RESPOND Project Fault Level Report for Electricity North West Ltd

ENWL Fault Level Report 2 V2, 19/07/2016

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Change record		
Date	**Edited by**	**Reason**
11/07/2016	J. D. Outram	
19/07/2016	K. A. Edwards	Minor formatting changes

Contents

Introduction

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

At the end of June 2016, data was received from ENWL for the four FLMs for four substations. These are:

FLM serial No	Installed at	Recording Start Date	Recording End Date
0887	Hareholme	09/03/2016	28/06/2016
0888	Broadheath (100134)	11/03/2016	16/06/2016
0889	Atherton Town Centre	09/03/2016	22/06/2016
0890	Longridge	9/03/2016	22/06/2016

Broadheath data from FLM serial no 0888 was originally intended to be included in the 1st FLM results report of March 2016. At ENW's request the Broadheath results from this set of recordings have been added to that report, and are also included here.

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[1]
0887	Hareholme	29.2	2.926	11.61	32.13
0888	Broadheath (100134)	29.56	3.217	10.16	32.78
0889	Atherton Town Centre[2a]	23.35	2.416	9.531	25.77
0889	Atherton Town Centre[2b]	12.85	2.416	5.401	15.27
0889	Atherton Town Centre[2c]	23.25	2.416	9.537	25.67
0889	Atherton Town Centre[2d]	18.9	2.416	7.816	21.32
0889	Atherton Town Centre[2e]	22.38	2.416	9.317	24.80
0890	Longridge	26.2	2.241	10.98	28.44

[1] 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.

[2a-e] Several results were obtained for Atherton Town Centre. See Appendix 3. The most definitive is probably the last, row [2e] in the table.

General comment on results

Good results were obtained from all sites. At Atherton Town Centre there appears to have been an outage or voltage disconnection of several days during March, and there is some evidence of poor current sensor connection on Ia during June. However over 11 weeks of clean data is available and this is used for the results reported here.

Various other interruptions and gross spikes occurred at different sites, and these are commented upon in the relevant sub-station appendix.

Atherton Town Centre appears to have seen three different Fault Level conditions during the test interval.

As at sites previously reported, for the Upstream Fault Level contributions, there is not a lot of scope for manipulation. 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.

General sources of error

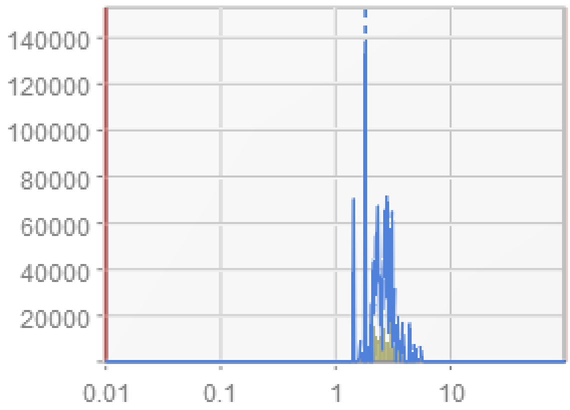
Quality of the Fault Level results are susceptible to noise, incorrect hook-up, sensor failure, short term frequency measurement accuracy, and less obvious but nevertheless systematic faults such as VT and CT errors. Amplitude errors clearly translate into equivalent Fault Level errors. In particular 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%.

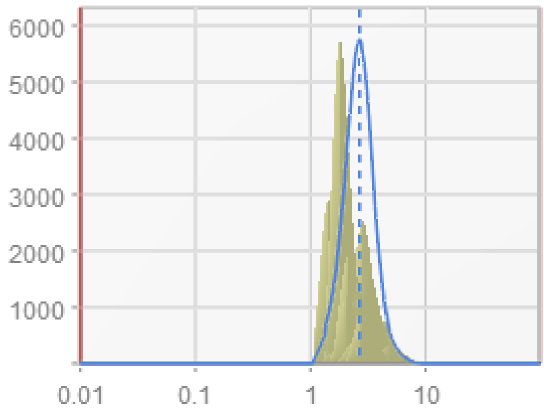
Manipulation of the data, data lumping, smoothing/filtering

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.

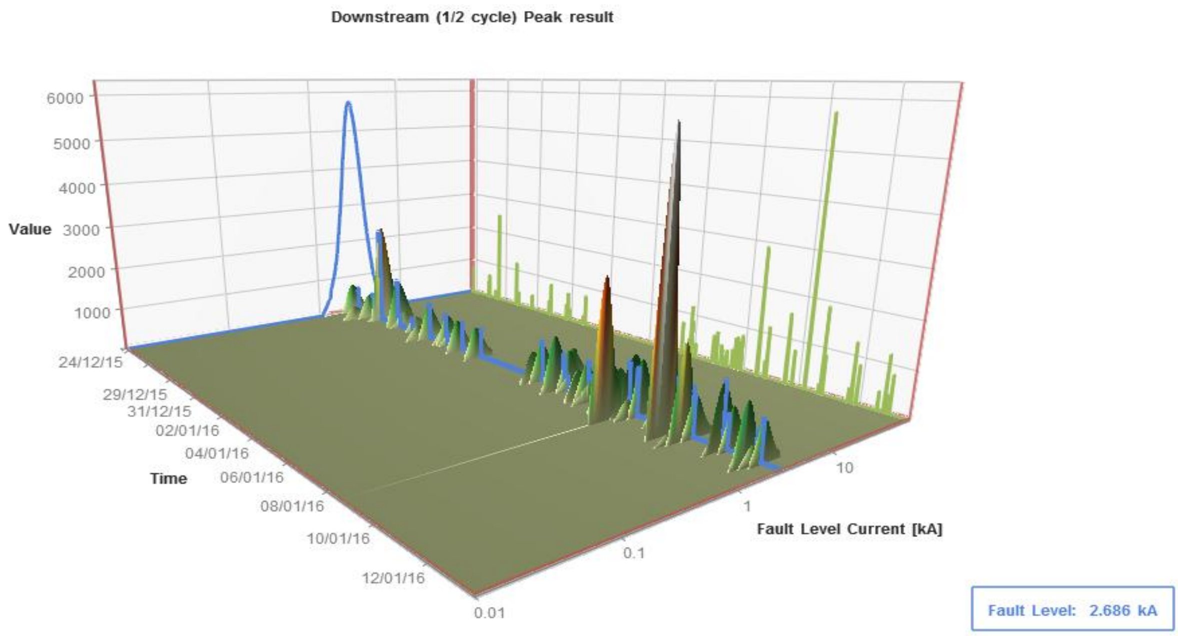




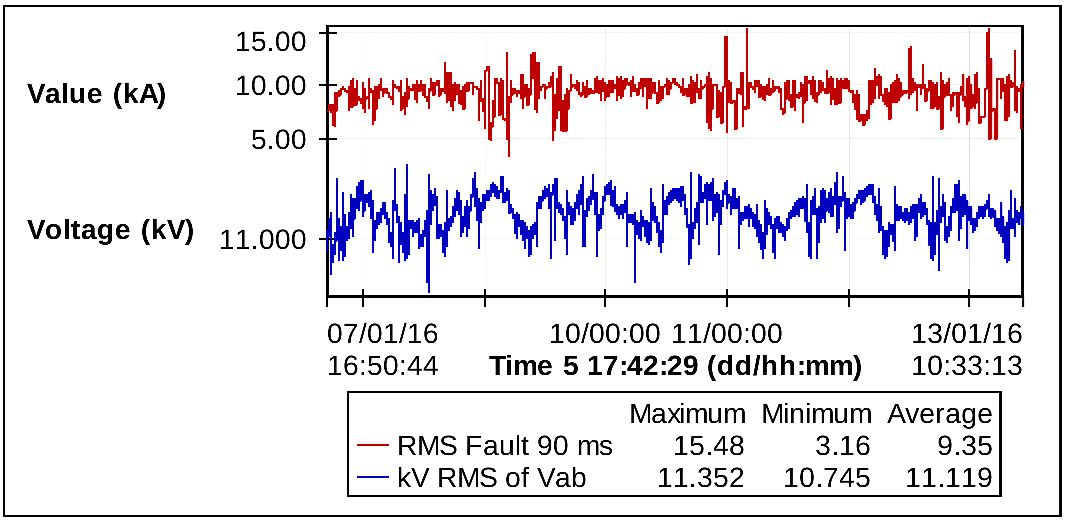
The general rule is to use as little filtering as is necessary to create a bell–shaped distribution around the area of interest.

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 as shown 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.

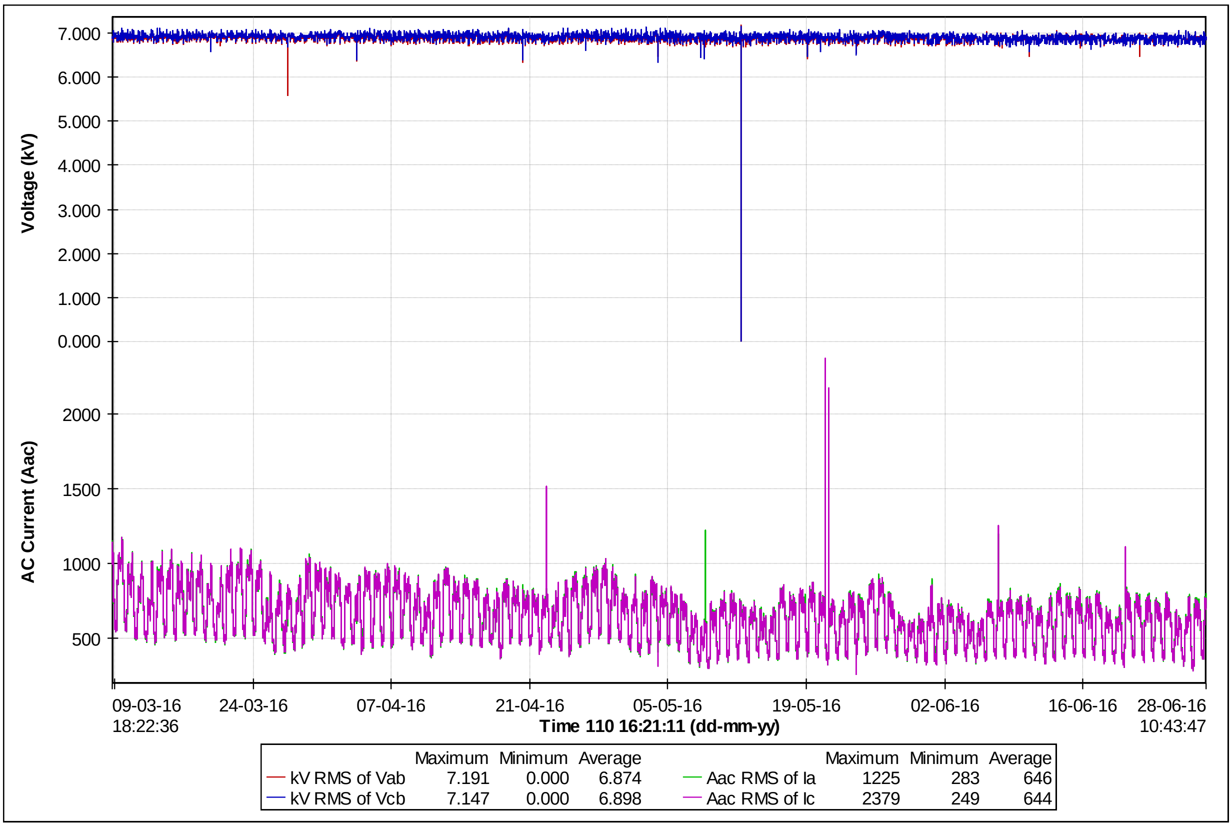
Appendix 1. Hareholme. FLM Serial No 887

Sources of error

The overall results for Hareholme over the 16 week period are reasonably unambiguous in spite of relatively little disturbance energy. 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 outage below).

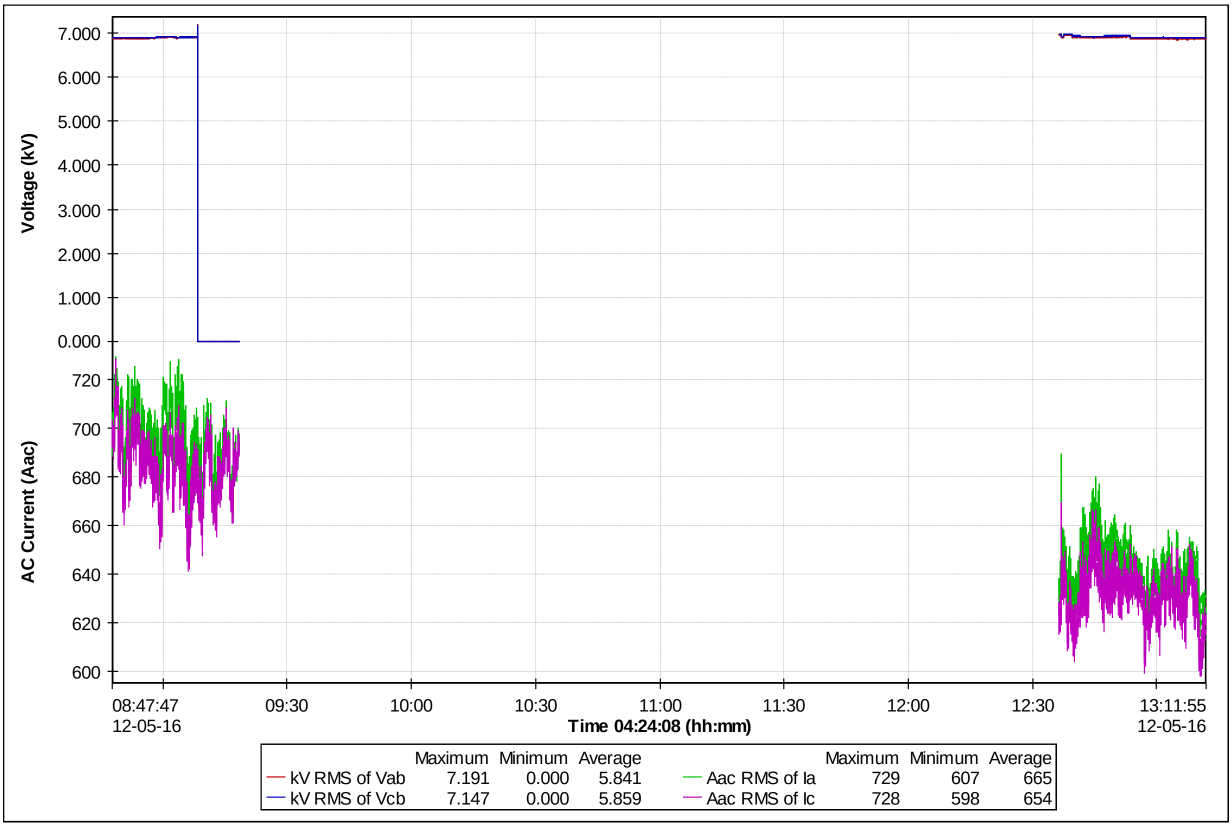
Hareholme results, General observations

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

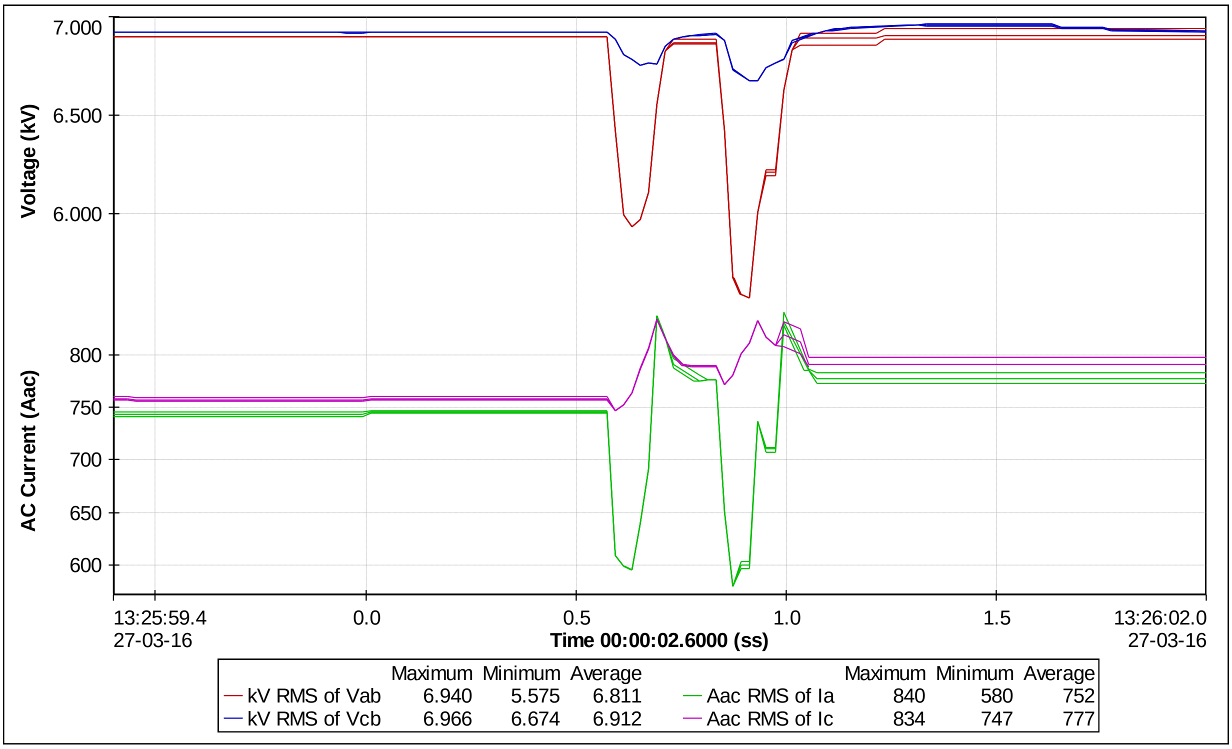


Graph 1. Volts and Current for the full recorded period.

