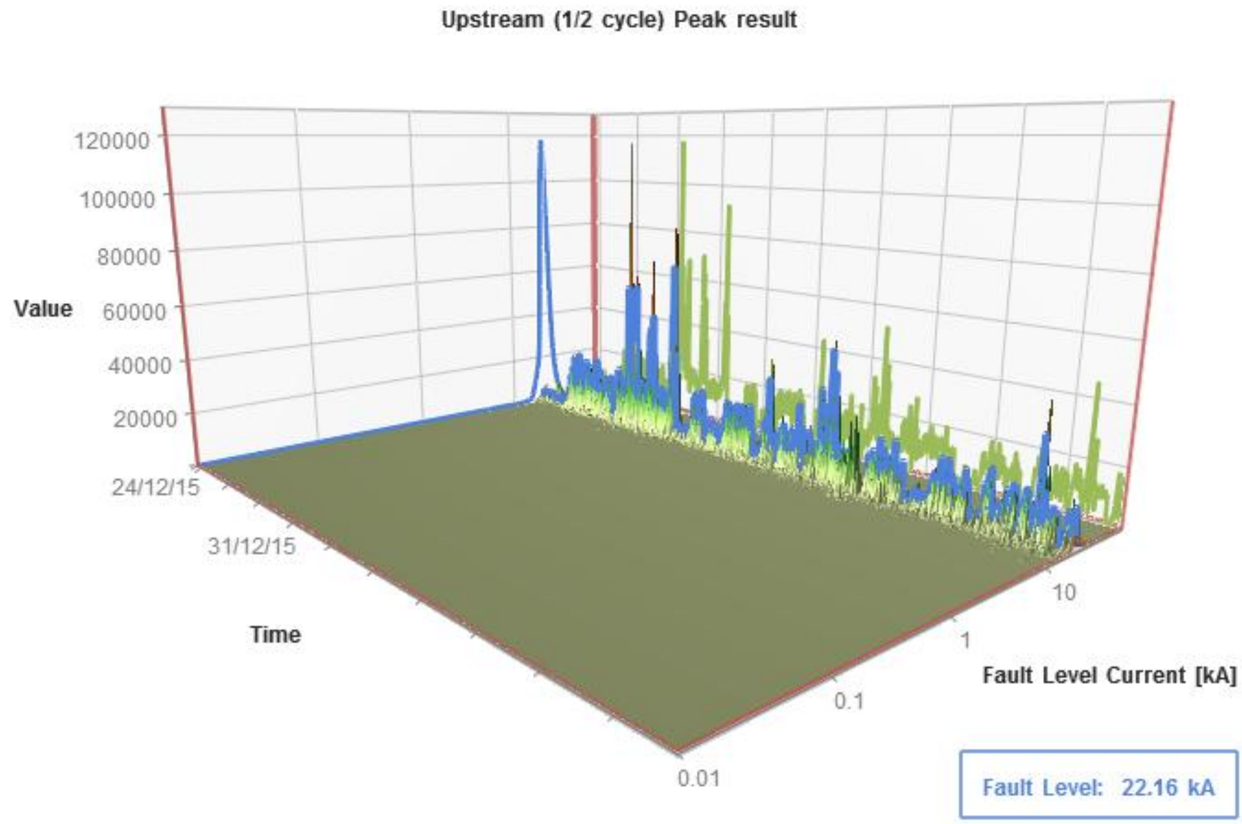
Graph 7 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with no filtering.

Graph 8 below shows the same data with 3% filtering.

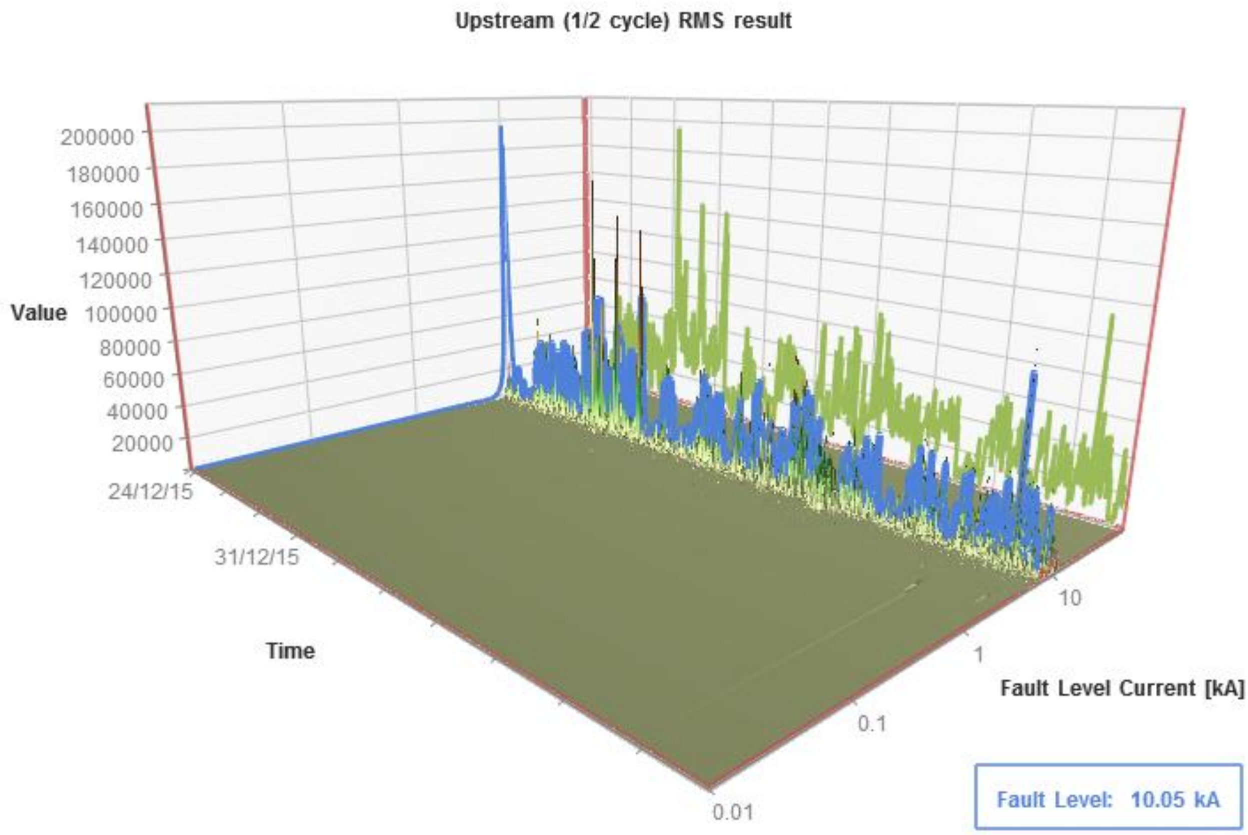


Graph 8 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with 2% filtering.

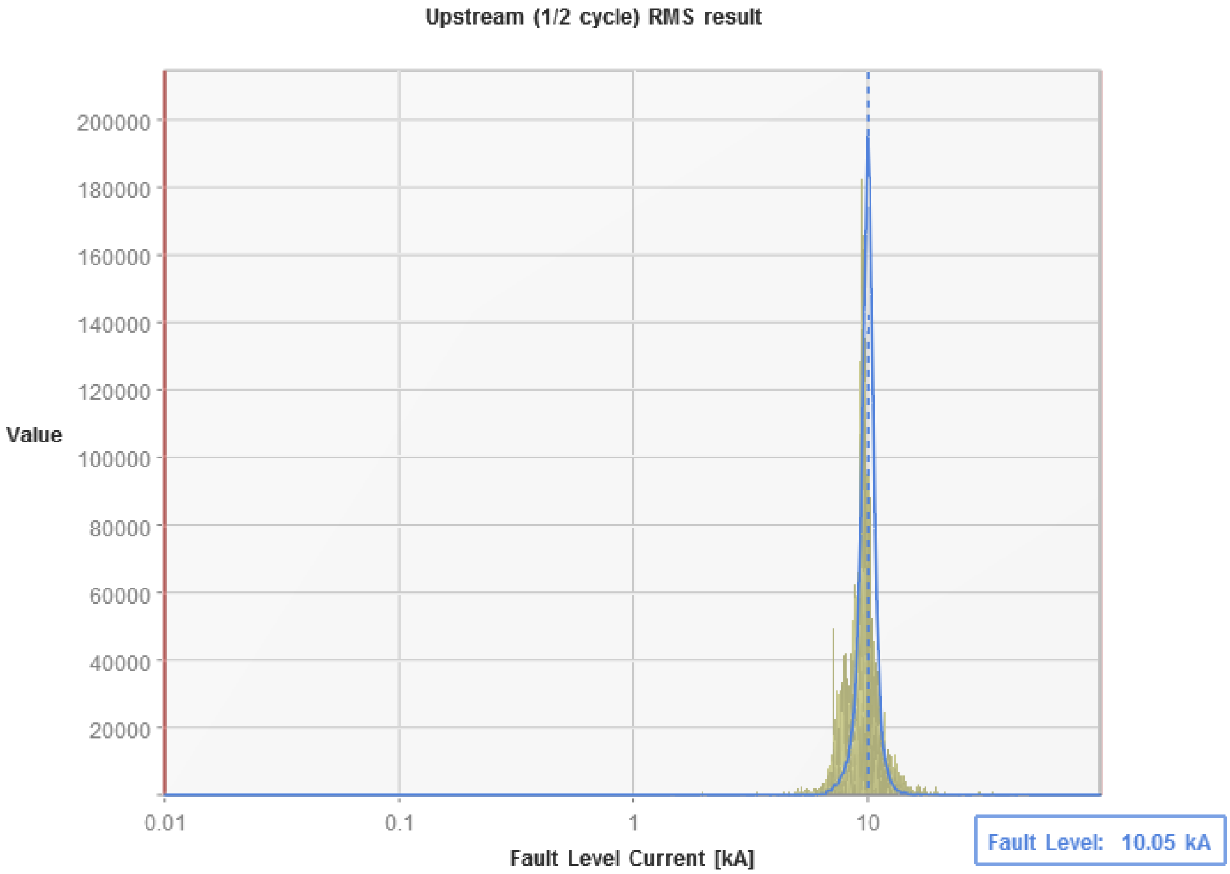
The peak of the distribution is now detected at 22.16kA. Graph 9 is the 3D version, showing the distribution of disturbance energy over time.



Graph 9 Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 3% filtering.

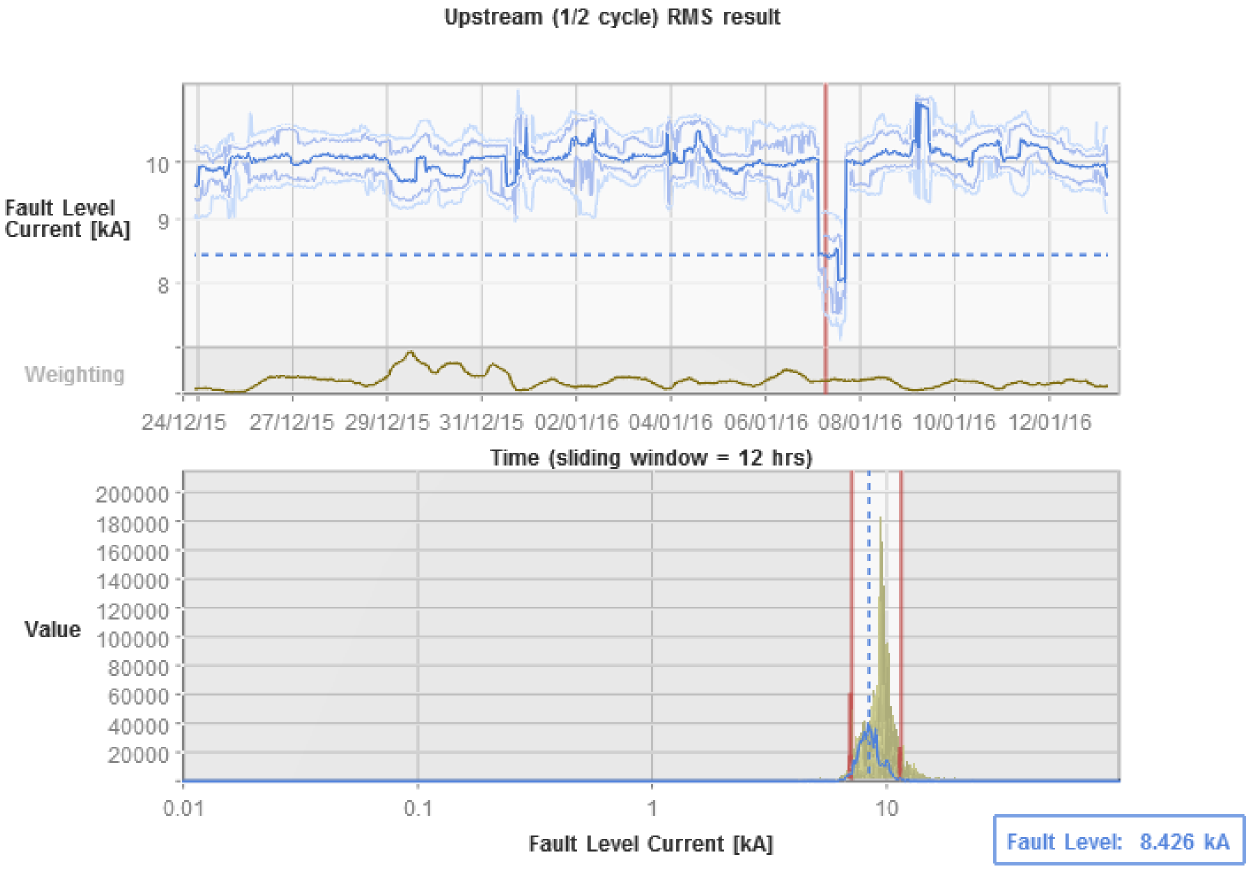


Graph 10. Upstream RMS Fault level at ½ cycle. 3D Distribution shown with no filtering.



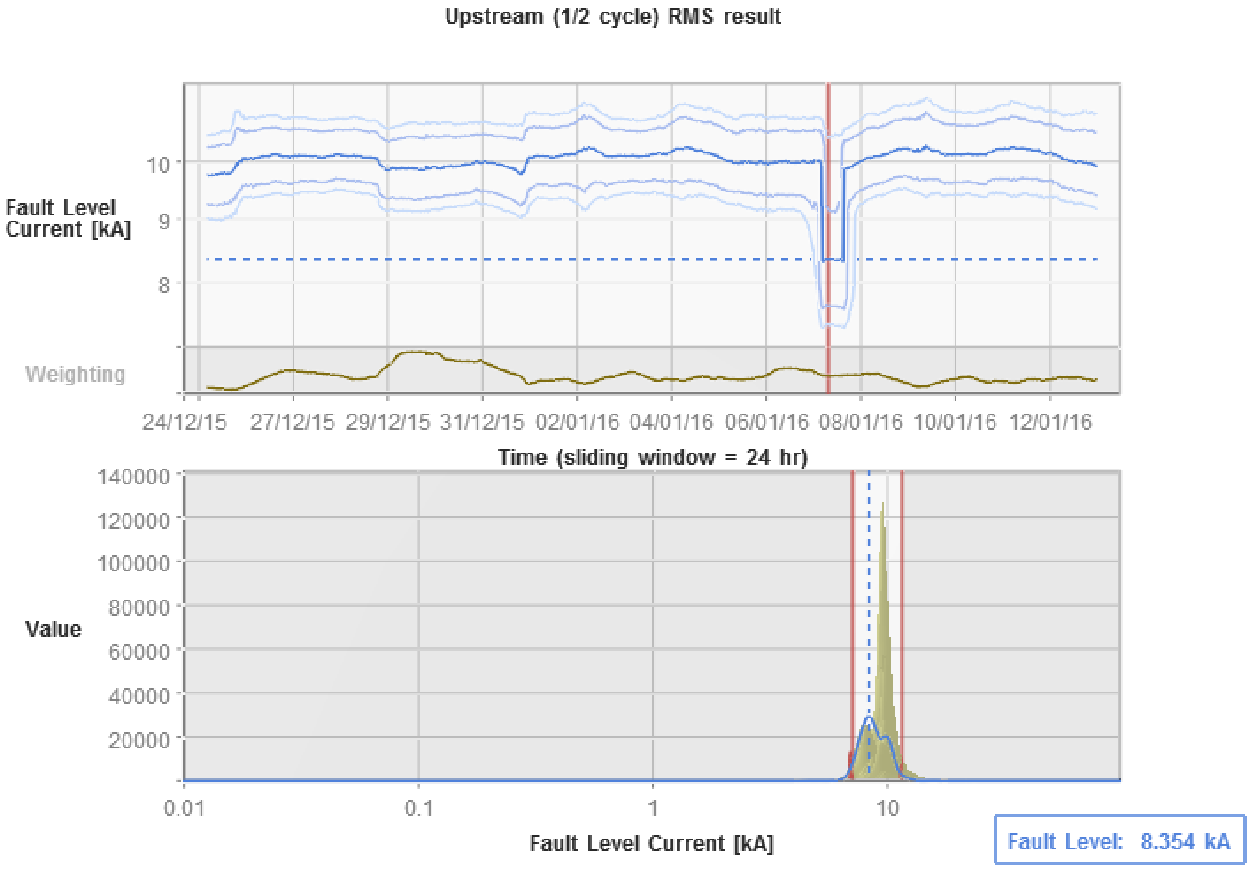
Graph 11. Upstream RMS Fault level at ½ cycle. 2D Distribution shown with no filtering.

The RMS result also at ½ cycle is shown in Graphs 10 and 11. The cleanliness of this distribution suggests it is a good basis for searching for significant changes in Fault Level during the period such as due to switching operations. Graph 12 shows a sliding window of 12 hours applied with no filter.



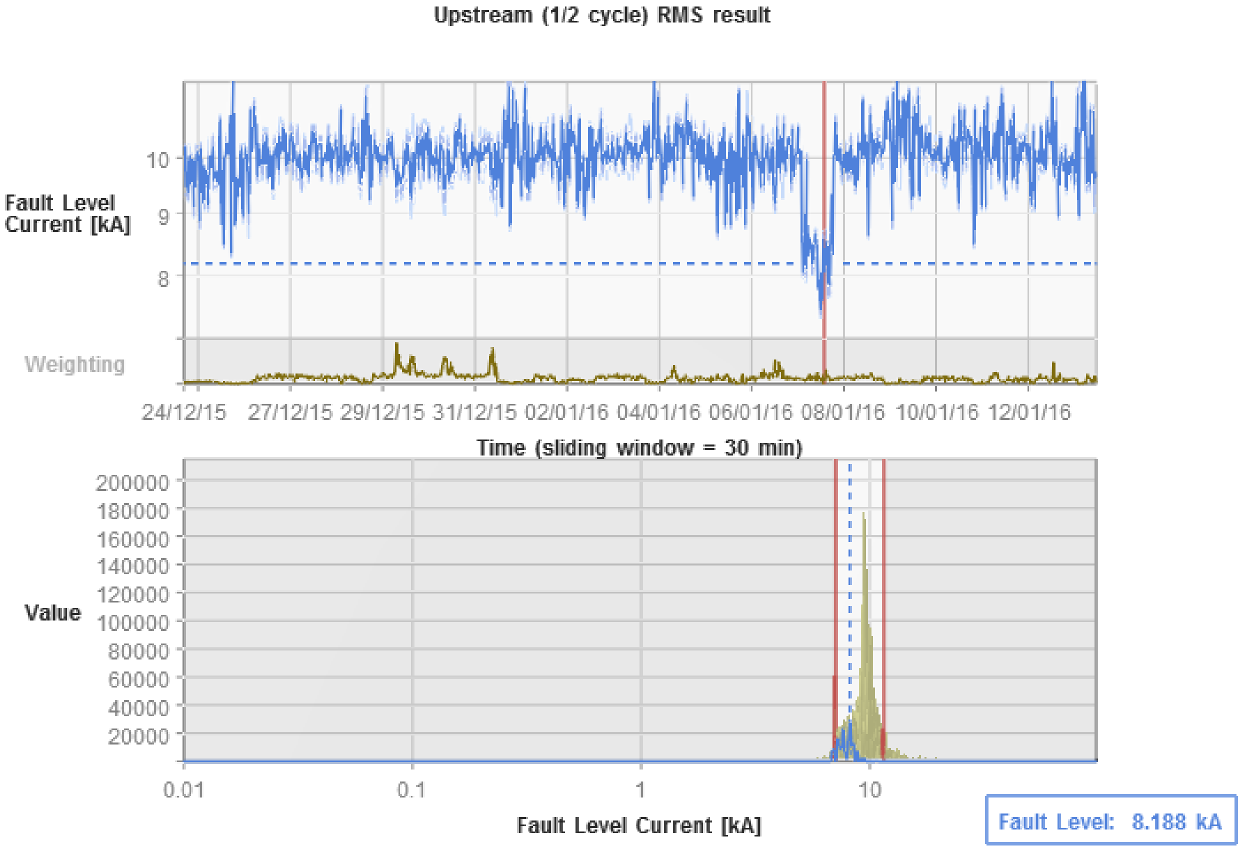
Graph 12. Upstream RMS Fault level at ½ cycle. 12 hr Time varying result shown with no filtering.

Graph 12 suggests some kind of systematic change to fault level occurred on the 7th January. Graph 13 attempts to make this clearer by using a 24 hours sliding window and a small amount of filtering (2%).



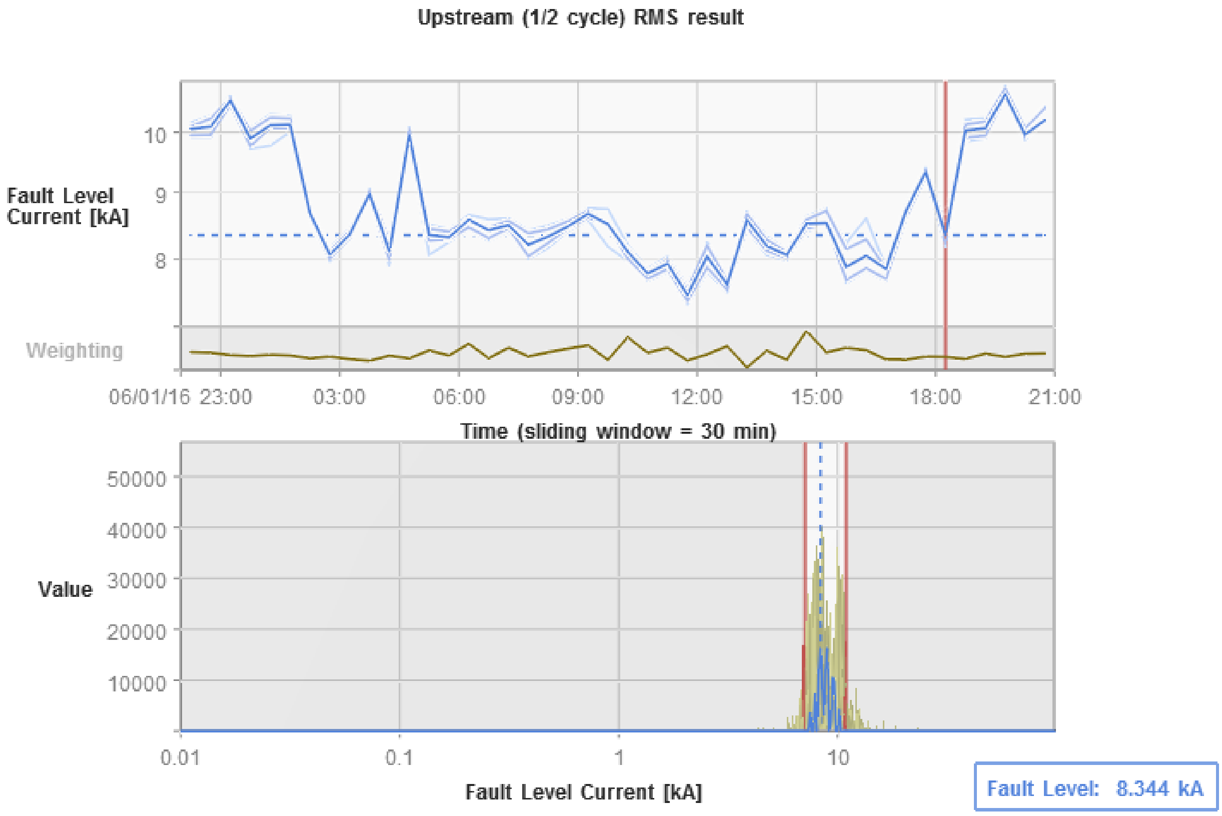
Graph 13. Upstream RMS Fault level at ½ cycle. 24 hr Time varying result shown with 2% filtering.