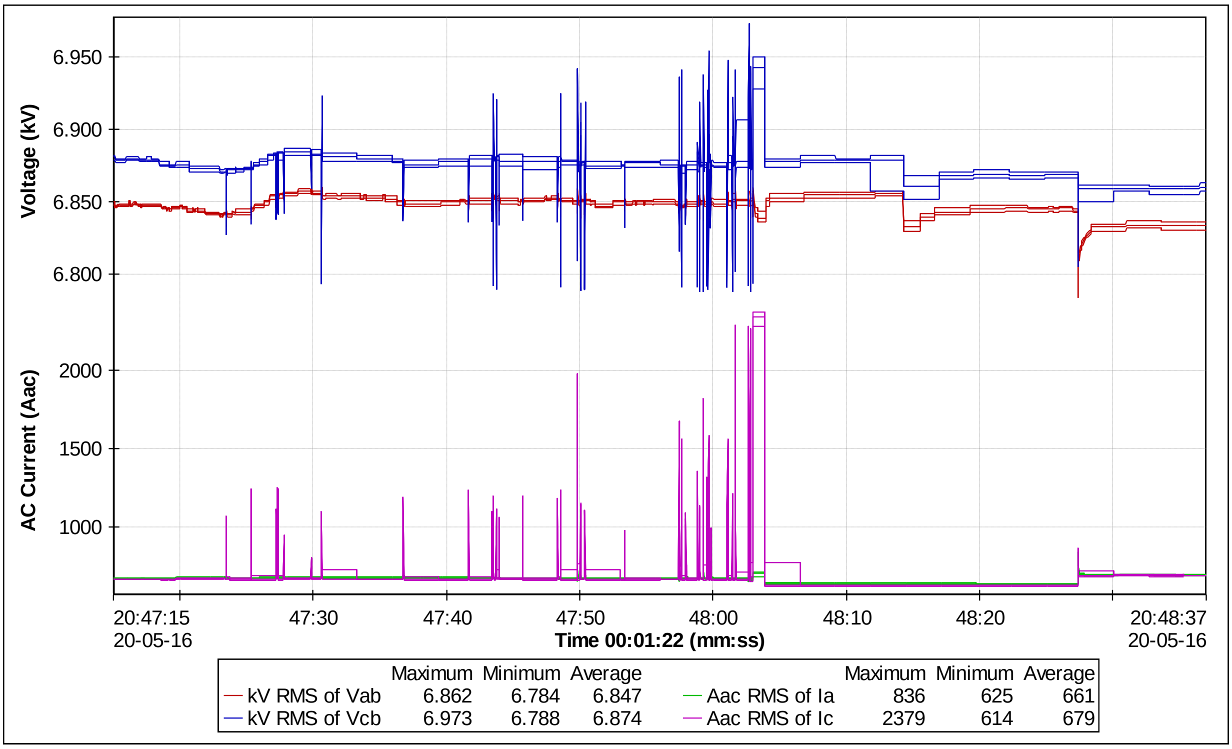
There appear to have been one major voltage event and several smaller ones. An outage lasting about 3 ½ hours apparently occurred on 12th May, but current continued to flow after the voltage (both Vab and Vcb) collapsed. This needs a proper explanation because one conclusion from this evidence might be that the voltage being monitored was NOT that of the bus bar through which the current was passing, i.e. volts and current are not associated, and hence the Fault Level results might be meaningless. The FLM (correctly) turned itself off about 10 minutes after the start, and resumed again some three hours later. None of these appear to have been caused by a load downstream of this substation/feeder. There were two major current events. Graphs 2-5 show the RMS detail.



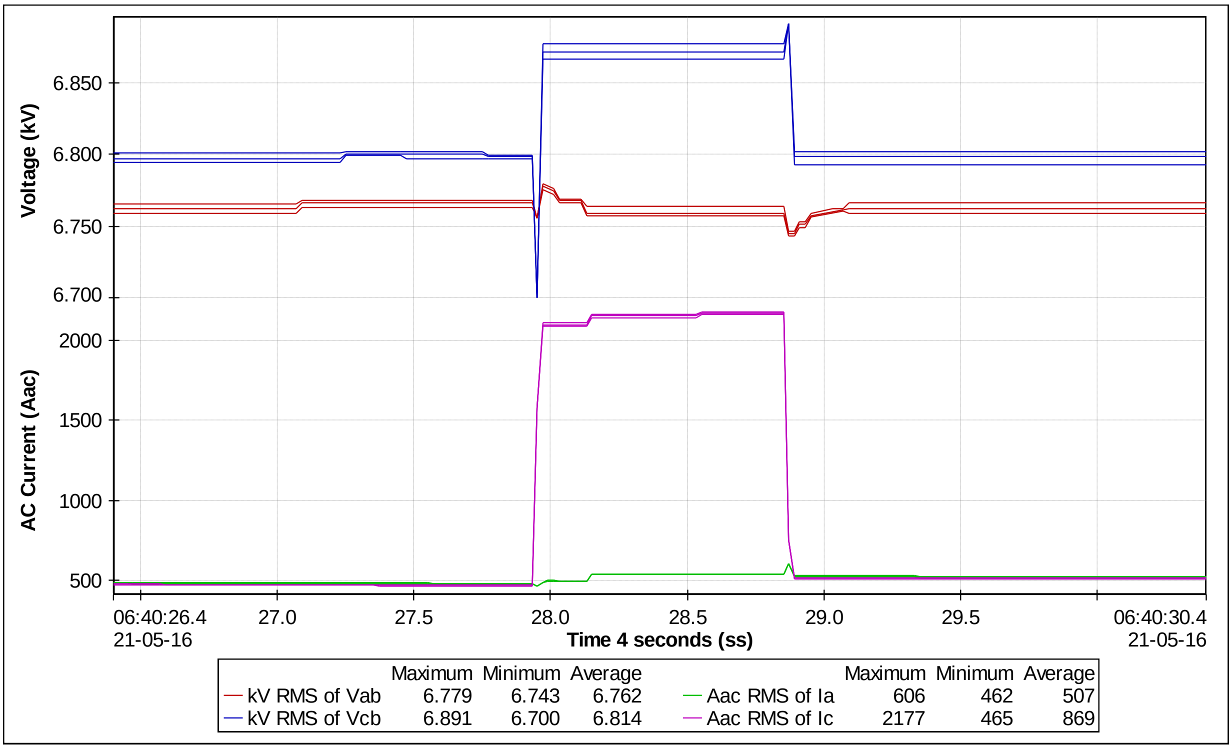
Graph 2. Outage on Voltage, 12 May 2016.



Graph 3. A-B phase voltage disturbance on 27th March 2016.



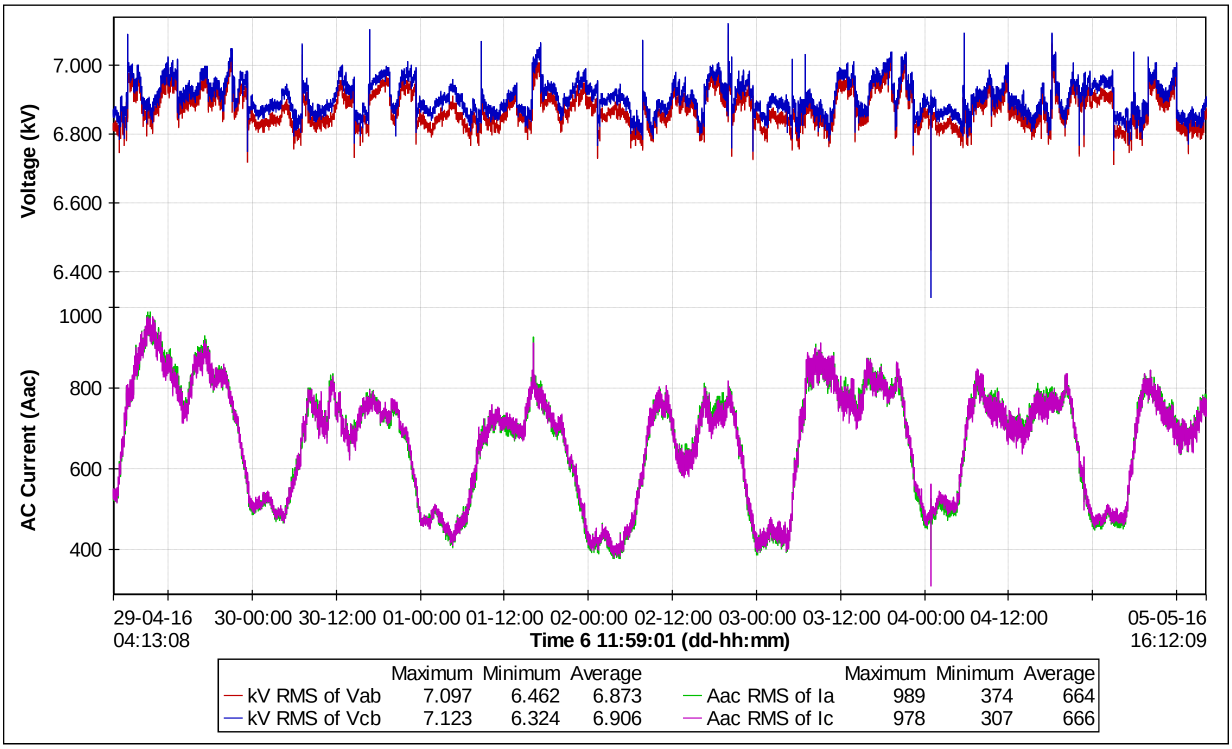
Graph 4. First C phase current disturbance on 20th May 2016.



Graph 5. Second C phase current disturbance on 21st May 2016.

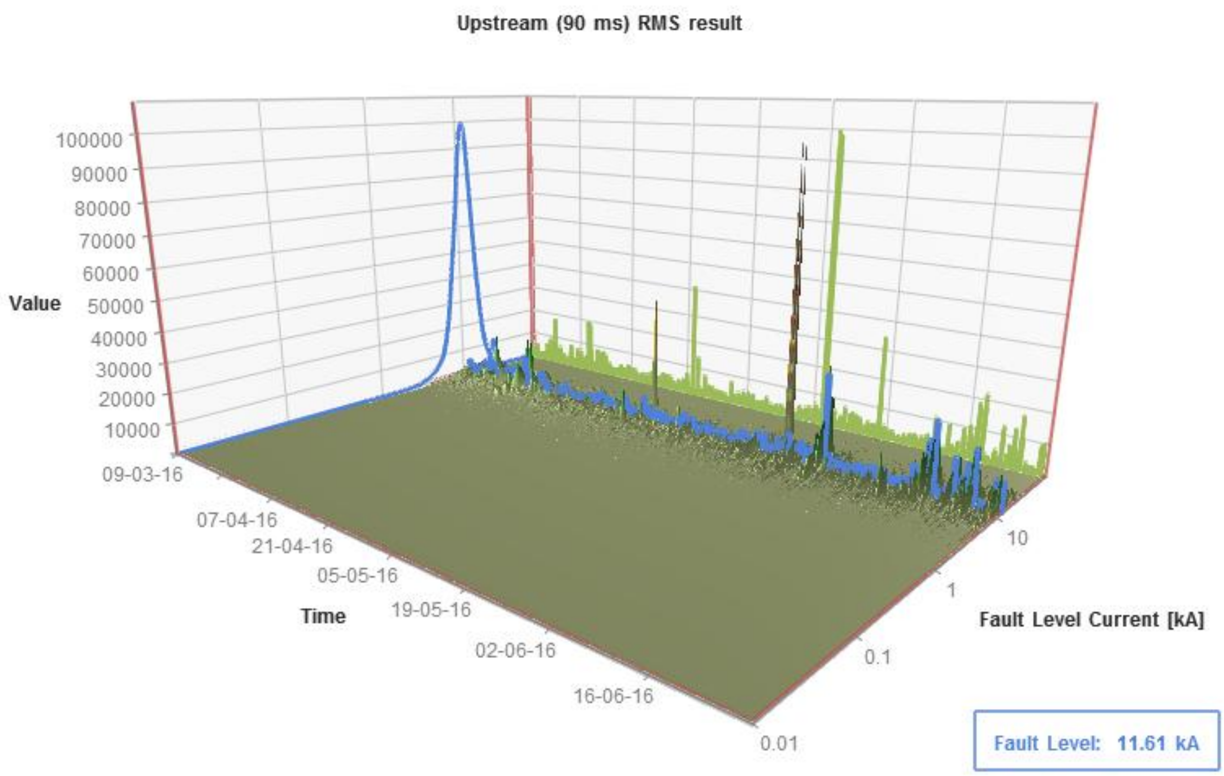
Useful Fault Level type disturbances.

Apart from a few large current disturbances, there was little current activity for the FLM to work on, but quite a bit of voltage noise (not useful). Graph 6 shows a typical 6 day section of the recording.



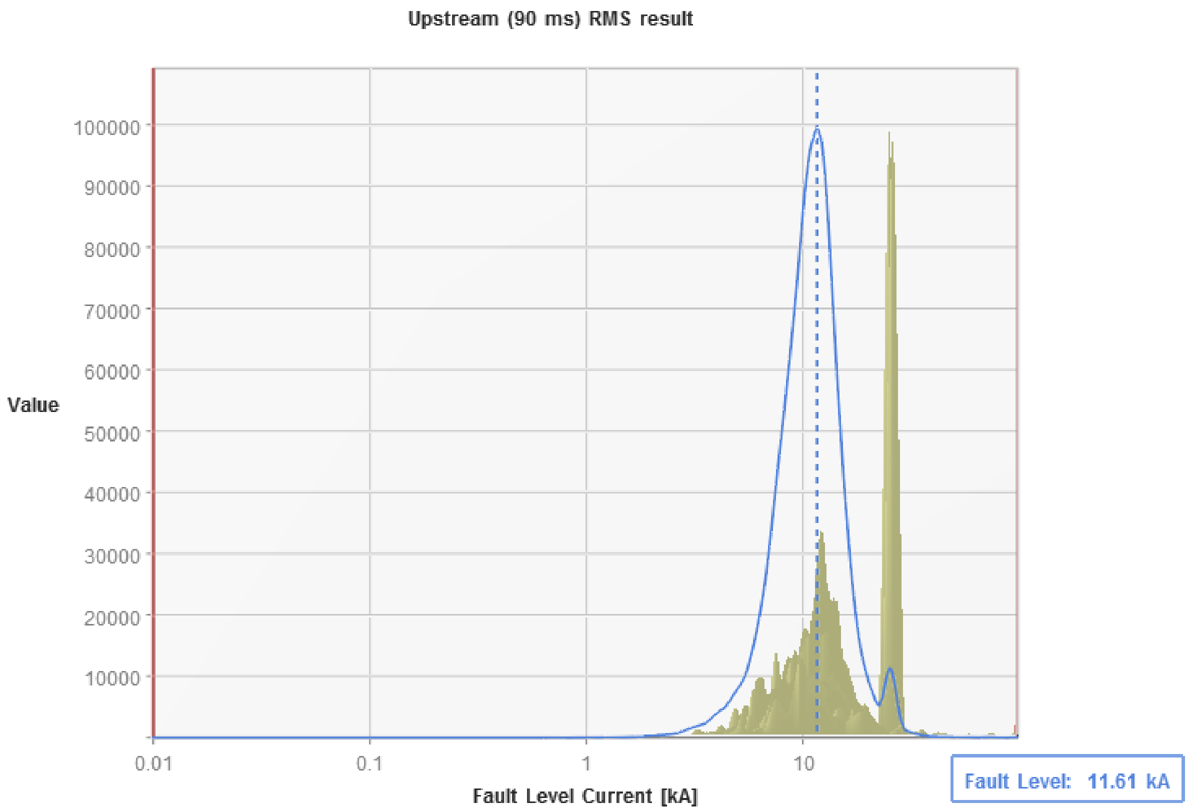
Graph 6. Typical disturbance activity.