To determine when such an event might have occurred, we need to minimise the sliding window to limit the historical disturbance influence on the region of interest. Graph 14 shows the same base data with a 30 minute sliding window. This is the minimum we can get down to based on the Accrual Interval selected on the FLM at the start of the recording. Graph 14 is without filtering yet the significant reduction in Fault Level is very definitely present.



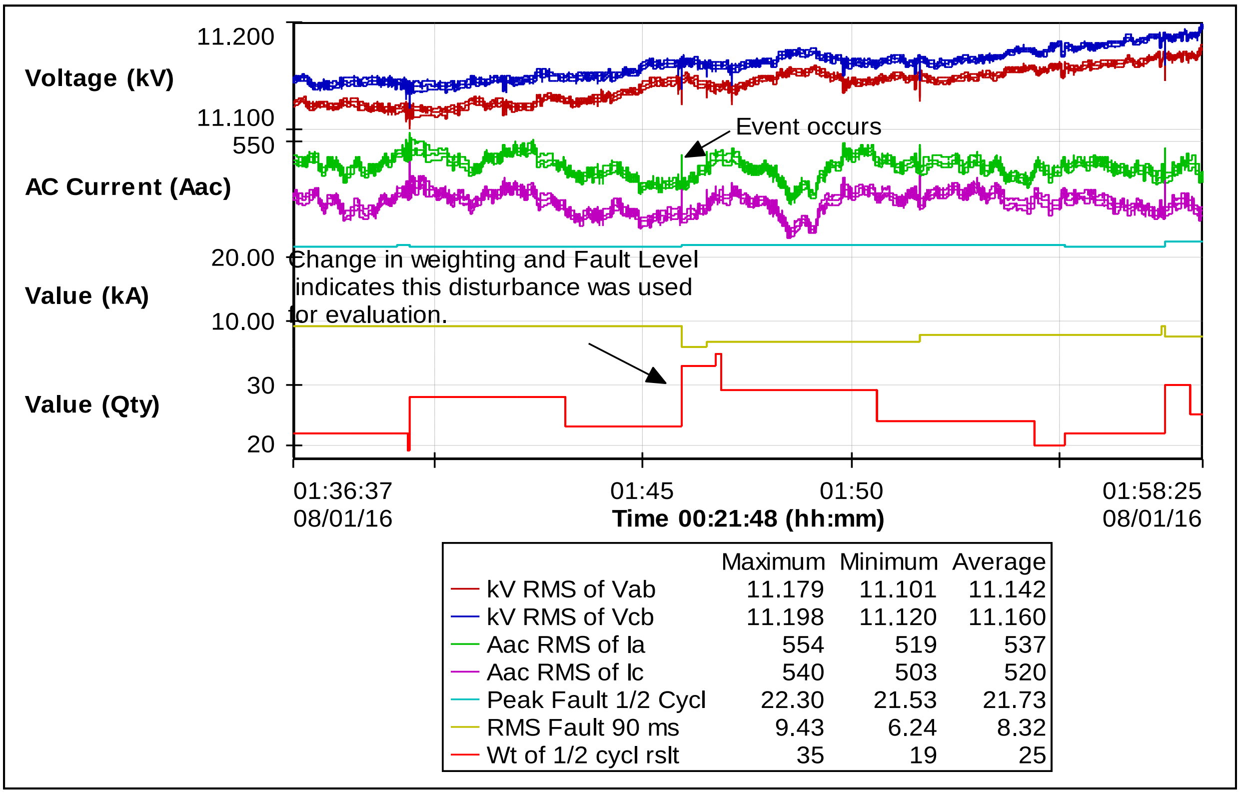
Graph 14. Upstream RMS Fault level at ½ cycle. 30 min Time varying result shown with no filtering.

By restricting the interval over which the Fault Level analysis is performed, we can identify to the 30 minutes when the event began and finished. From Graph 15 it appears to have begun at around 2.00am on 7th January, and finished around 18:30.



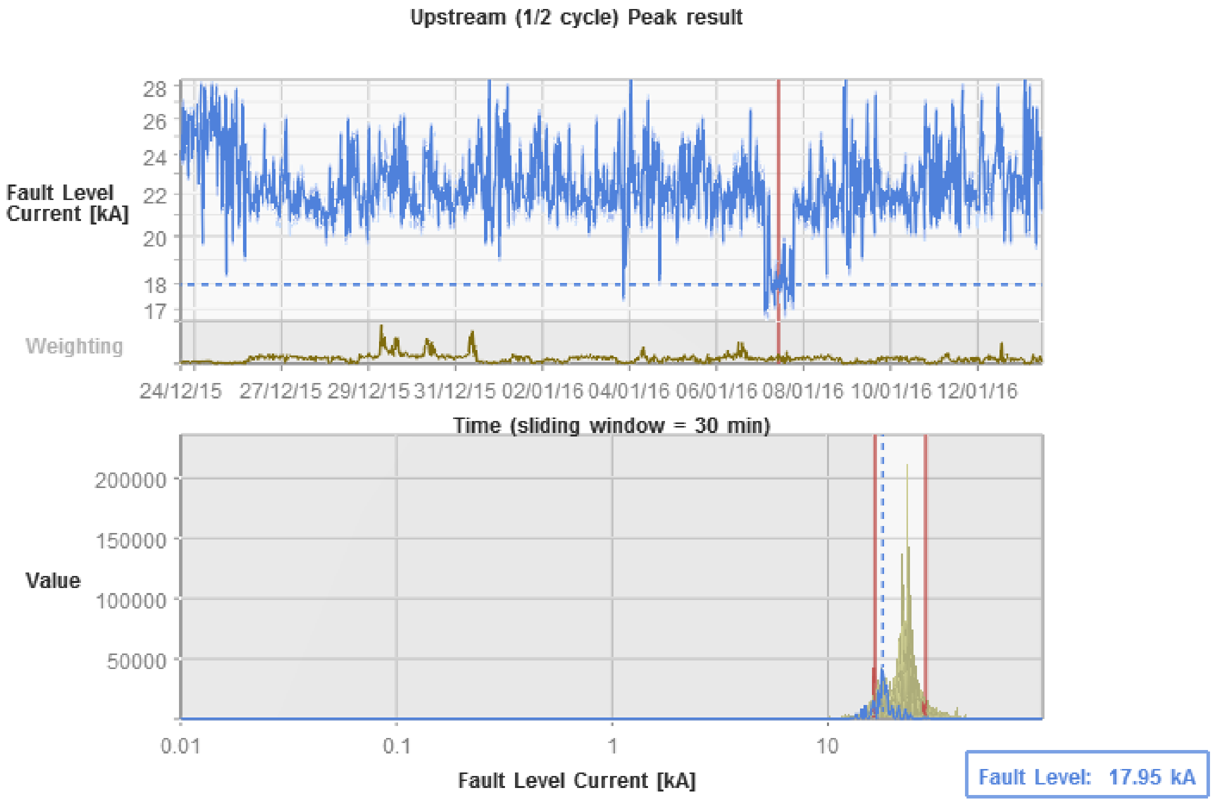
Graph 15. Upstream RMS Fault level at ½ cycle. 30 min Time varying result shown with no filtering.

Trying to pin-point this further, from examination of the volts, current, Fault Level and weighting graphs, shown in Graph 16, it appears that the change in Fault Level (if such it was) was first detected at about 1:46 am on the 7th, when a modest load disturbance gave a Fault Level measurement opportunity.



Graph 16. Trying to pinpoint the time at which the possible Fault Level reduction was first detected.

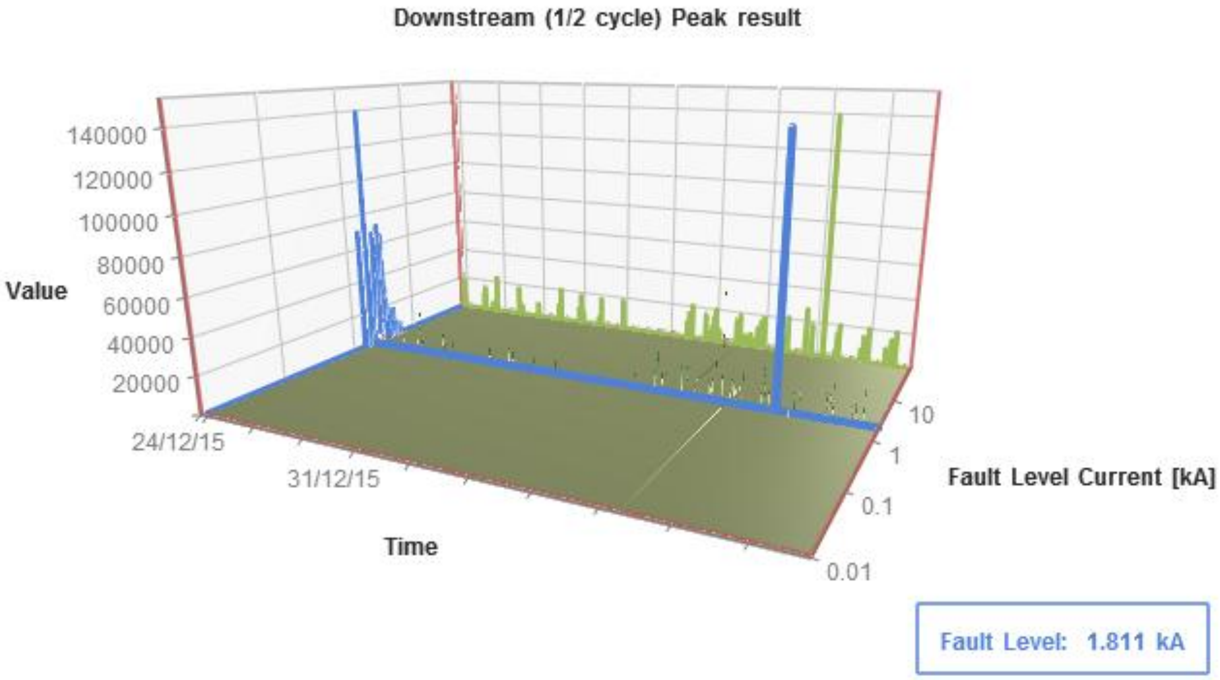
Graph 17 below shows the Peak half cycle result with a 30 min window and no filtering.



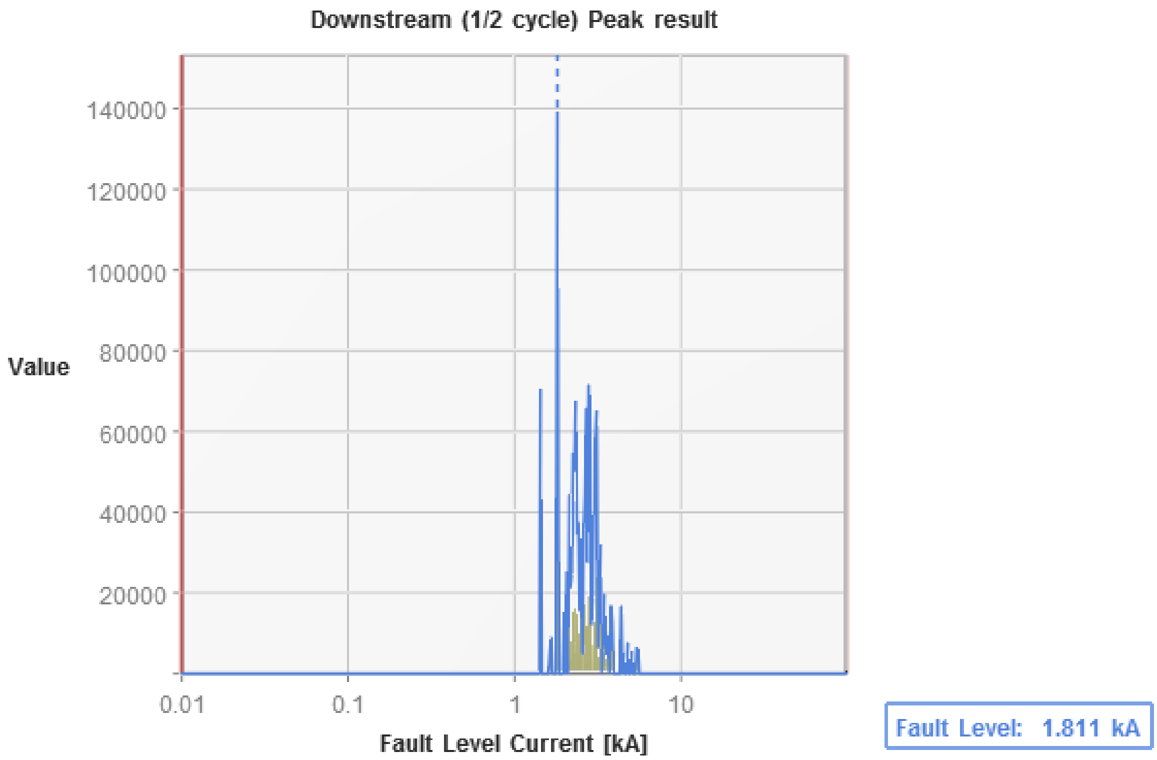
Graph 17. Upstream Peak Fault level at ½ cycle. 30 min Time varying result shown with no filtering.