Fault Level Results



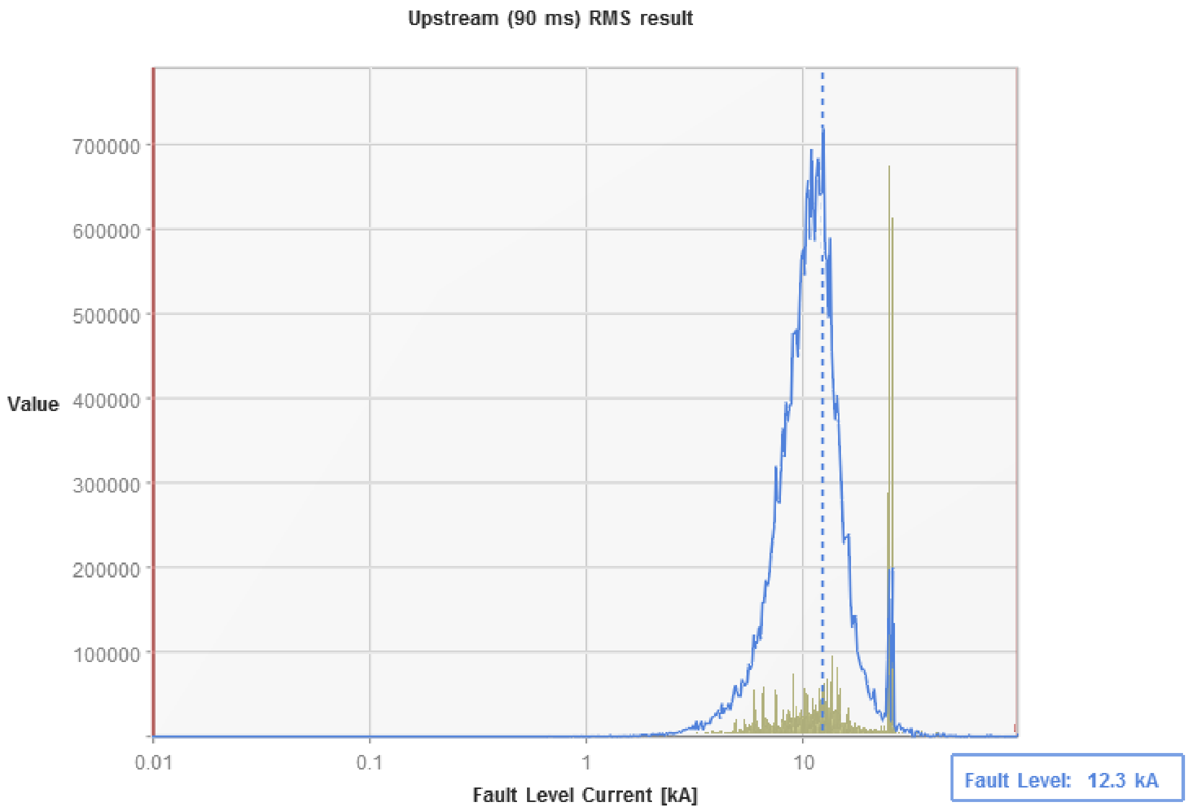
Graph 7. Upstream RMS Fault level at 90ms. 3D Distribution shown with 3% filtering.

Graph 7 shows that the mean Upstream 90ms RMS Fault Level for the period was 11.61 kA. Graph 8 shows the same thing in 2 dimensions.



Graph 8. Upstream RMS Fault level at 90ms. 2D Distribution shown with 3% filtering.

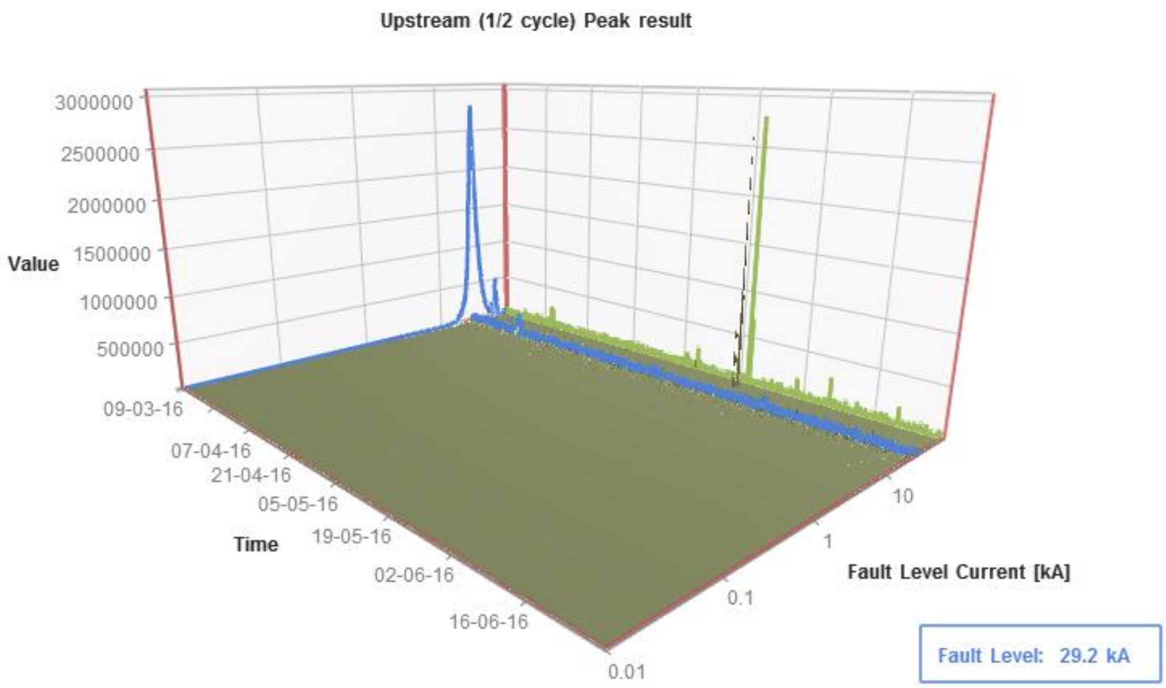
A modest degree of filtering was used to extract this peak, as without it, the nose of the distribution is slightly biased high, as shown in Graph 9 below.



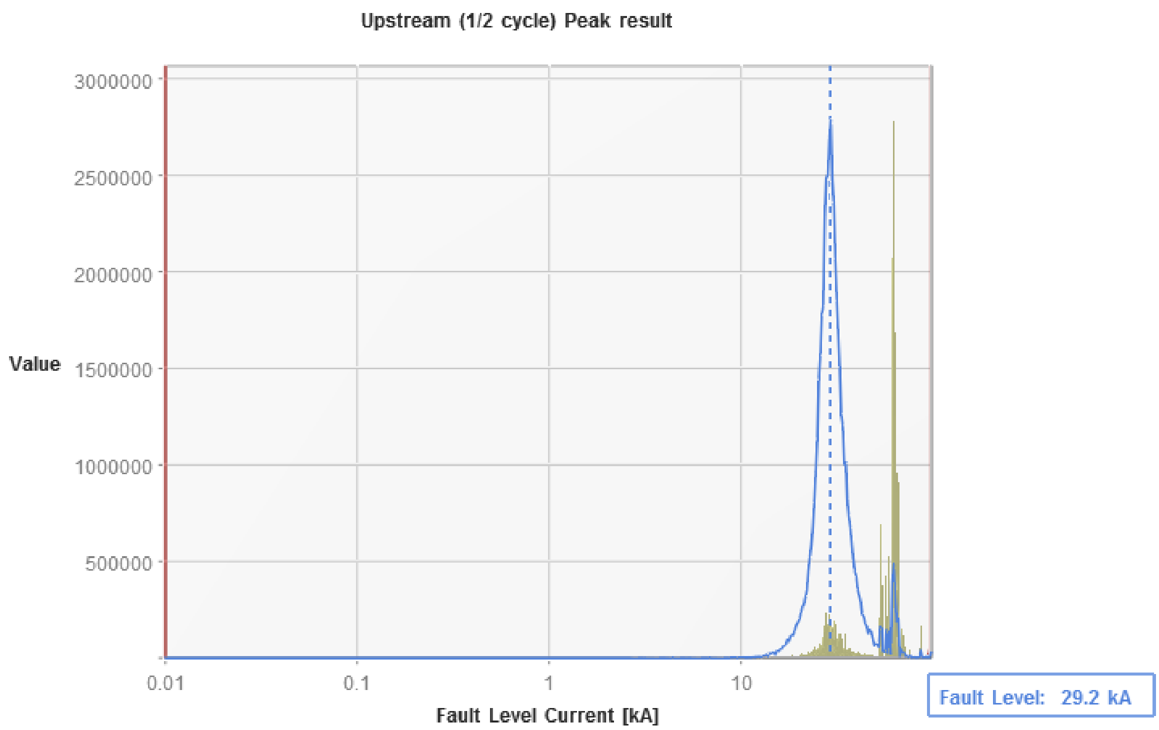
Graph 9. Upstream RMS Fault level at 90ms. 2D Distribution shown with no filtering.

Both graphs 8 and 9 show the large result to the right (higher Fault Level) of the main lobe. This arises from the big current spike on the 19th May which may be distorted and consequently not representative. 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 10 and 11 show the Peak Upstream Fault Level for the whole period.

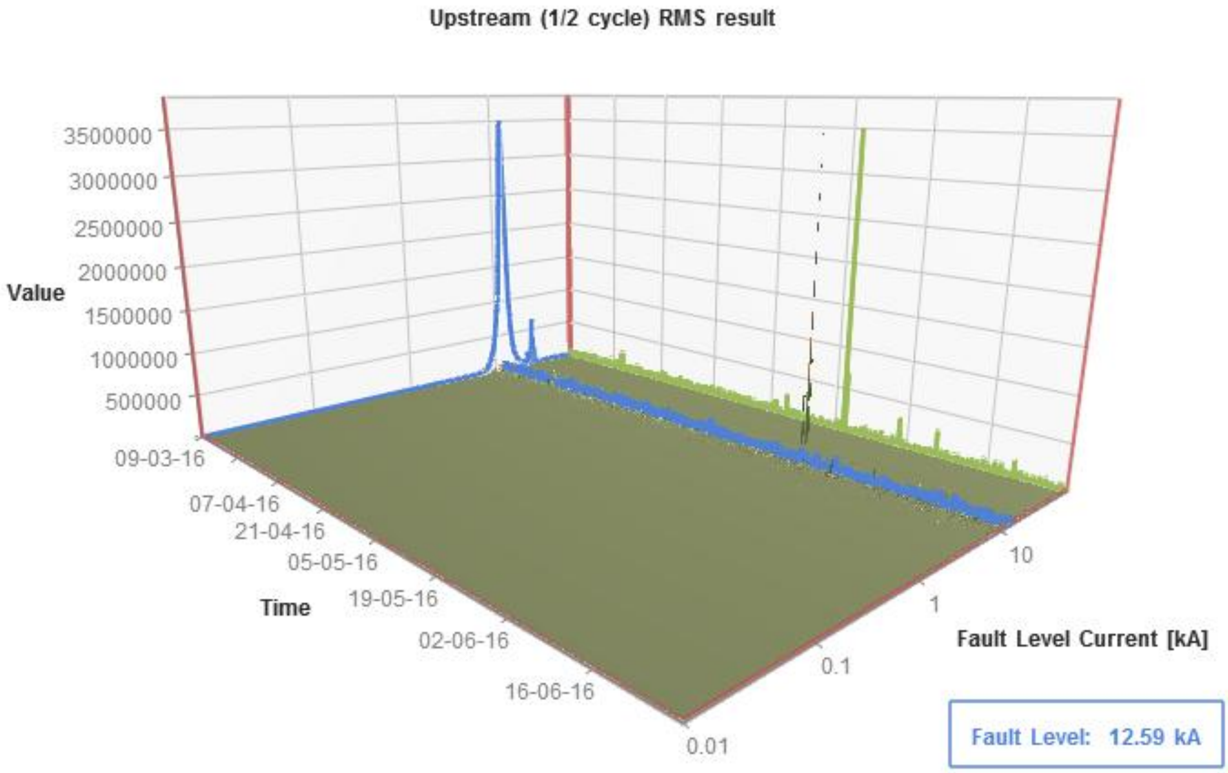


Graph 10. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with no filtering.

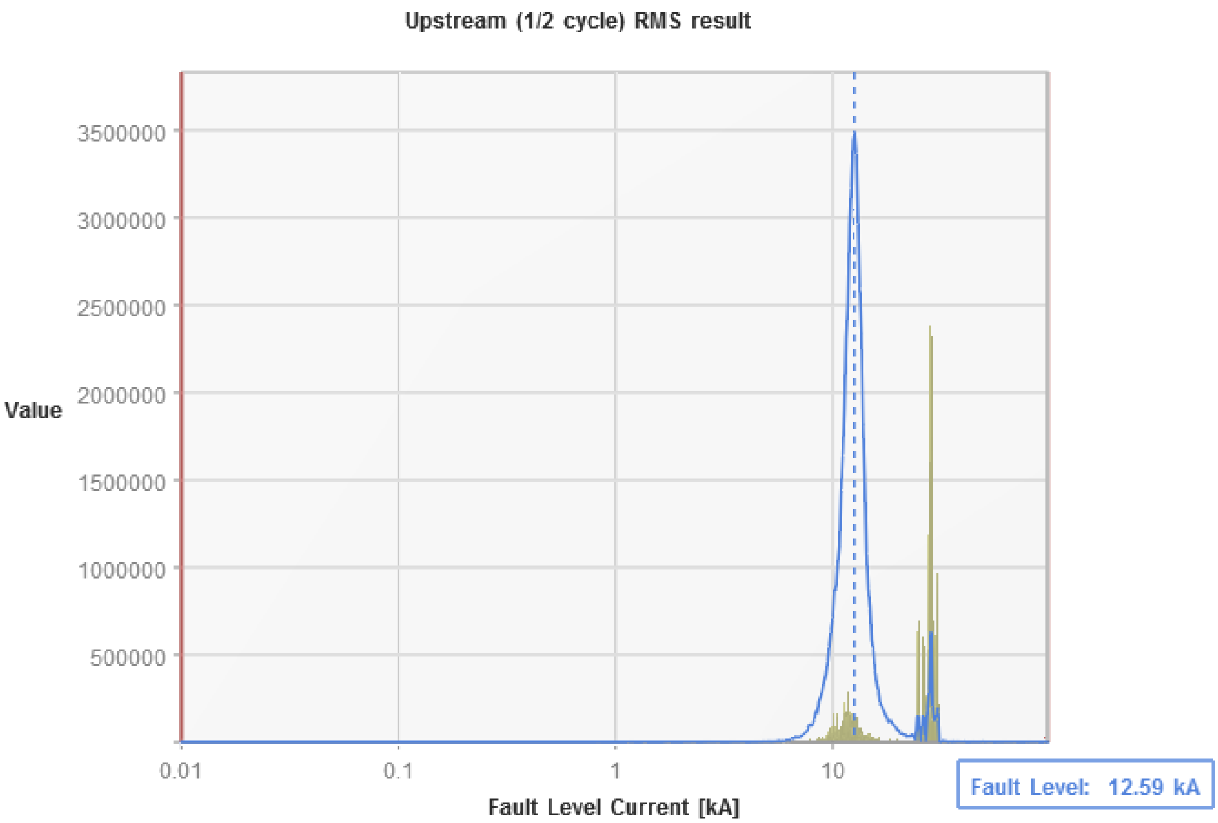


Graph 11. Upstream Peak Fault level at ½ cycle. 2D Distribution shown with no filtering.

Graphs 12 and 13 show the Upstream RMS result at half-cycle.