Downstream Fault Level contribution

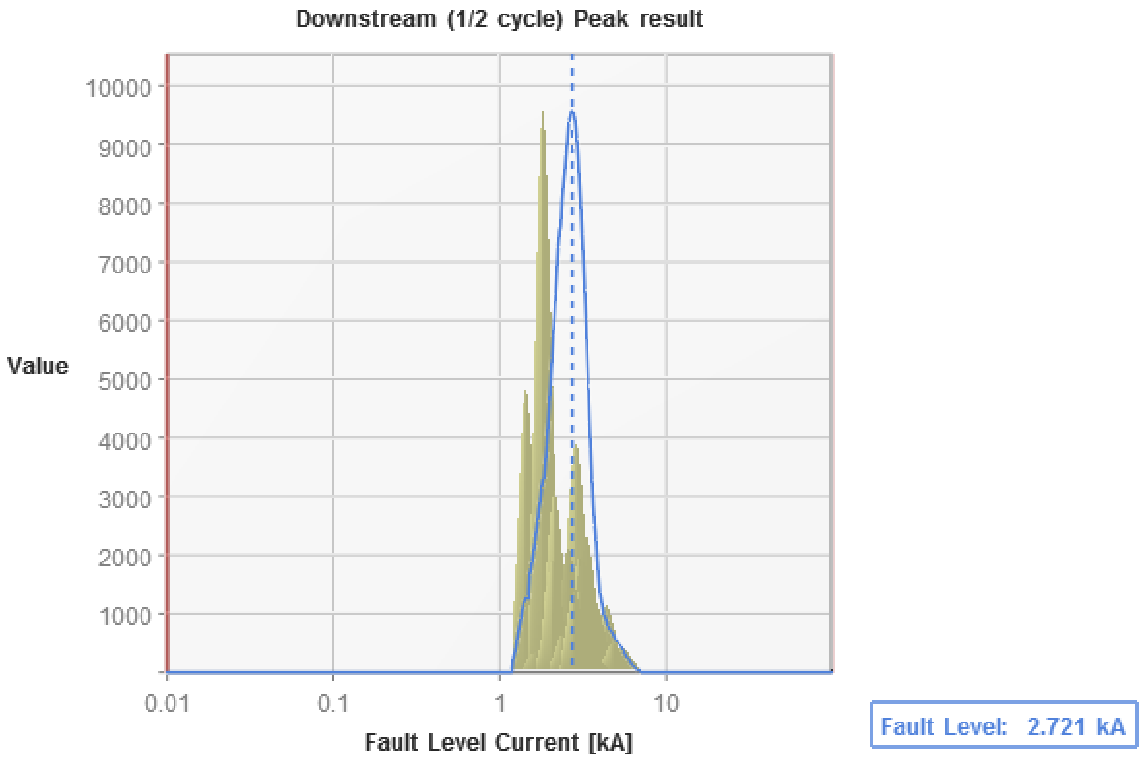
Graphs 18, 19 and 20 show the Peak half cycle Fault Level detected for downstream contribution. Graph 18 is 3D with no filtering showing that the distribution is fairly sparse. Graph 19 is 2D, again no filtering, and Graph 20 with 6%.



Graph 18. Downstream Peak Fault Level contribution at ½ cycle. 3D representation with no filtering.

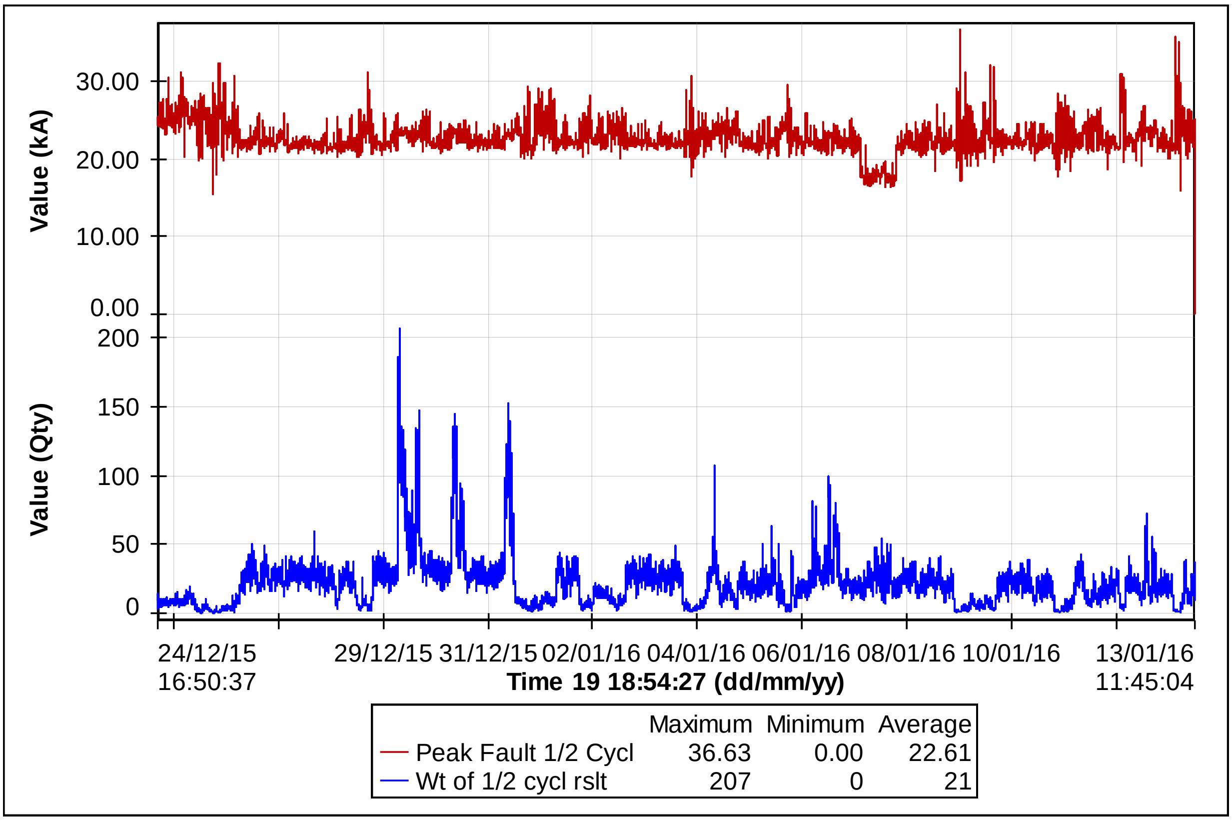


Graph 19. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with no filtering.

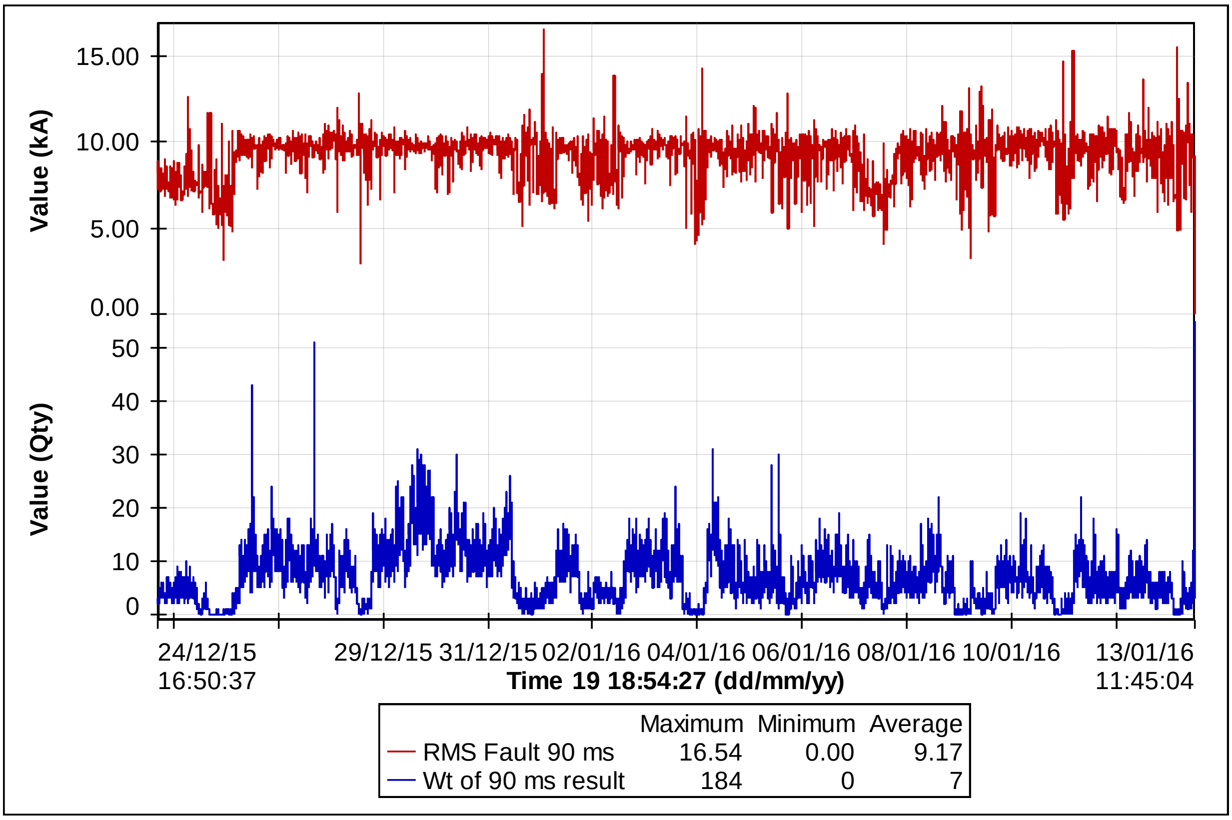


Graph 20. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 6% filtering. The best peak appears to be around 2.72kA.

The following graphs 21 and 22 show the detail results and weighting applied at ½ cycle and 90 ms respectively.



Graph 21. Peak upstream results and weighting present at ½ cycle.



Graph 22. RMS upstream results and weighting present at 90ms.

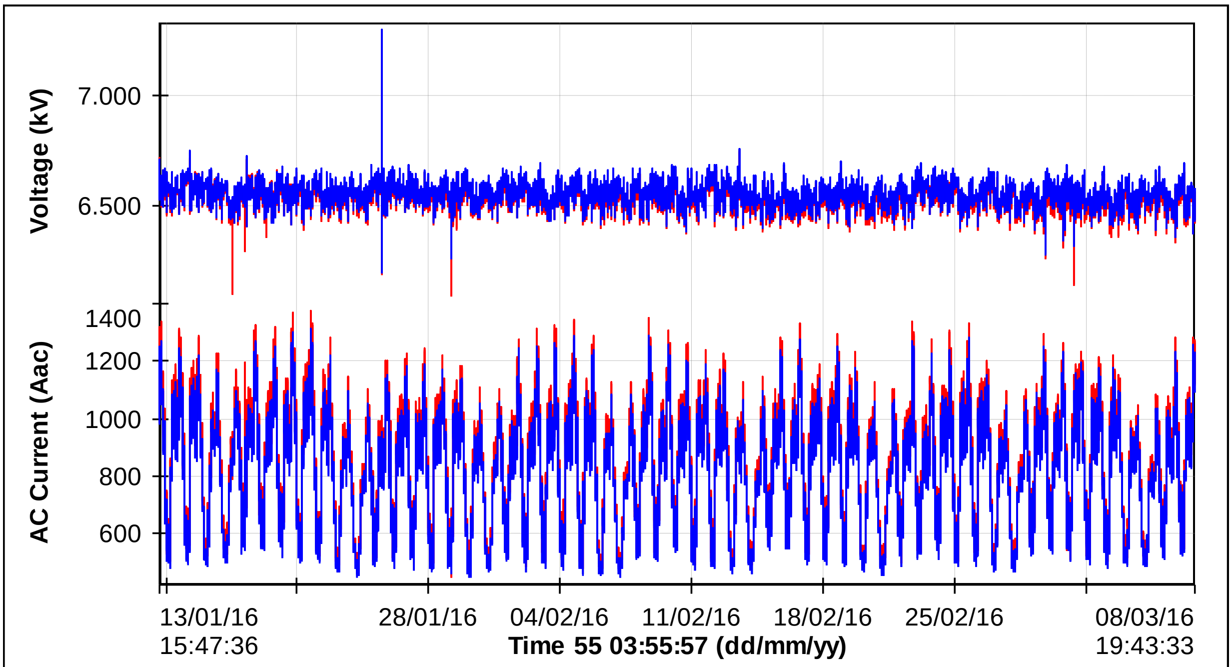
Appendix 5. Denton West. FLM Serial No 0890

Sources of error

The overall results for Denton West over the 8 week period are again strong. As with Wigan, there is little room for manipulation of these results, so sources of error are principally the systematic ones of incorrect assumptions, wrong CT settings, faulty sensors, cables etc. If the current and voltage results recorded by the PM7000 and shown below match the independent measurements reported by the ENWL SCADA or other systems, then it is unlikely that these results are wrong.

Denton West results, General observations

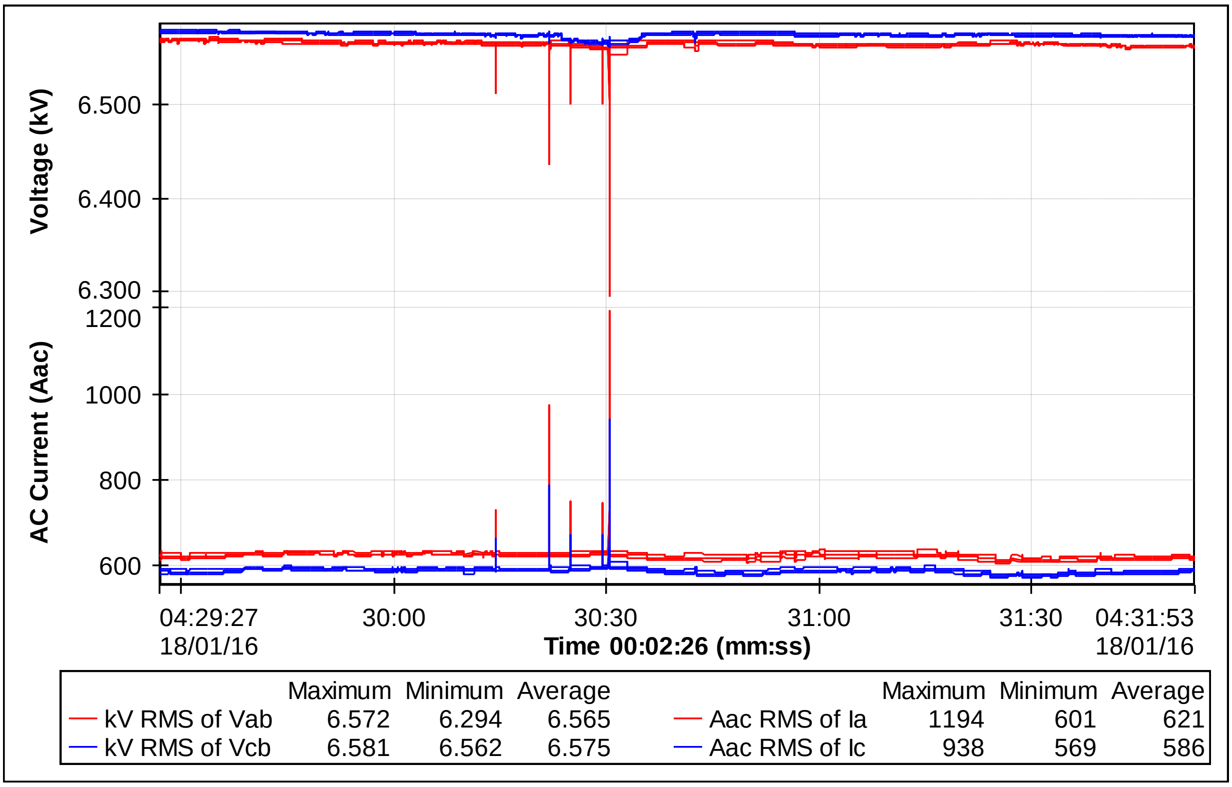
Graph 1 shows the voltage and current for the full recording period.



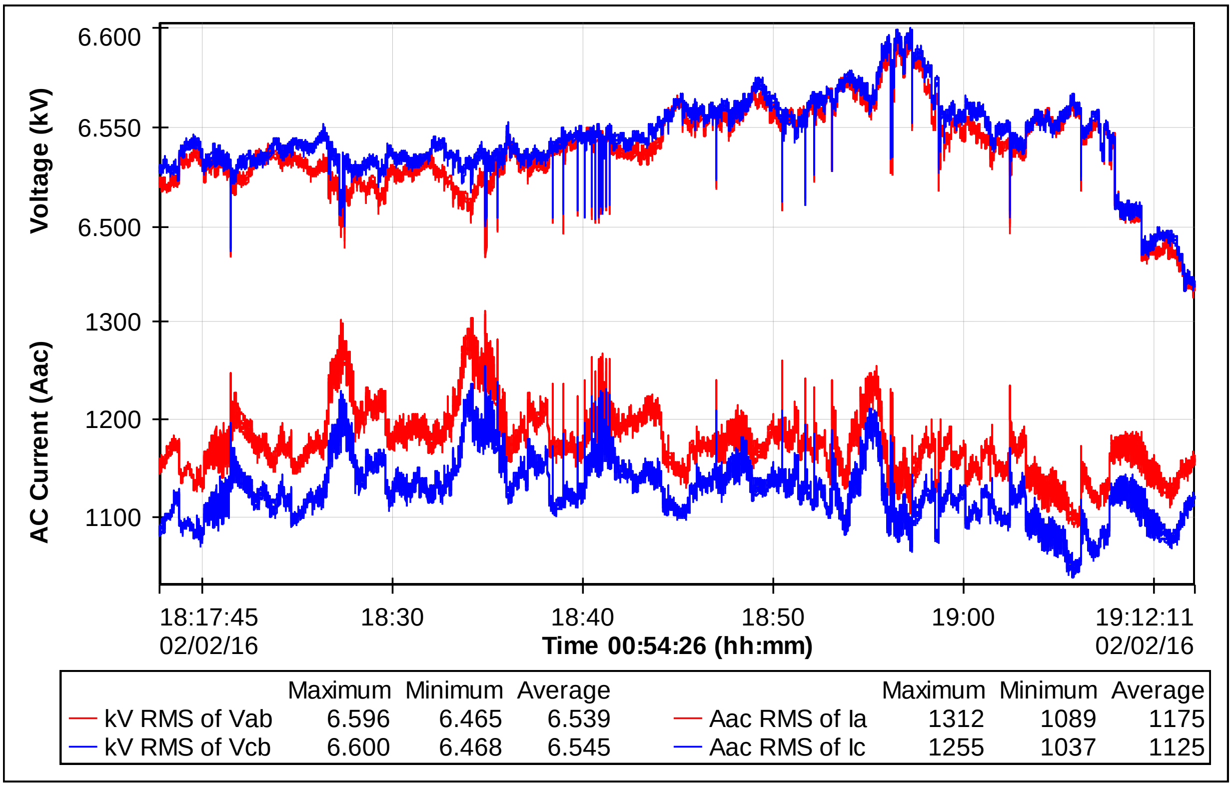
	Maximum	Minimum	Average		Maximum	Minimum	Average
kV RMS of Vab	7.272	6.091	6.539	Aac RMS of Ia	1379	441	847
kV RMS of Vcb	7.294	6.196	6.554	Aac RMS of Ic	1313	444	808

Graph 1. Volts and Current for the full recorded period.

There was a large disturbance on the 18th January, and others of around 1% at various times during the recording. Graphs 2 and 3 show examples.

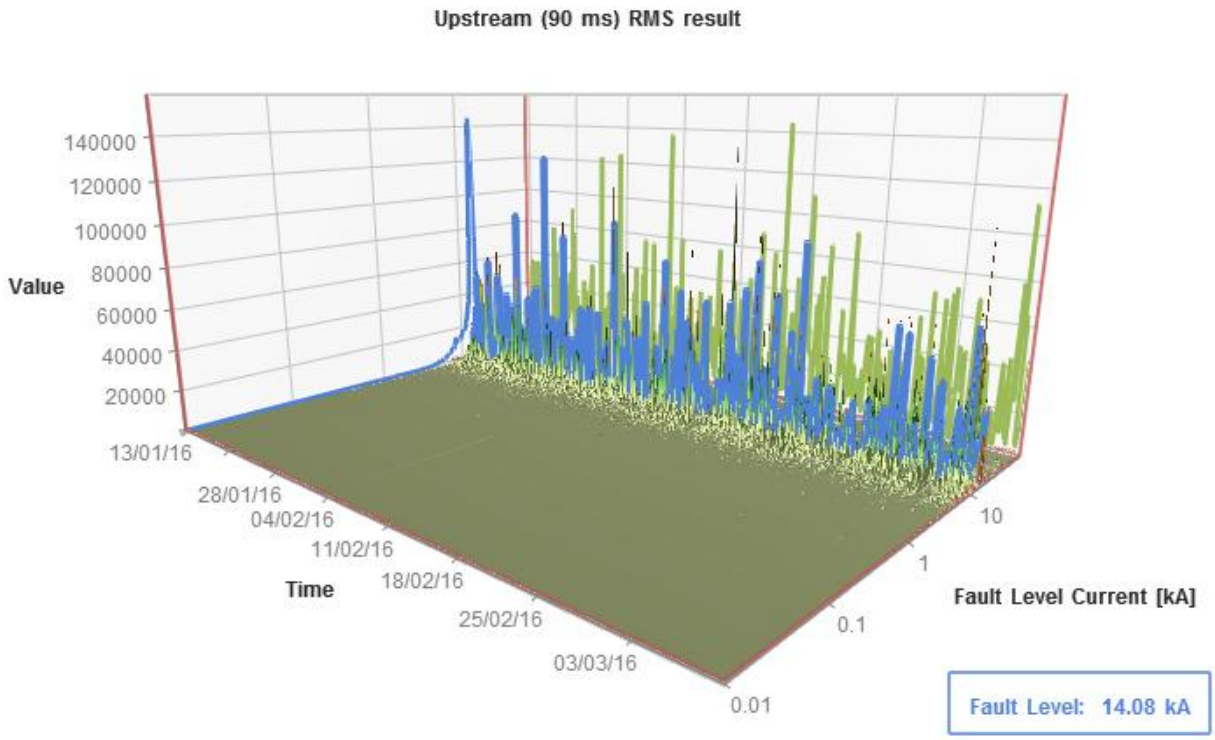


Graph 2. At least one big disturbance on 18th January.