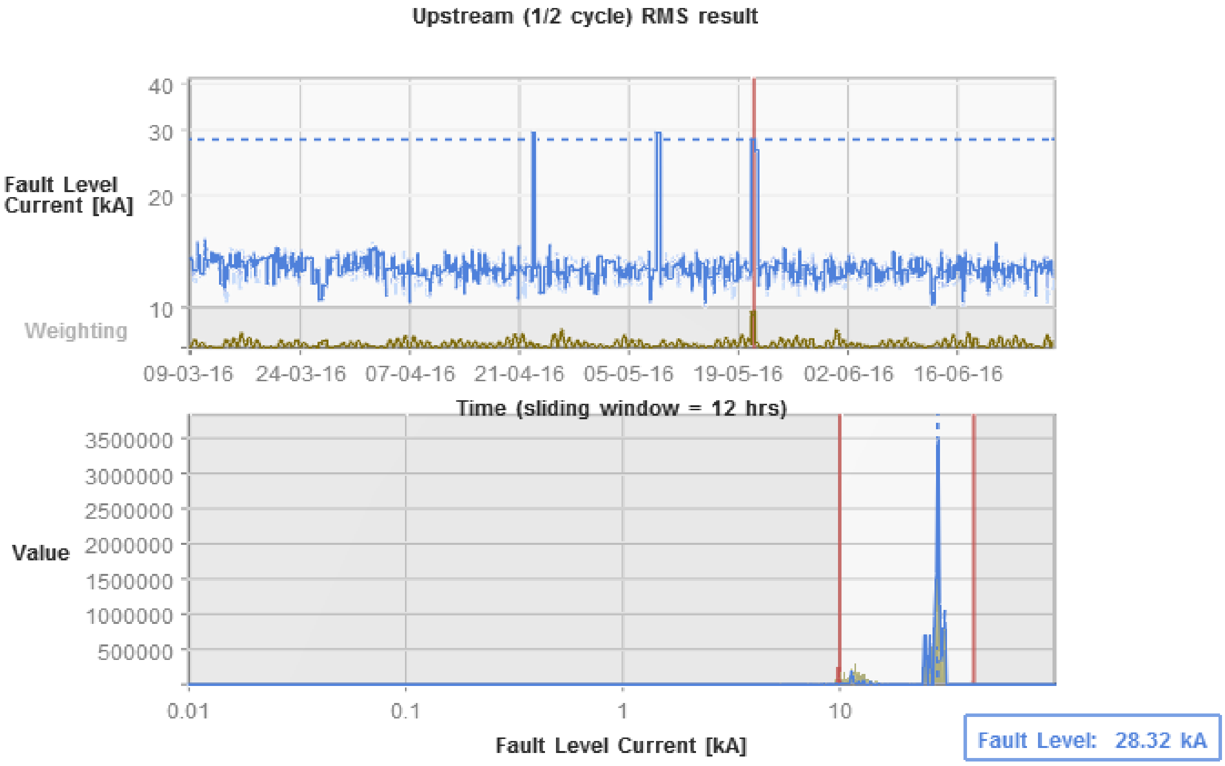


Graph 12. Upstream RMS Fault level at ½ cycle. 3D Distribution shown with no filtering.



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

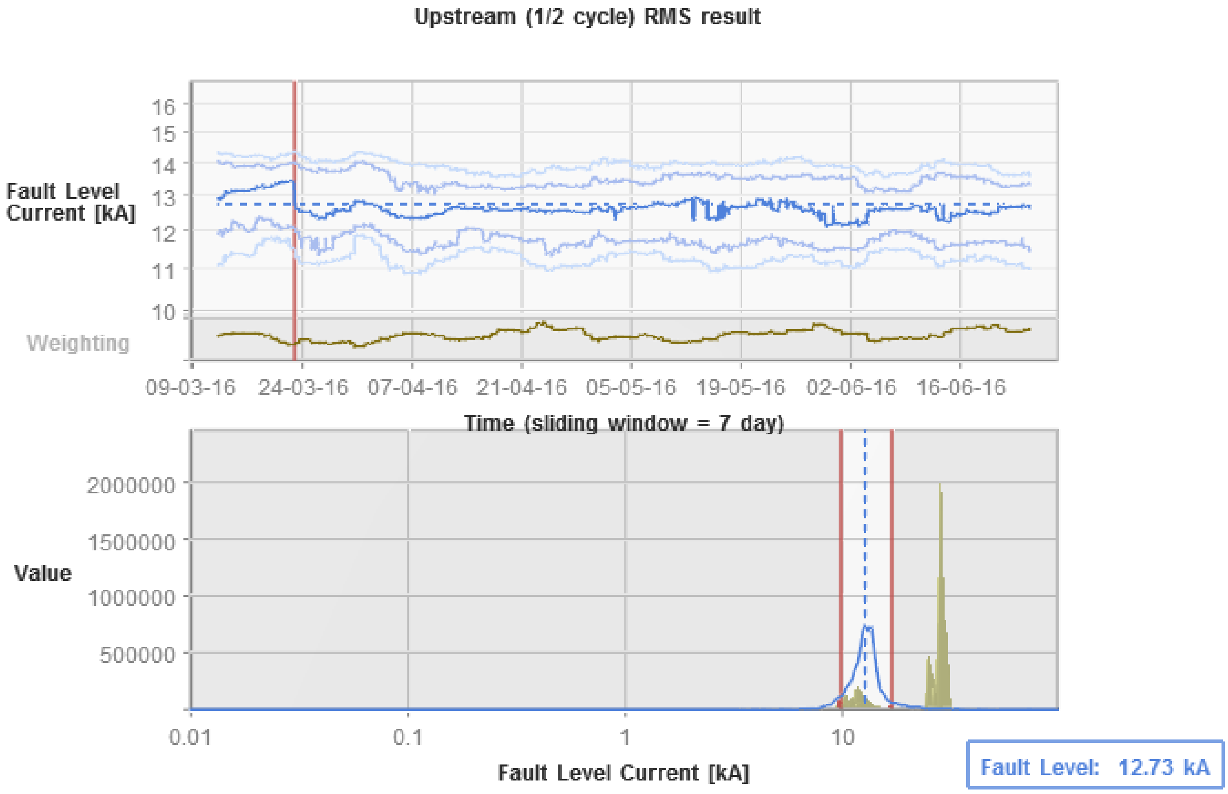
Looking at these results over much shorter times, we can observe short term variation associated with the various gross events. Graph 14 below shows the cleanest of the above (the ½ cycle RMS result) averaged over 12 hours.



Graph 14. Upstream RMS Fault level at ½ cycle. 12 hr Time varying result shown with no filtering.

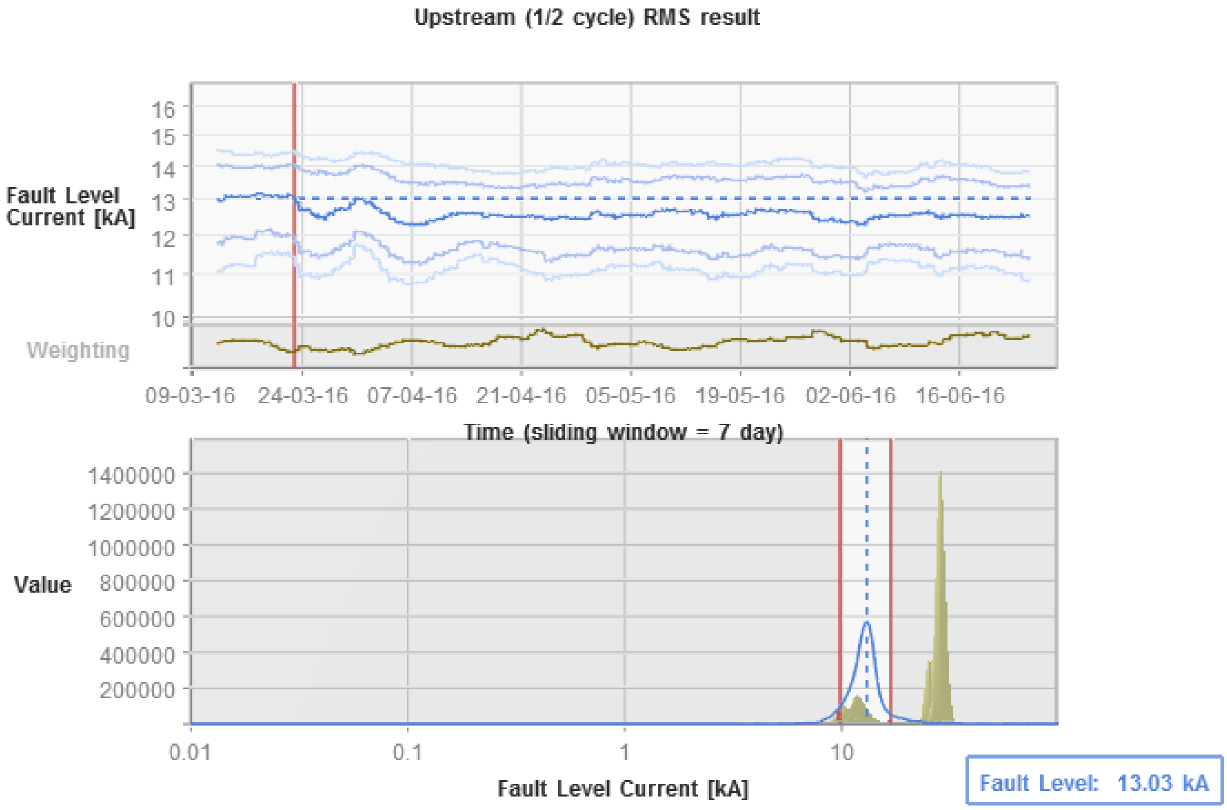
The vertical red lines in the lower graph are the lower and upper Fault Level bounds used for the upper graph. The weighting section of the upper graph shows the disturbance energy used to produce the Fault Level result.

Extending the averaging period out to 7 days and adding 1% filtering, there does not appear to be much variation over the recording except for the event on 22nd May (underneath the red vertical line in the upper graph). See graph 15.



Graph 15. Upstream RMS Fault level at ½ cycle. 7 day Time varying result shown with 1% filtering.

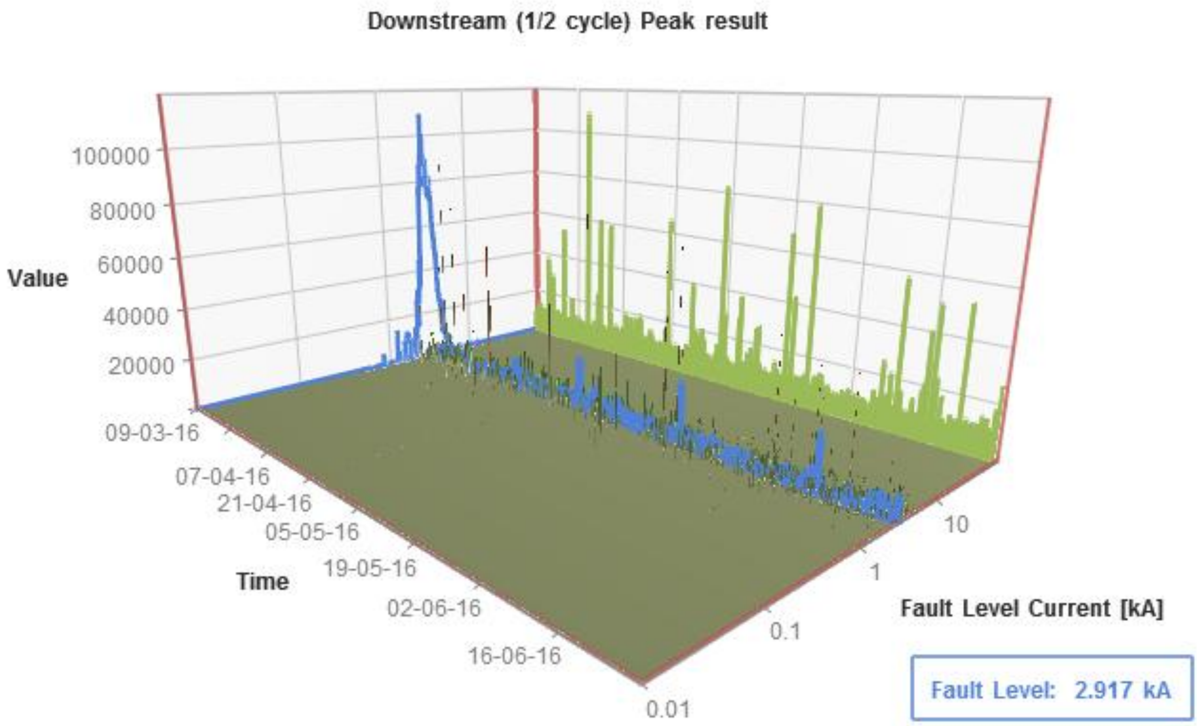
Although the bolder blue line in upper Graph 15 (representing the peak of the distribution contained within the 7-day sliding boxcar) does have some variation on it particularly on 23rd March, this may not be very significant because the 3 and 6dB skirts of the distribution (the two lighter blue lines) do not show the same positive movement. This suggests that the bulk of the population did not move convincingly, even though the local peak moved. Close examination of the lower Graph 15 shows two little ears on the population at that time, and the peak is transitioning between them. Raising the filtering to 2% resolves that issue but leaves the impression that the Fault Level is varying a few percent. See Graph 16.



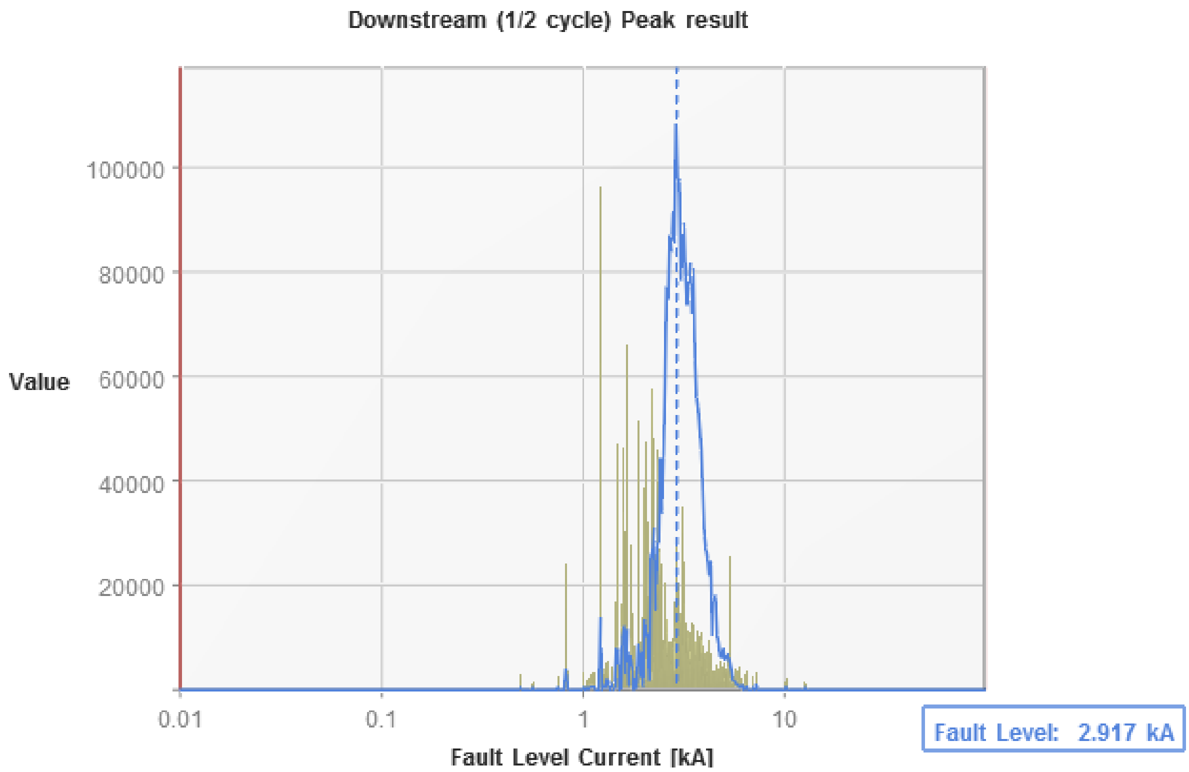
Graph 16. Upstream RMS Fault level at ½ cycle. 7 day Time varying result shown with 2% filtering.

Downstream Fault Level contribution

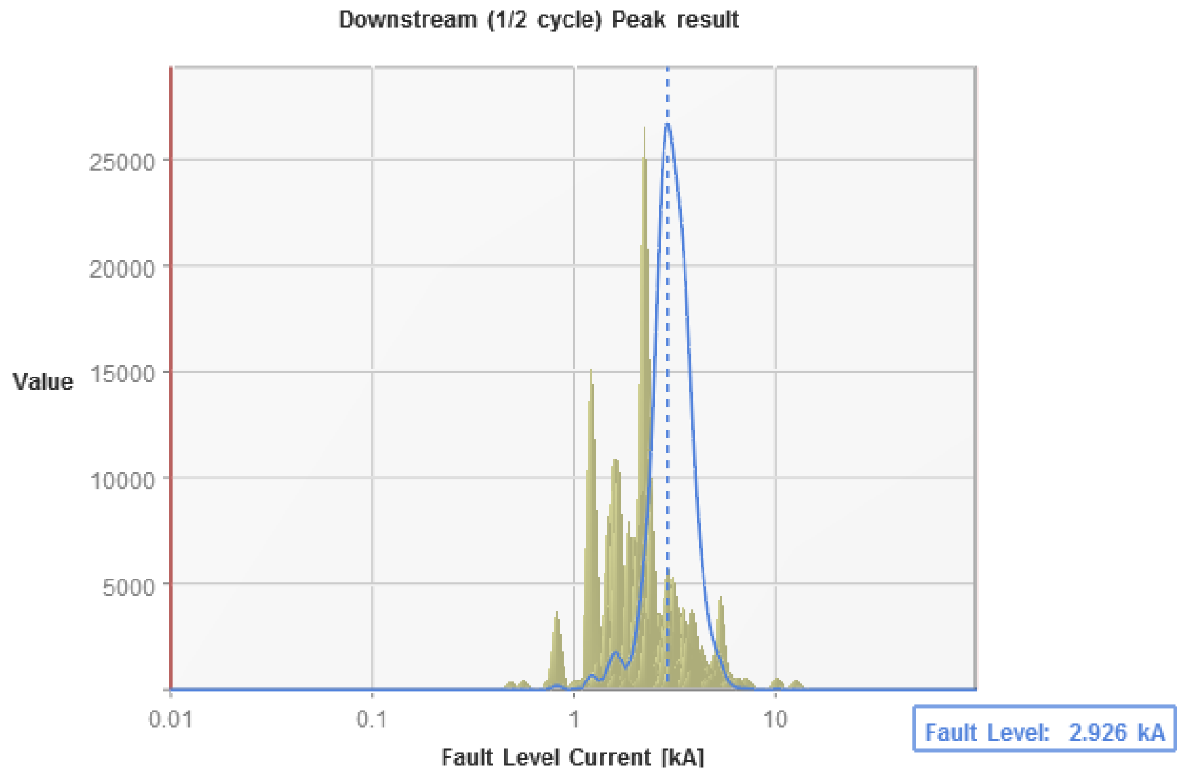
Graphs 17 and 18 show the Peak half cycle Fault Level detected for downstream contribution. Without any filtering, this is a fairly tight distribution for downstream contribution, and addition of filtering makes very little difference to the peak contribution result.