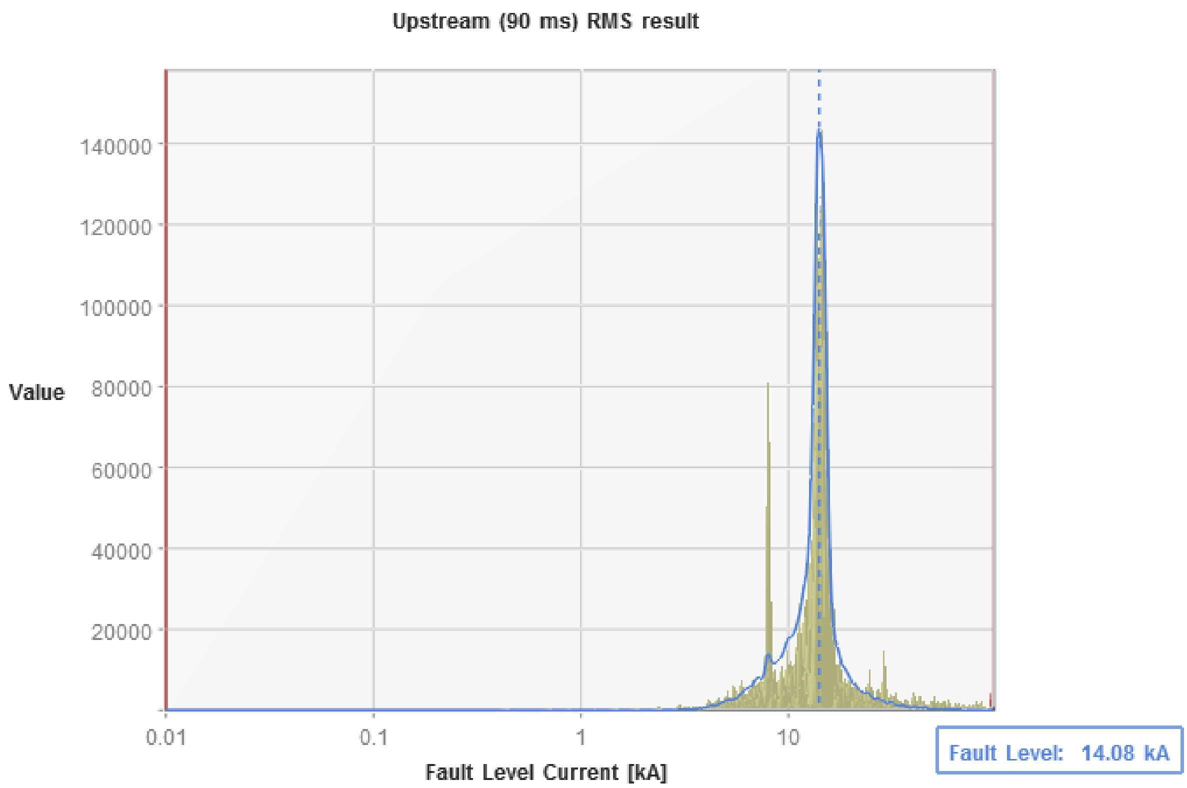
Graph 3. Example of batches of useful load disturbances on 2nd February.

Fault Level Results.



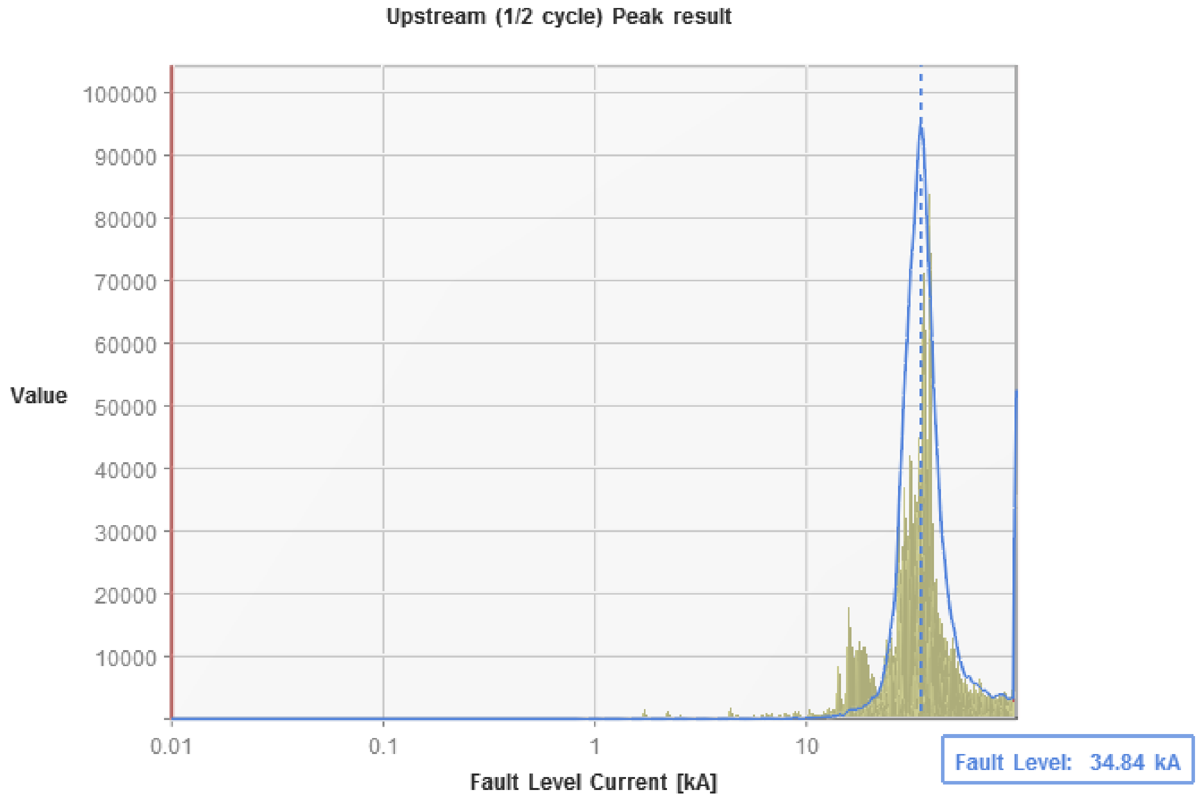
Graph 4. Upstream RMS Fault level at 90ms. 3D Distribution shown with 1% filtering.

Graph 4 shows that the mean Upstream 90ms RMS Fault Level for the period was 14.08 kA. Graph 5 shows the same thing in 2 dimensions.



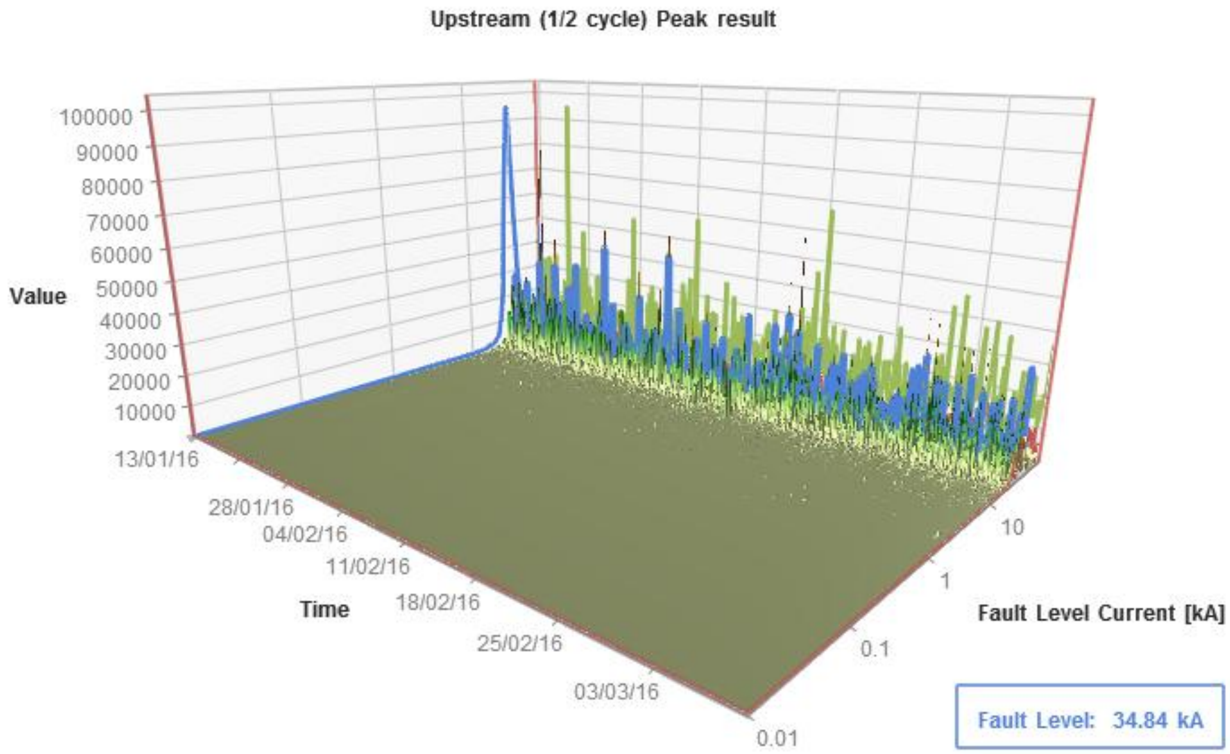
Graph 5. Upstream RMS Fault level at 90ms. 2D Distribution shown with 1% filtering.

Graph 6 below shows the Peak Fault Level at ½ cycle in 2D with 1% filtering.

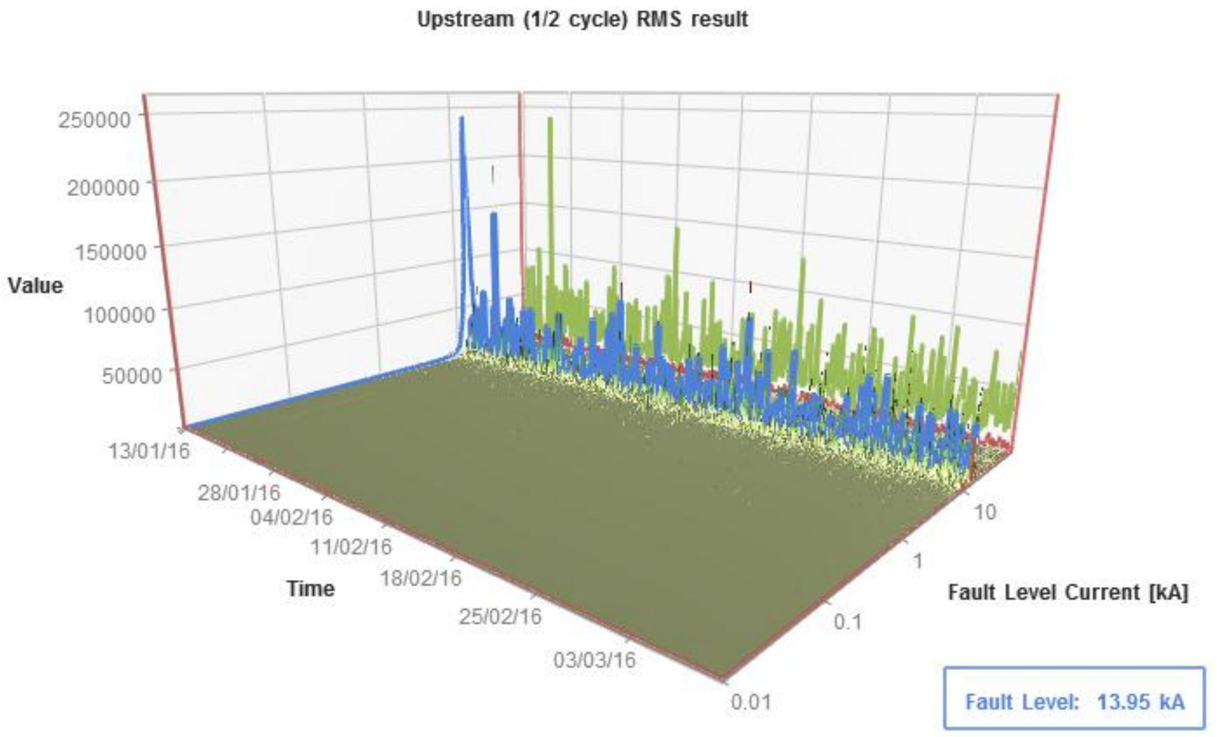


Graph 6 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with 1% filtering.