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

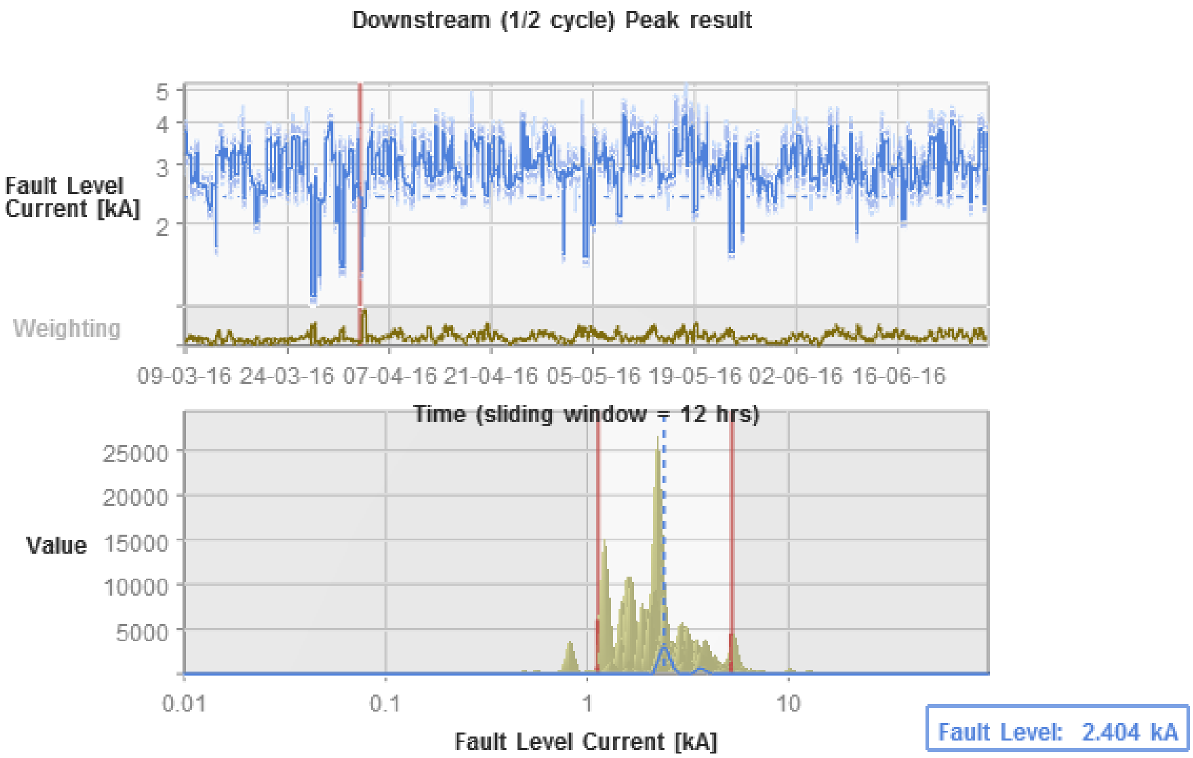


Graph 18. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with no filtering.



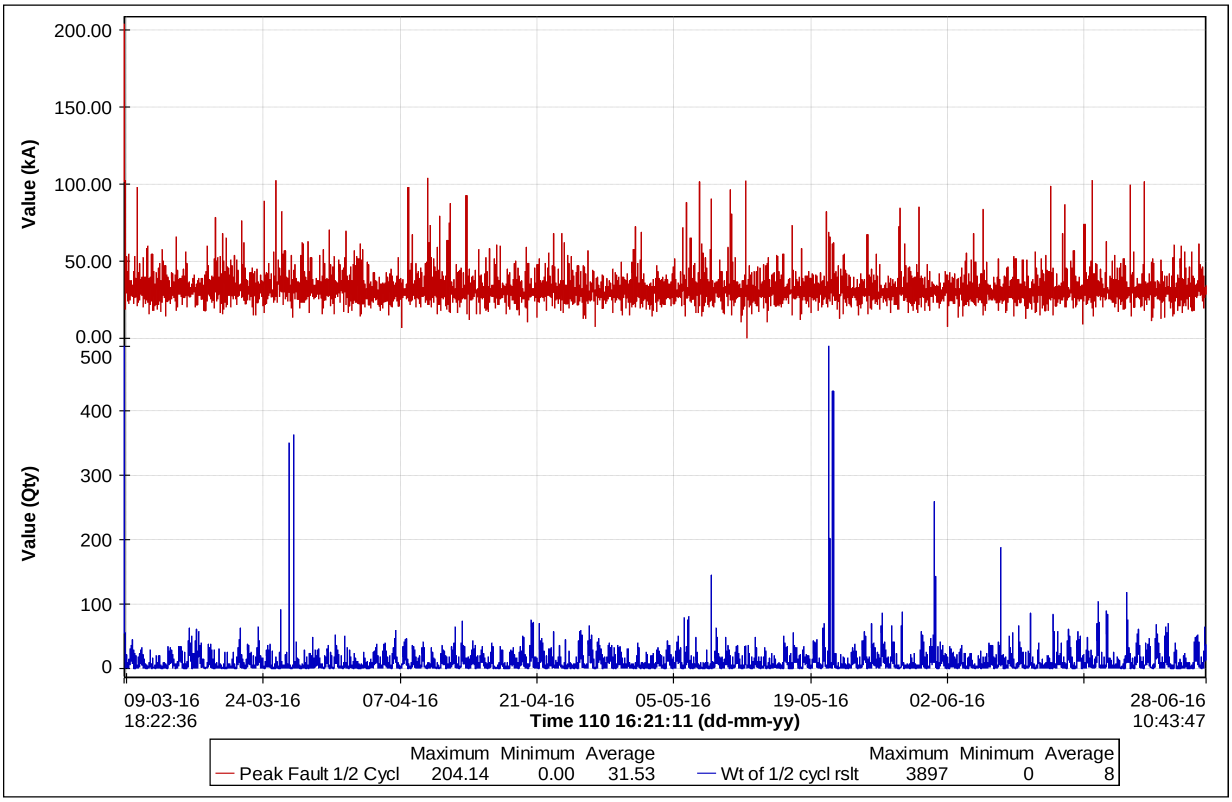
Graph 19. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 3% filtering.

Graph 20 below shows a 12 hour sliding window applied, also with 3% filtering. The downstream contribution is again relatively consistent.

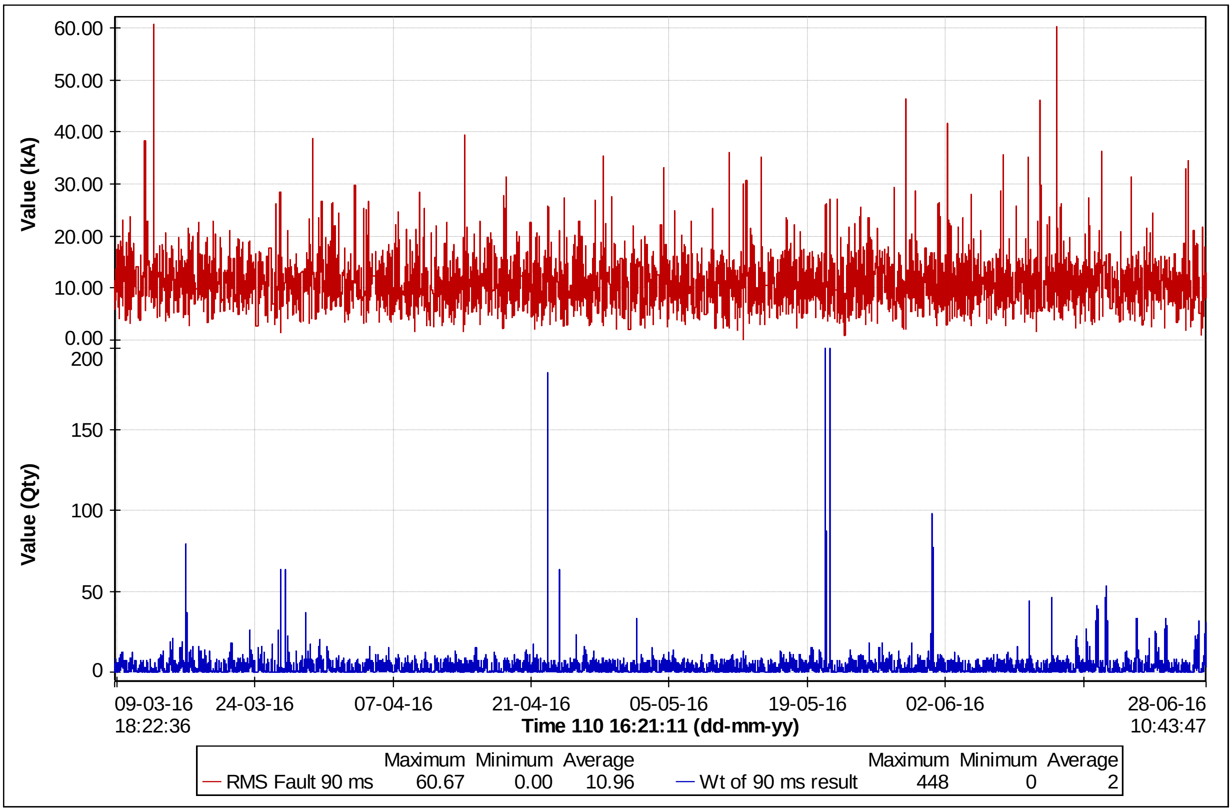


Graph 20. Downstream Peak Fault level at ½ cycle. 12 hr Time varying result shown with 3% filtering.

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.

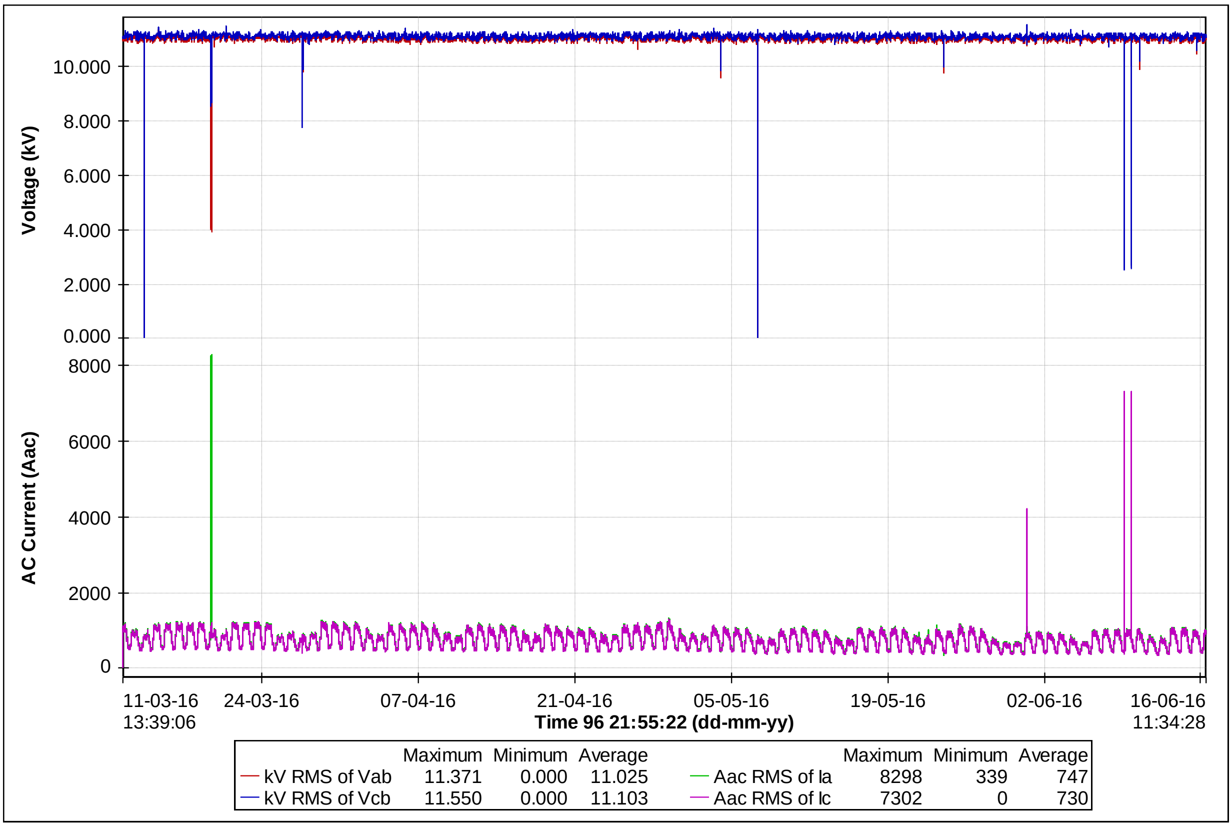
Appendix 2. Broadheath. FLM Serial No 888

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

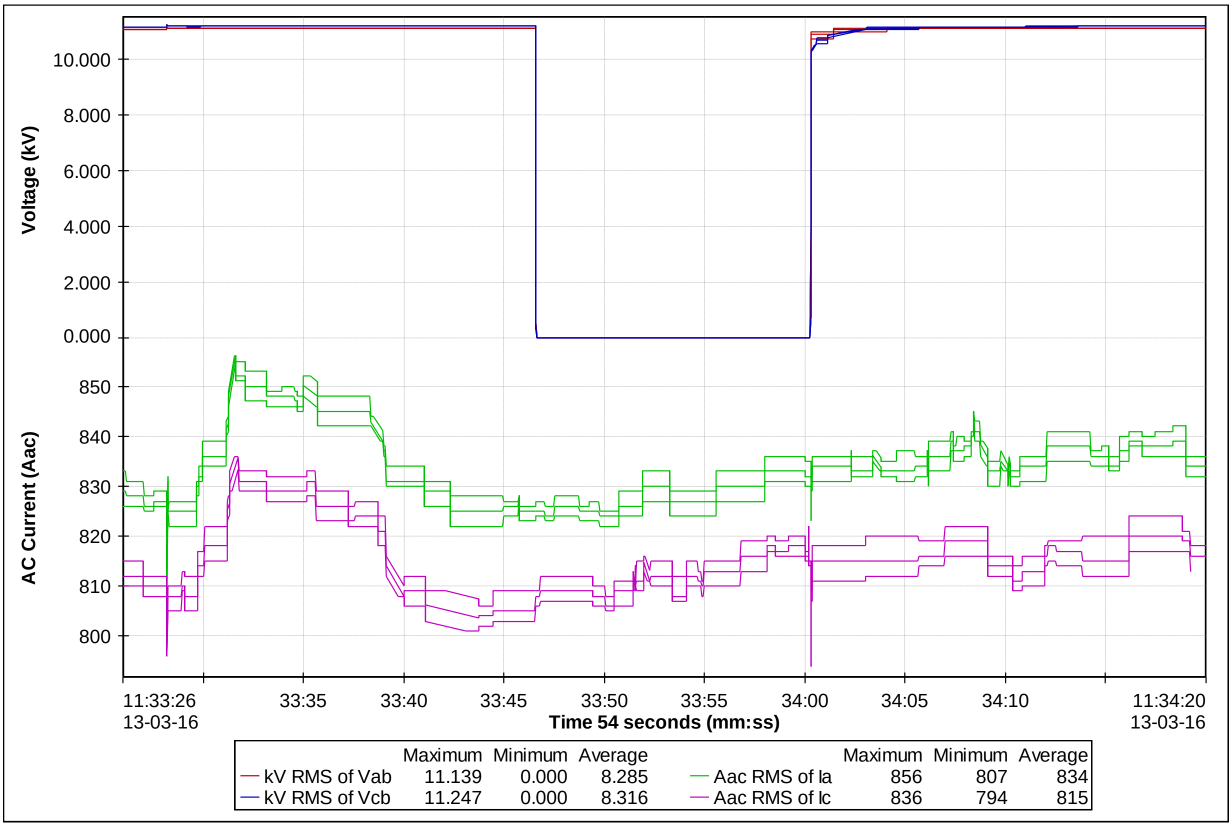
Graph 1 shows the voltage and current for the full recording period.



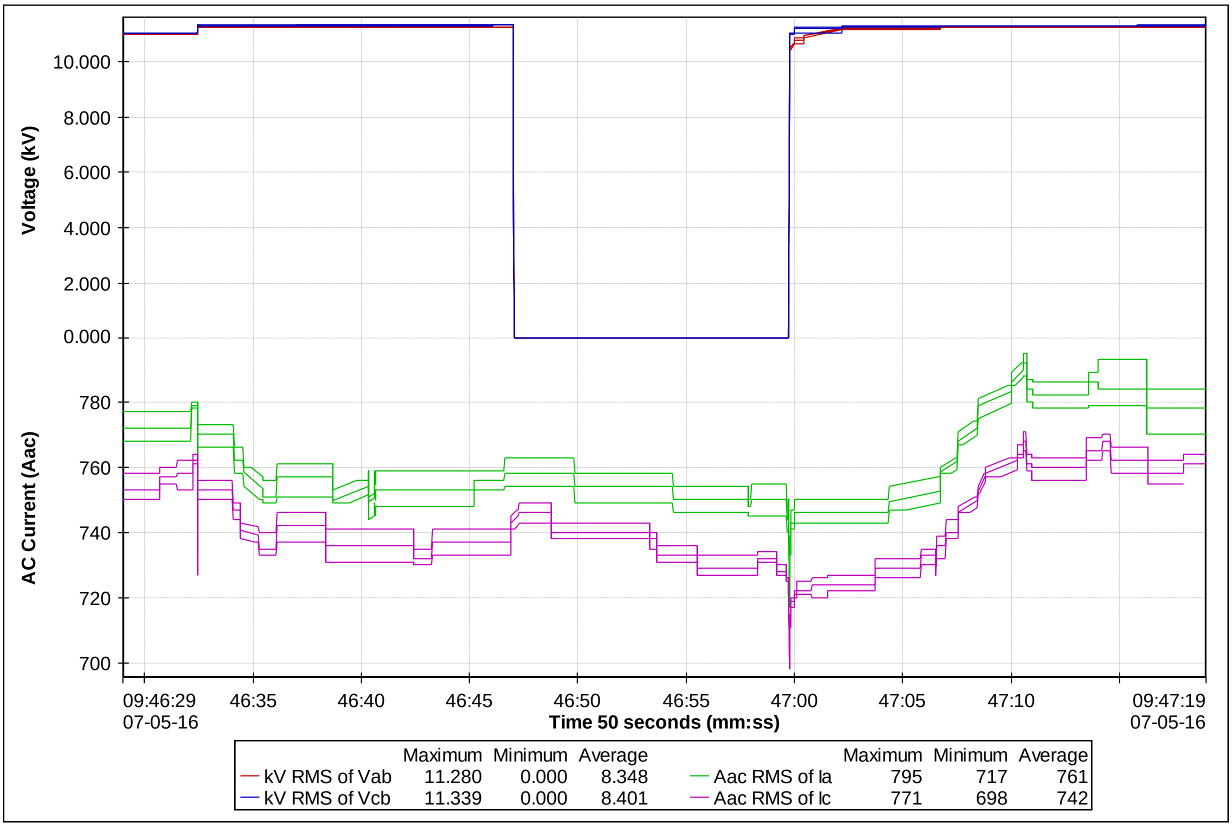
Graph 1. Volts and Current for the full recorded period.

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.

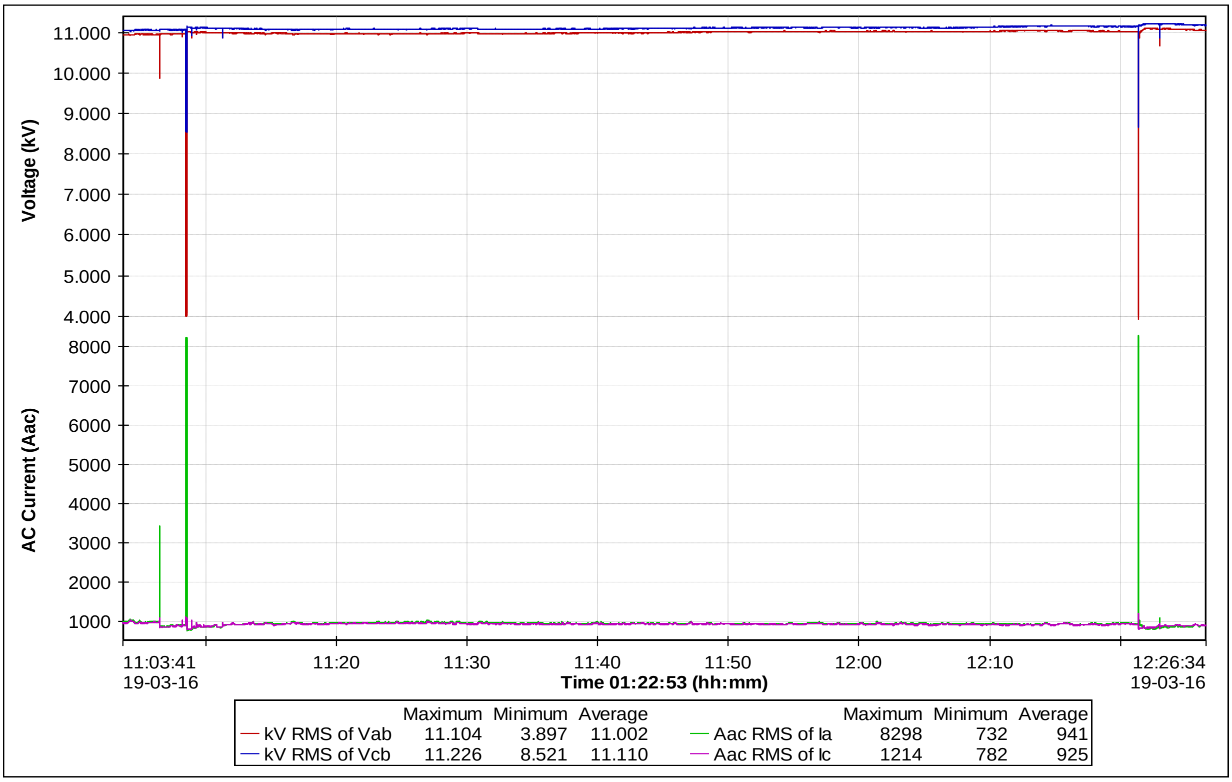
Graphs 2-9 show the RMS detail.



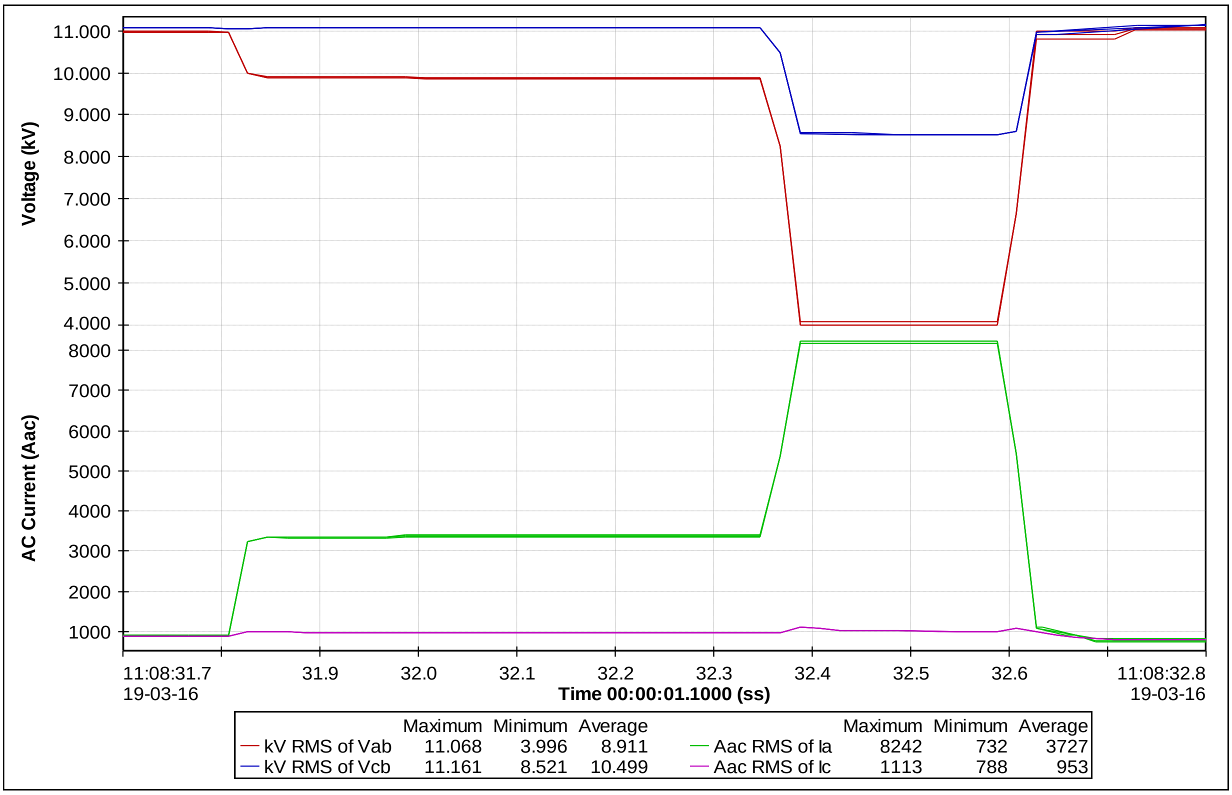
Graph 2. Interruption on Voltage, 13 March 2016.



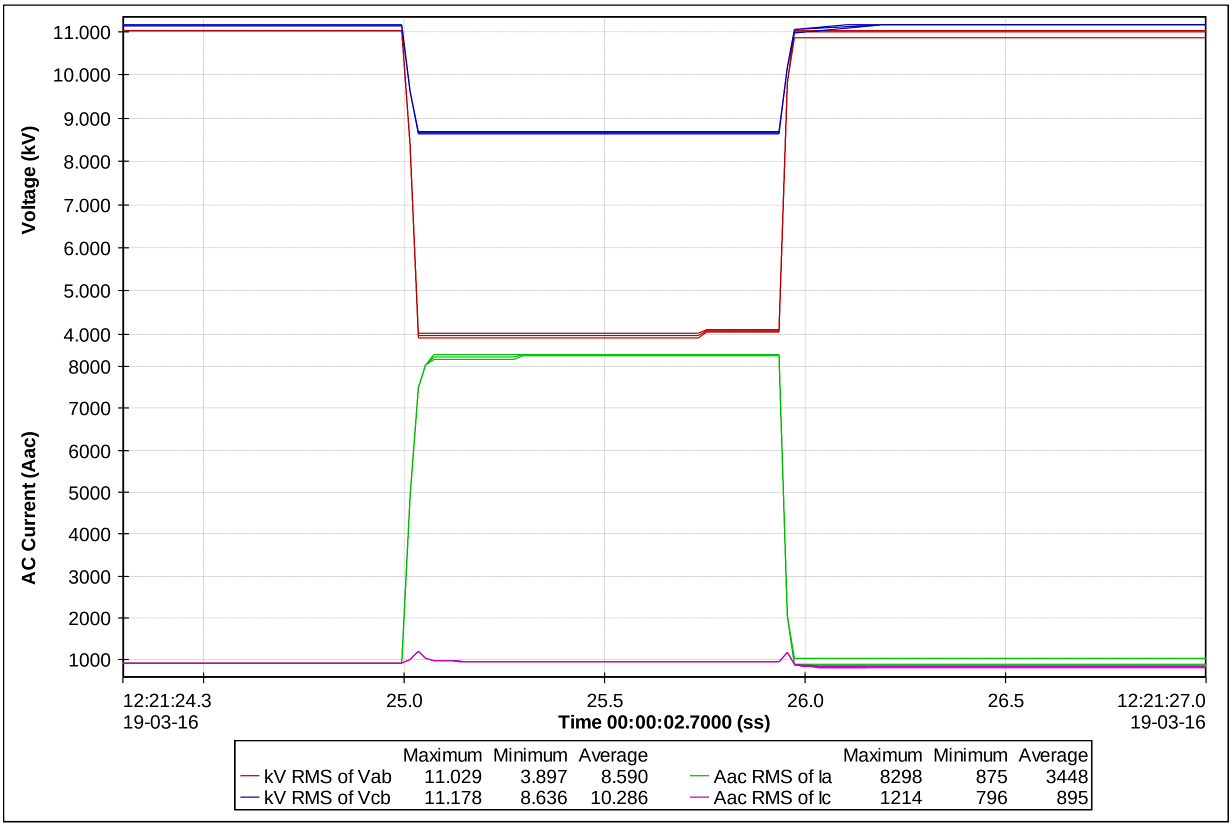
Graph 3. Interruption on Voltage, 7th May 2016.



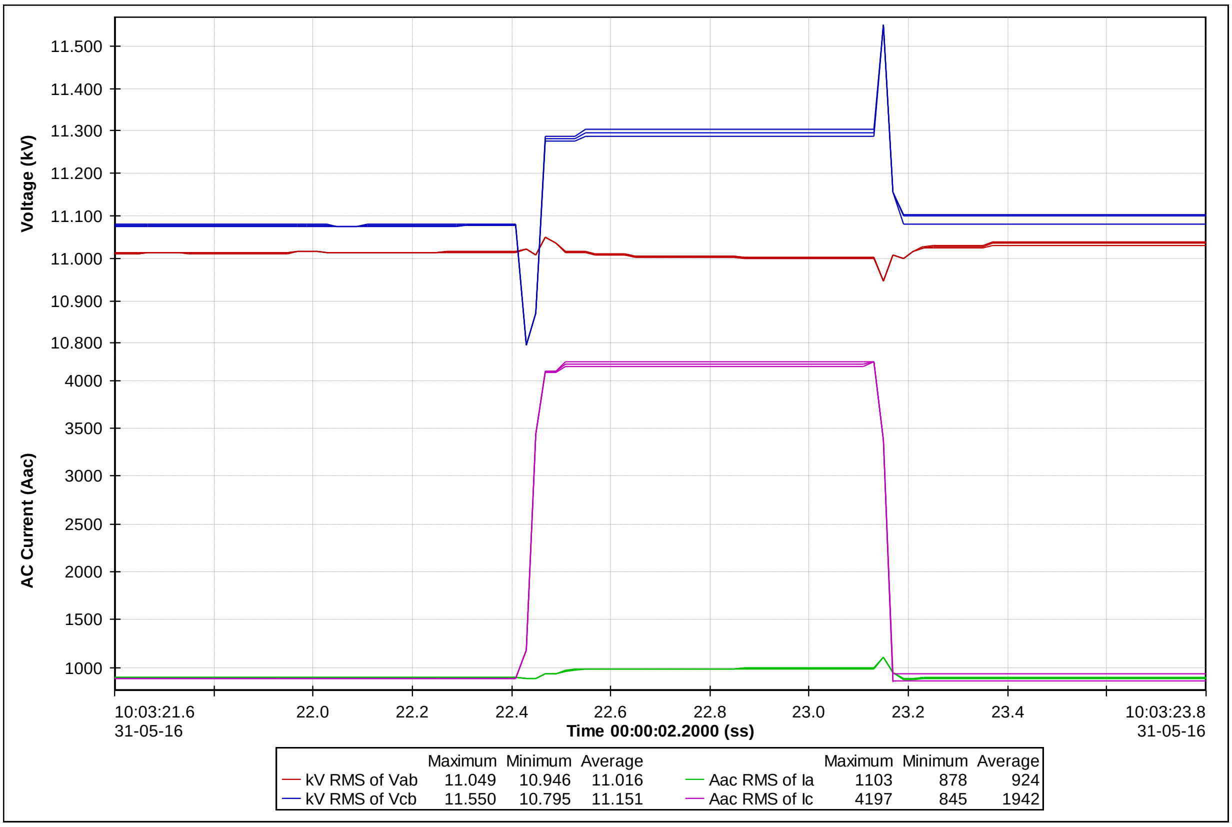
Graph 4. Pair of A phase current disturbances on 19th March 2016.