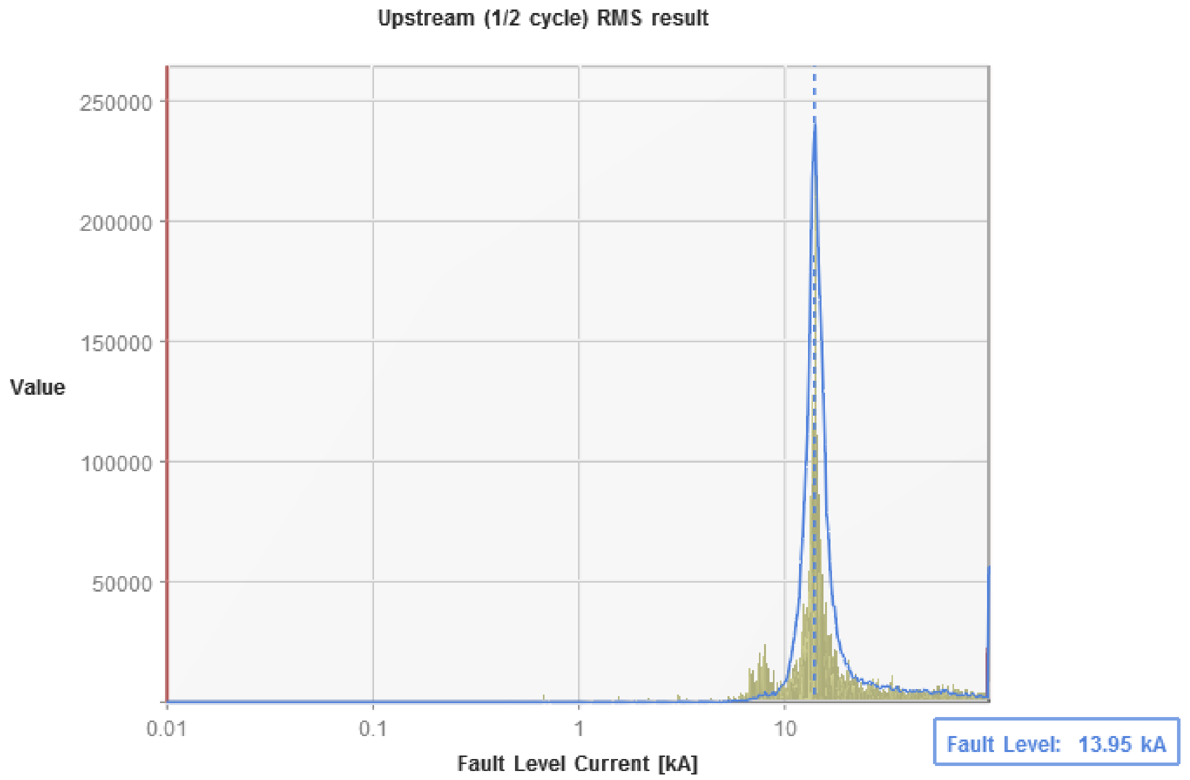
The peak of the distribution is now detected at 34.84kA. Graph 7 is the 3D version, showing the distribution of disturbance energy over time.



Graph 7. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 1% filtering.

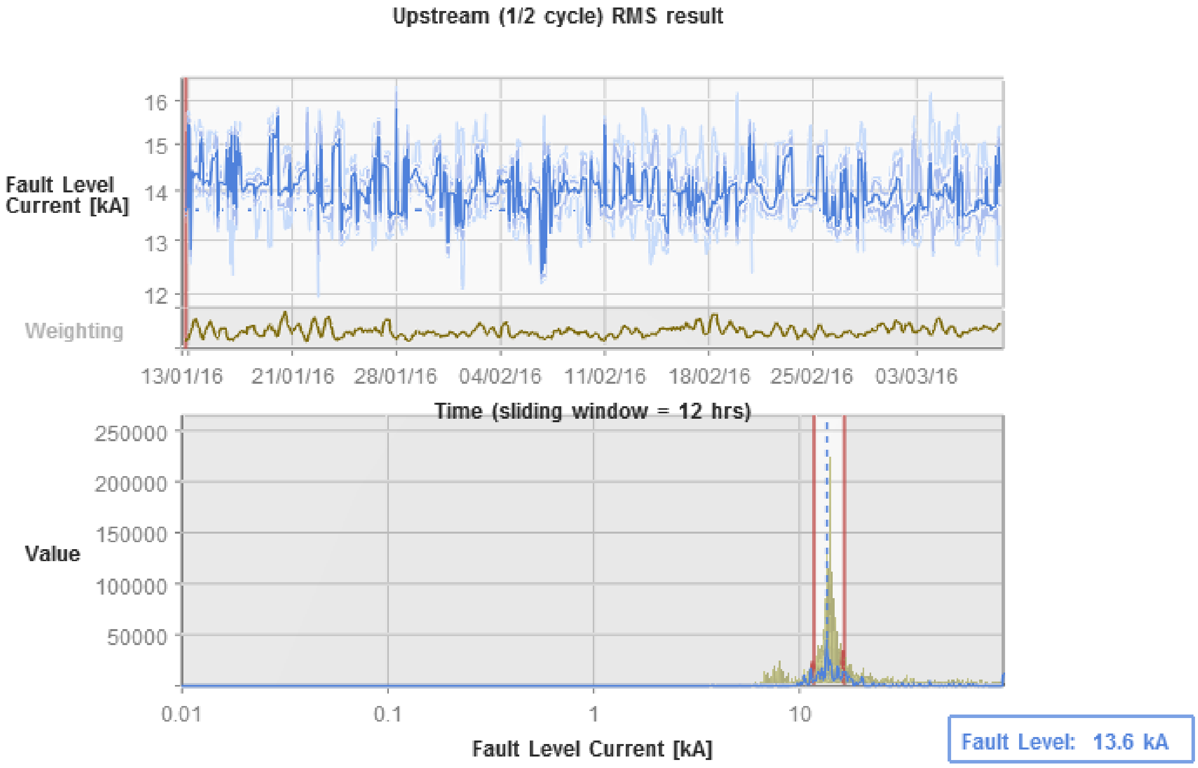


Graph 8. Upstream RMS Fault level at ½ cycle. 3D Distribution shown with no filtering.



Graph 9. Upstream RMS Fault level at ½ cycle. 2D Distribution shown with no filtering.

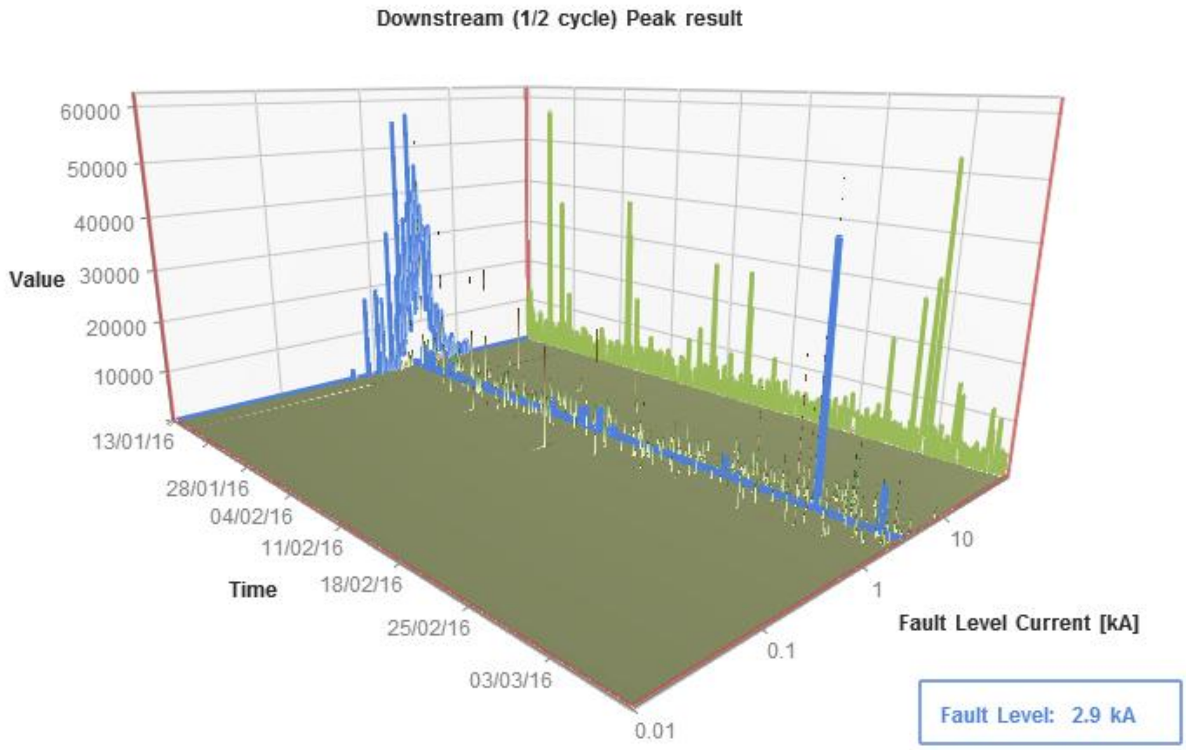
The RMS result also at ½ cycle is shown in Graphs 8 and 9. The cleanliness of this distribution suggests it is a good basis for searching for significant changes in Fault Level during the period such as due to switching operations. Graph 10 shows a sliding window of 12 hours applied with no filter.



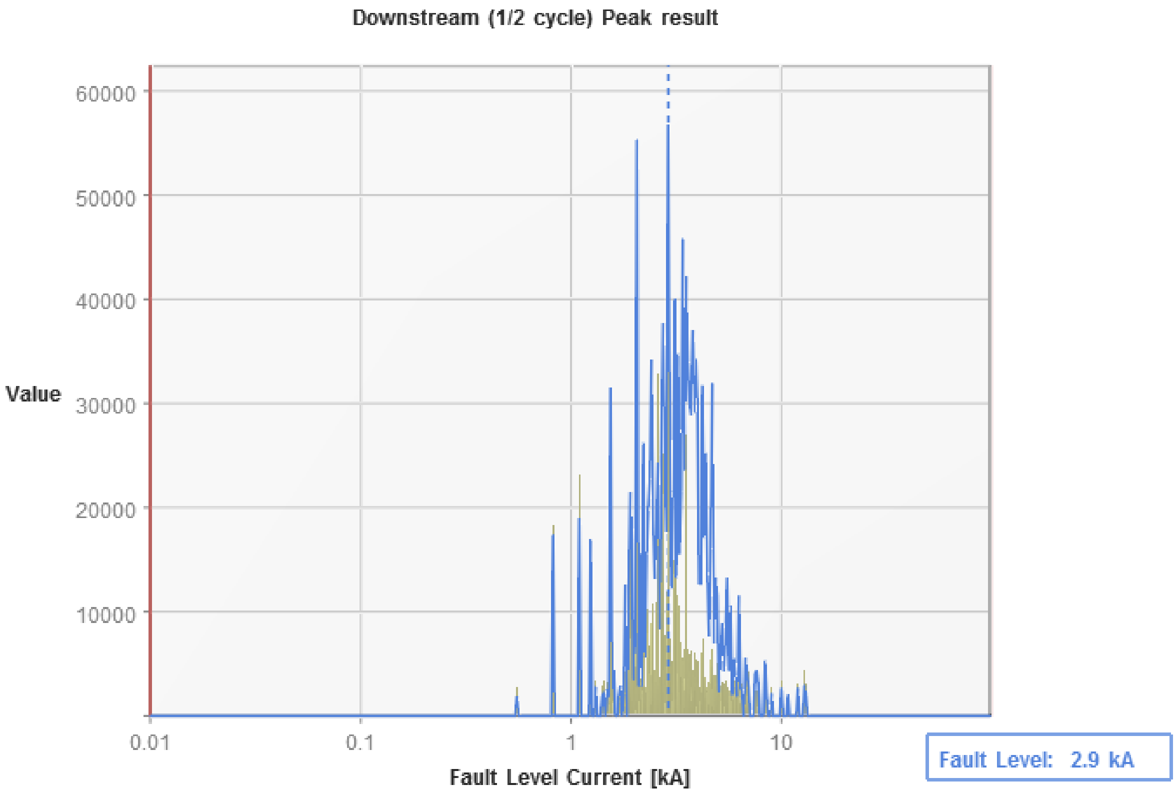
Graph 10. Upstream RMS Fault level at ½ cycle. 12 hr Time varying result shown with no filtering.

Downstream Fault Level contribution

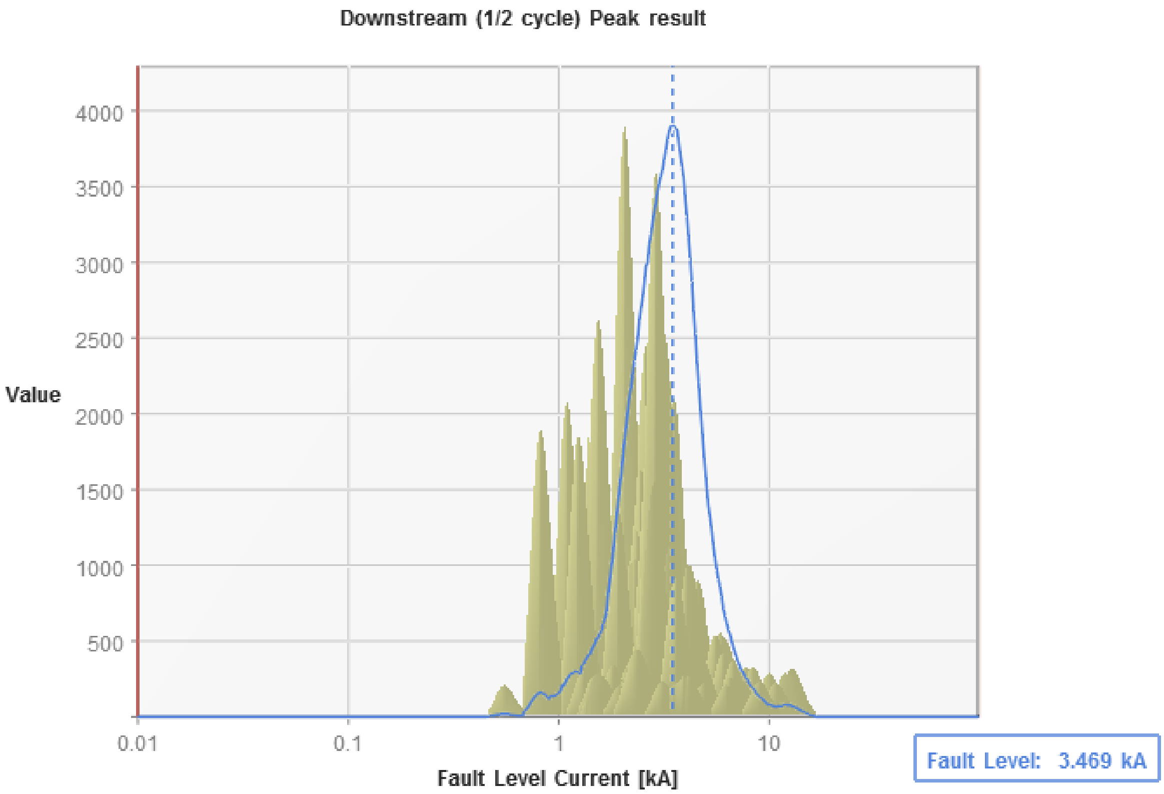
Graphs 11, 12 and 13 show the Peak half cycle Fault Level detected for downstream contribution. Graph 11 is 3D with no filtering showing that the distribution is small but well spread. Graph 12 is 2D, again no filtering, and Graph 13 with 6%.



Graph 11. Downstream Peak Fault Level contribution at ½ cycle. 3D representation with no filtering.

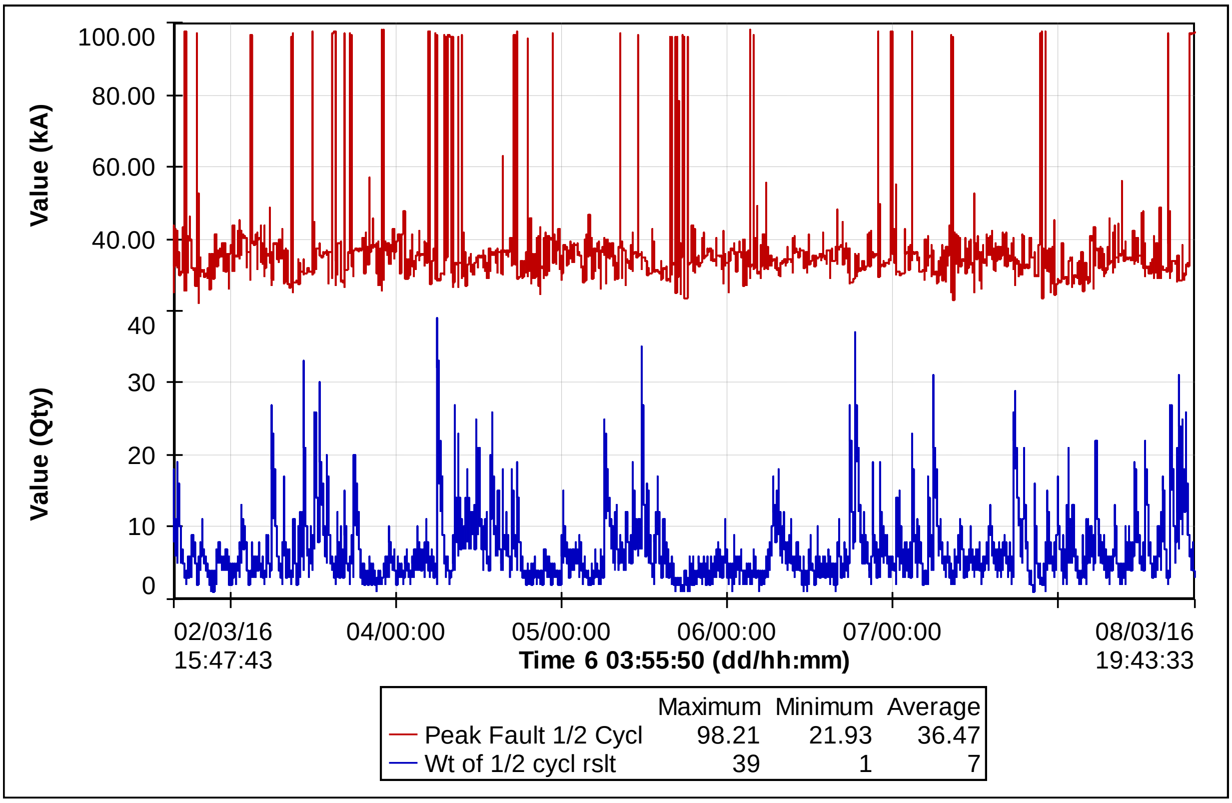


Graph 12. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with no filtering.



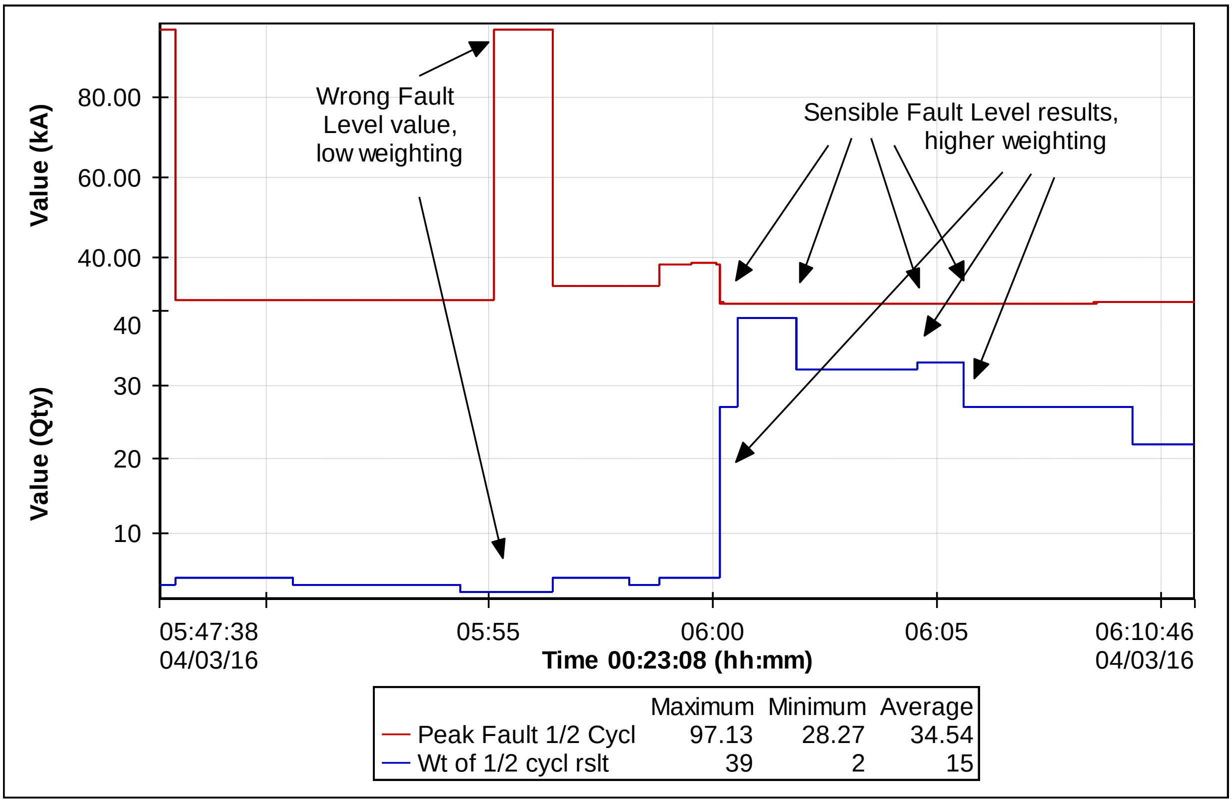
Graph 13. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 6% filtering. The best peak appears to be around 3.47kA.

The following graphs 14, 15 and 16 show the detail results and weighting applied at ½ cycle and 90 ms respectively.

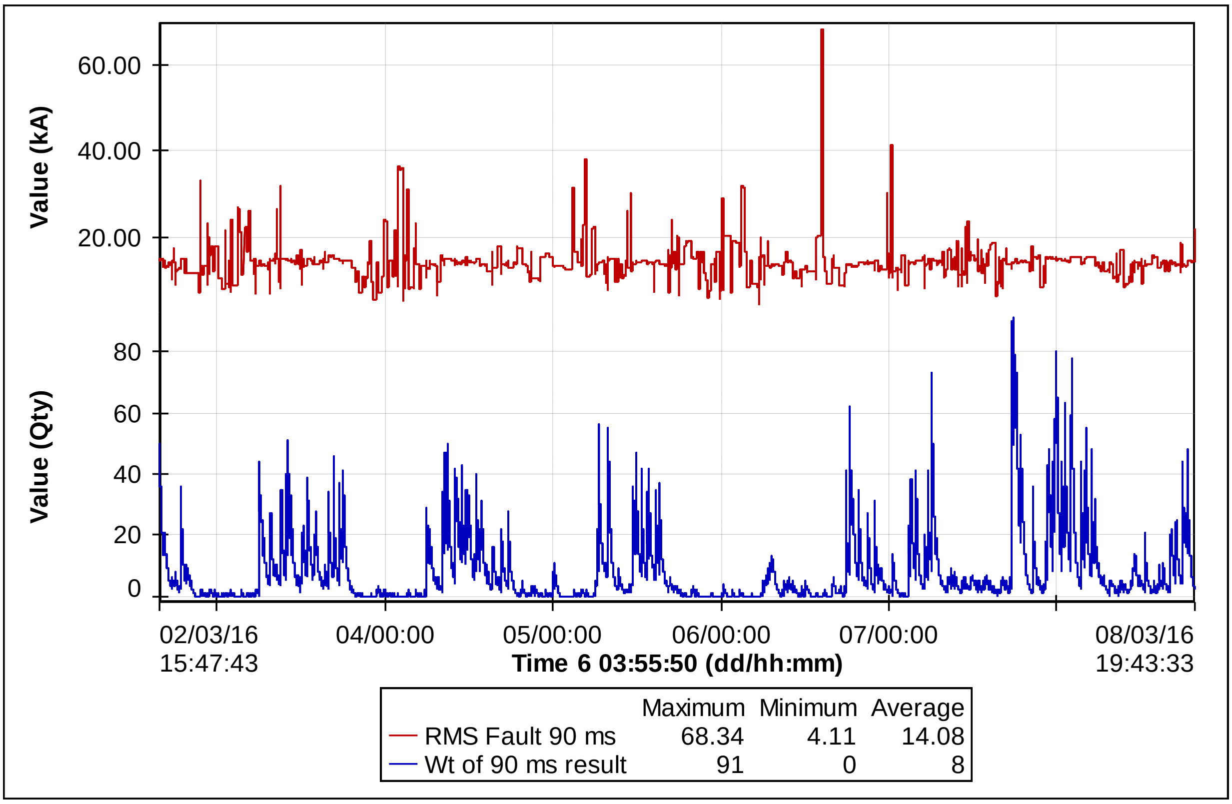


Graph 14. Peak upstream results and weighting present at ½ cycle.

Note that the Peak Fault level values of ~100kA in Graph 14 are associated with very small weights. These do not make a significant contribution to the declared Fault Level result, and should be ignored. They do illustrate why these standard Pronto time graphs should be treated with caution when graphing these irregularly stimulated results. The example in Graph 15 below shows that the high Fault Level result coincides with very low weighting, and that when a sizeable disturbance occurs, the Fault Level returns to a sensible value.



Graph 15. Beware using the Standard Pronto graphing. Relationship between quality of Fault Level result and weighting.



Graph 16. RMS upstream results and weighting present at 90ms.