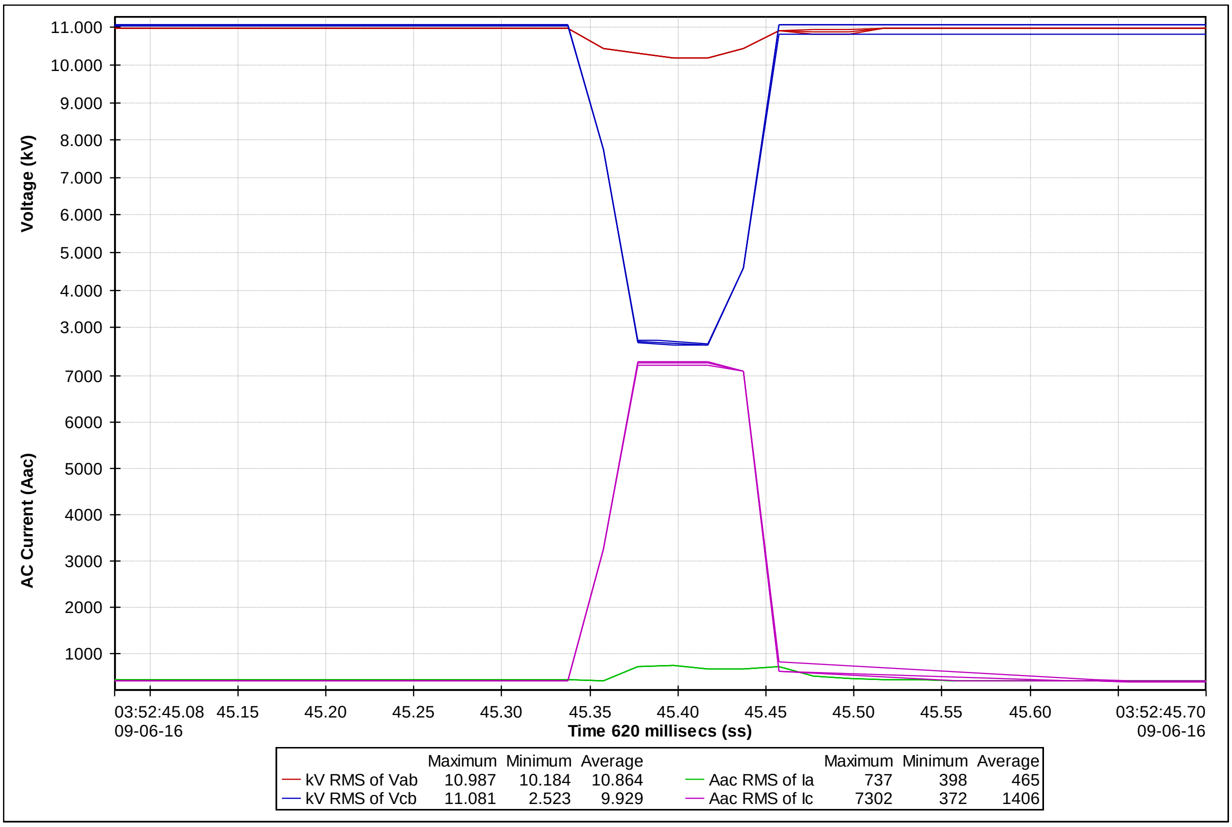
Graph 5. First A phase current disturbance on 19th March 2016.



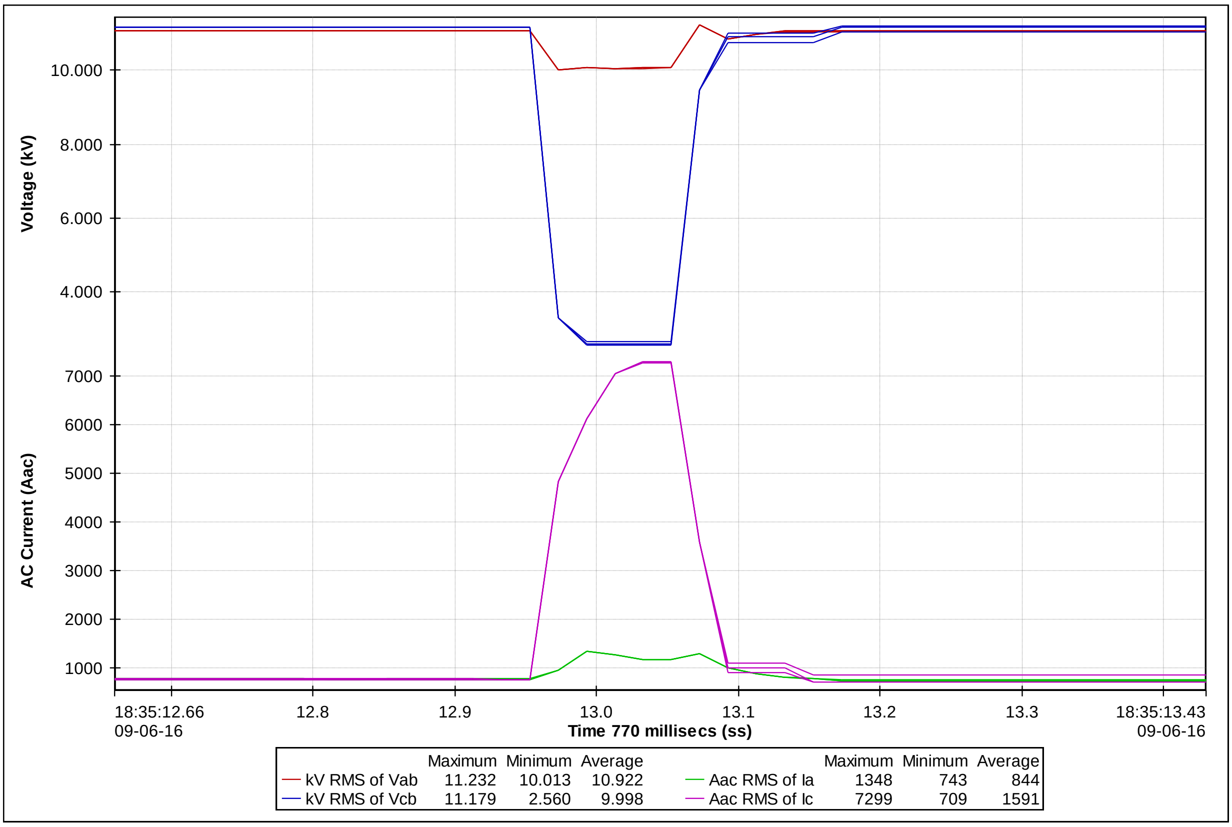
Graph 6. Second A phase current disturbance on 19th March 2016.



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



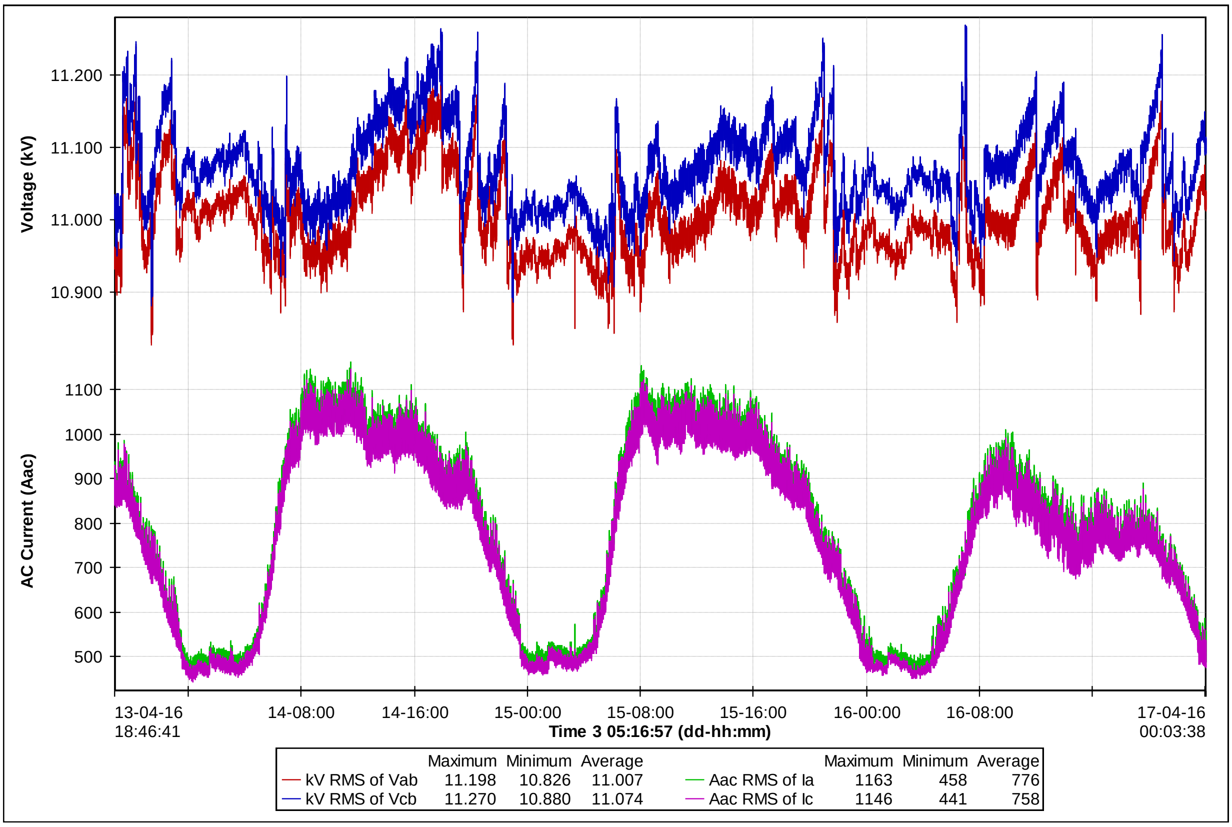
Graph 8. C phase current disturbance on 9th June 2016.



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

Useful Fault Level type disturbances.

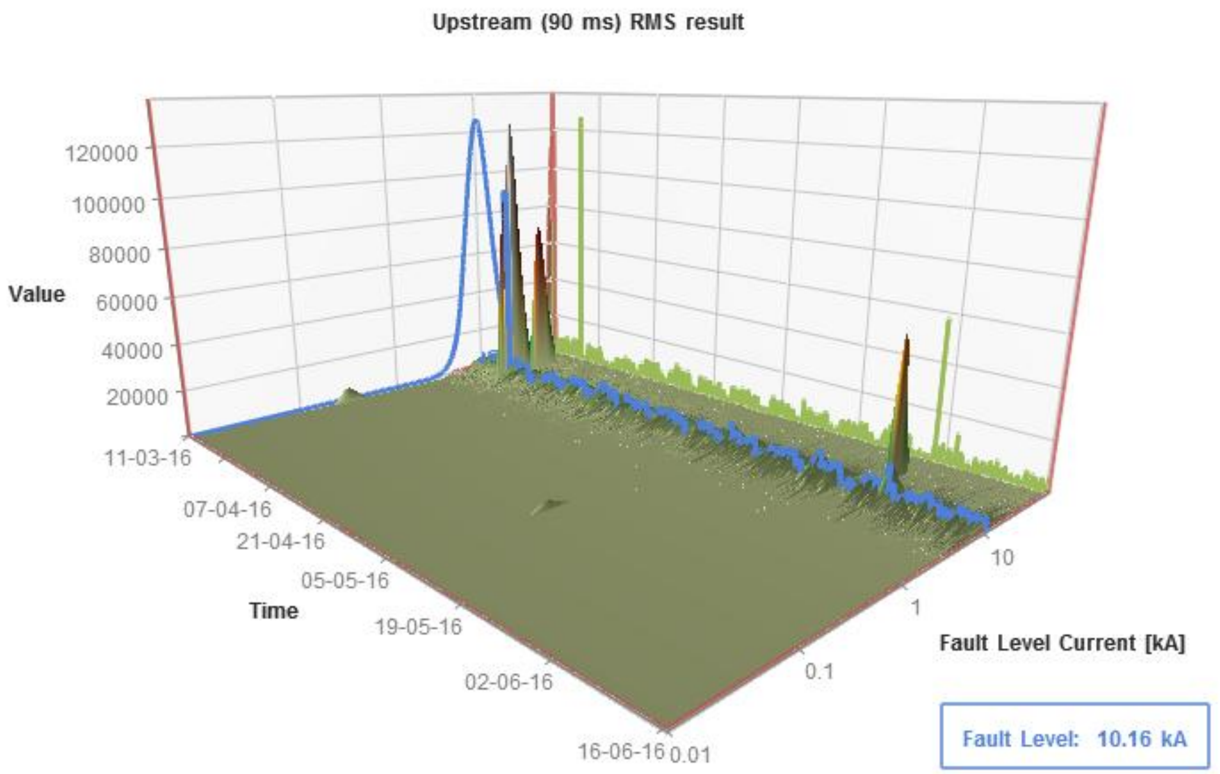
In addition to the few very large disturbances noted above, there was an underlying pattern of daytime current disturbances which should yield reasonable Fault Level results. Graph 10 shows a typical 3 day section of the recording.



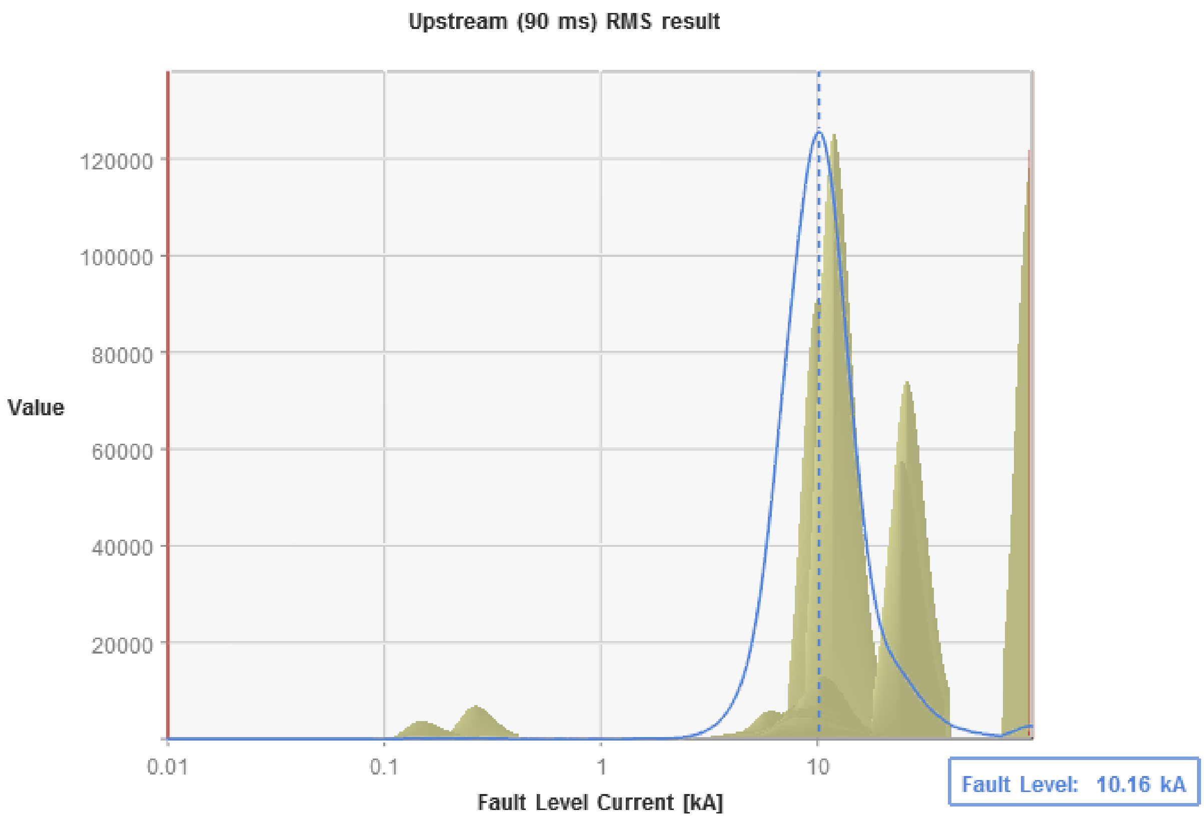
Graph 10. Typical disturbance activity.

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.

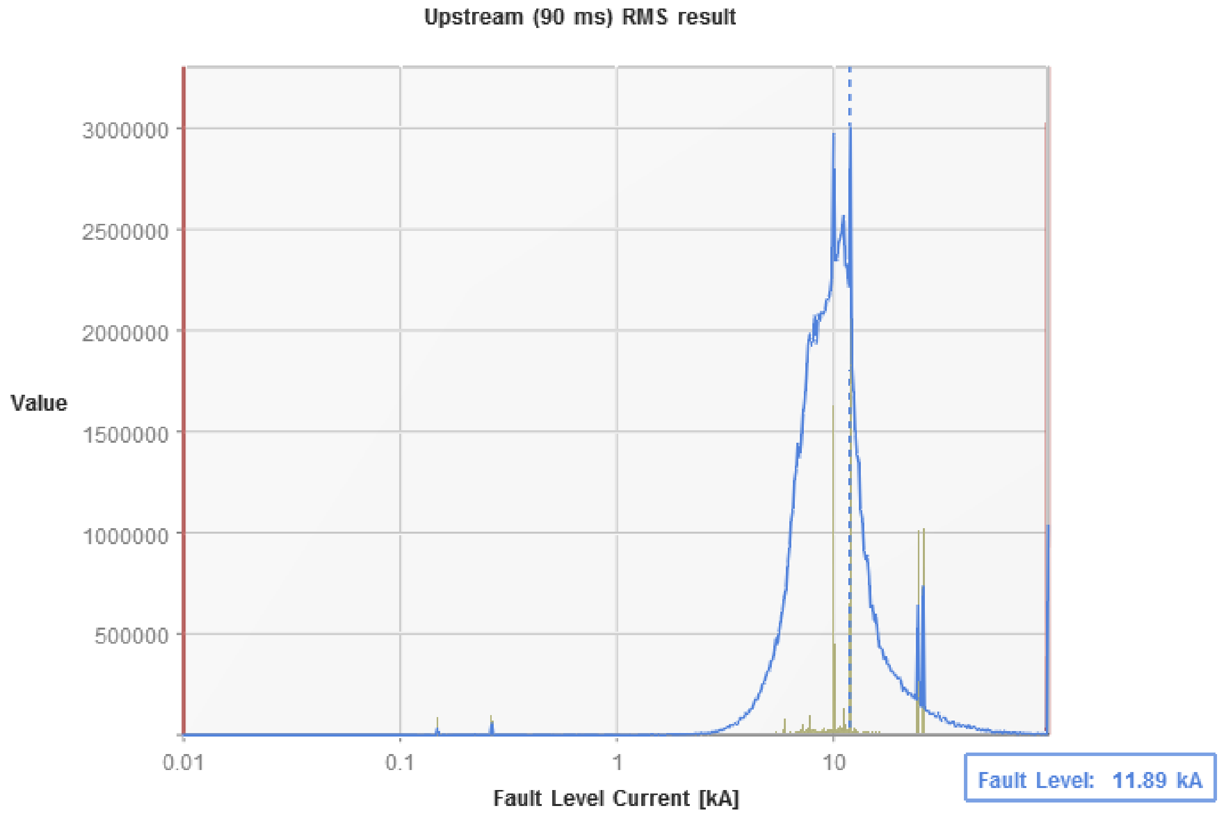


Graph 11. Upstream RMS Fault level at 90ms. 3D Distribution shown with 10% filtering.



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

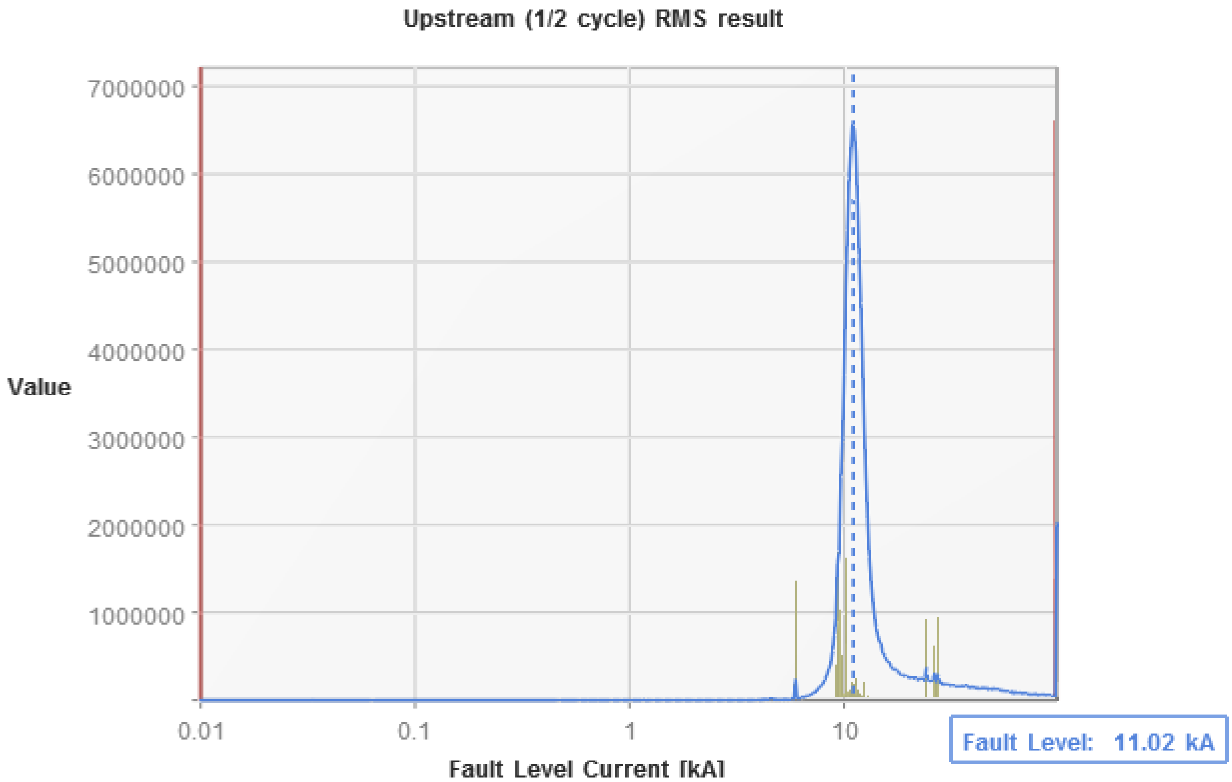
Without the filtering, the peak of the distribution is biased high, as shown in Graph 13 below.



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.

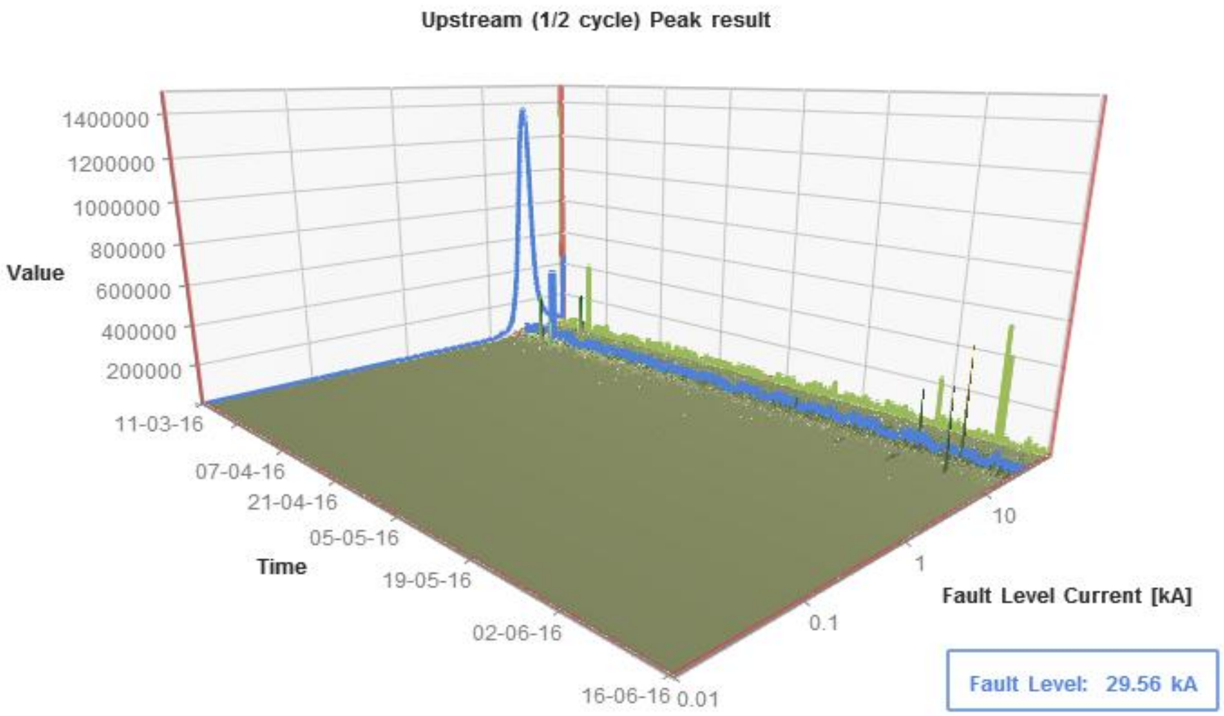
This is a case where examination of the 10ms RMS result can give an insight.



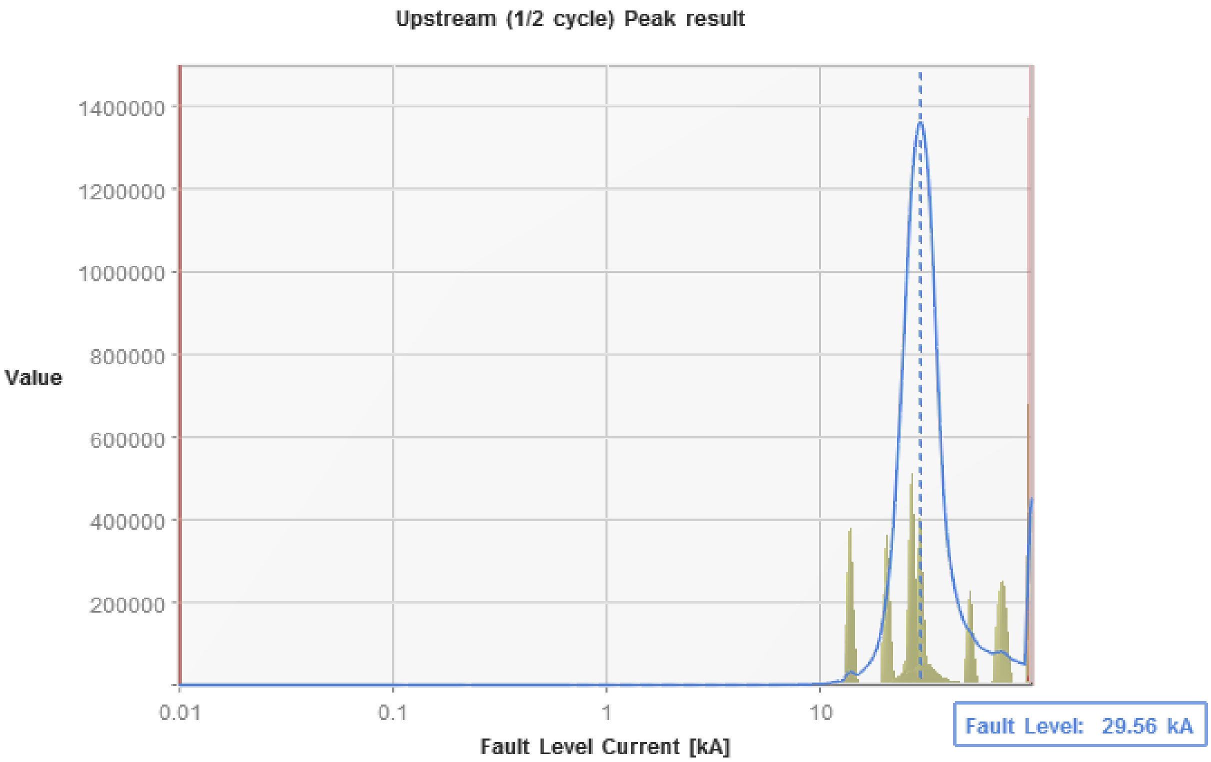
Graph 14. Upstream RMS result at half cycle, no filtering.

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.

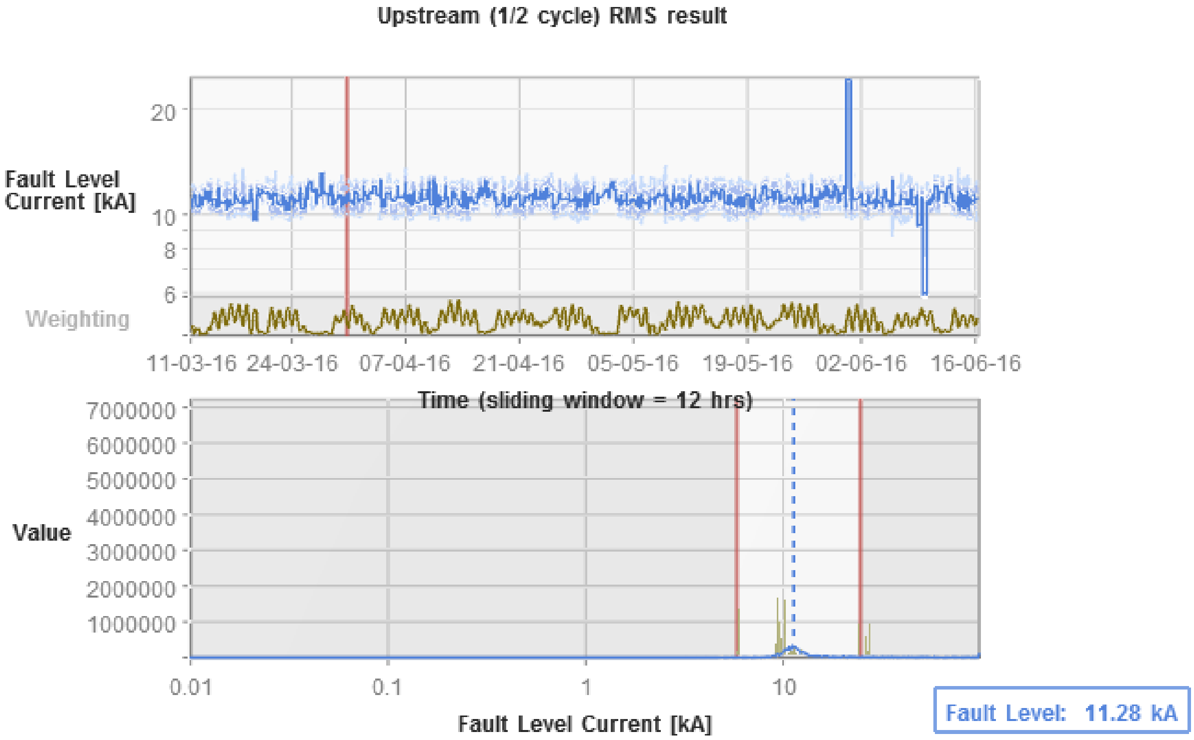


Graph 15. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 2% filtering.



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

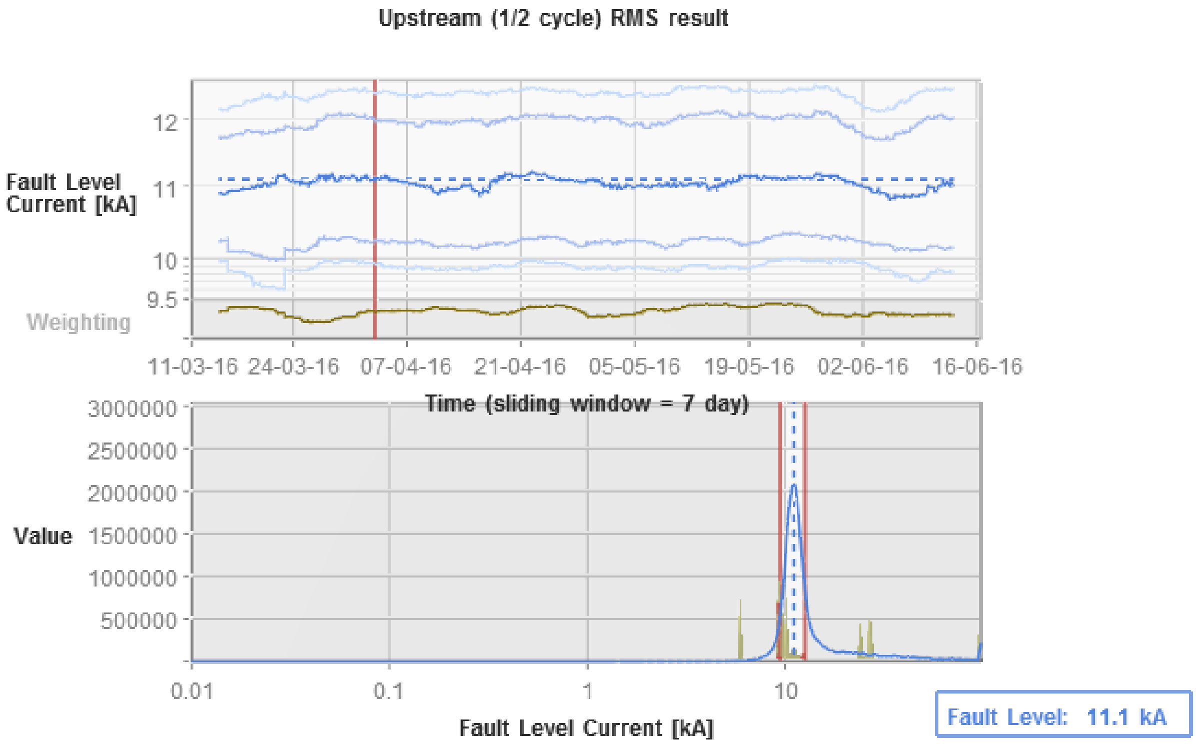
Looking at these results over much shorter times, we can observe short term variation associated with the some of the gross events. Graph 17 below shows the cleanest of the above (the ½ cycle RMS result) averaged over 12 hours.



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.

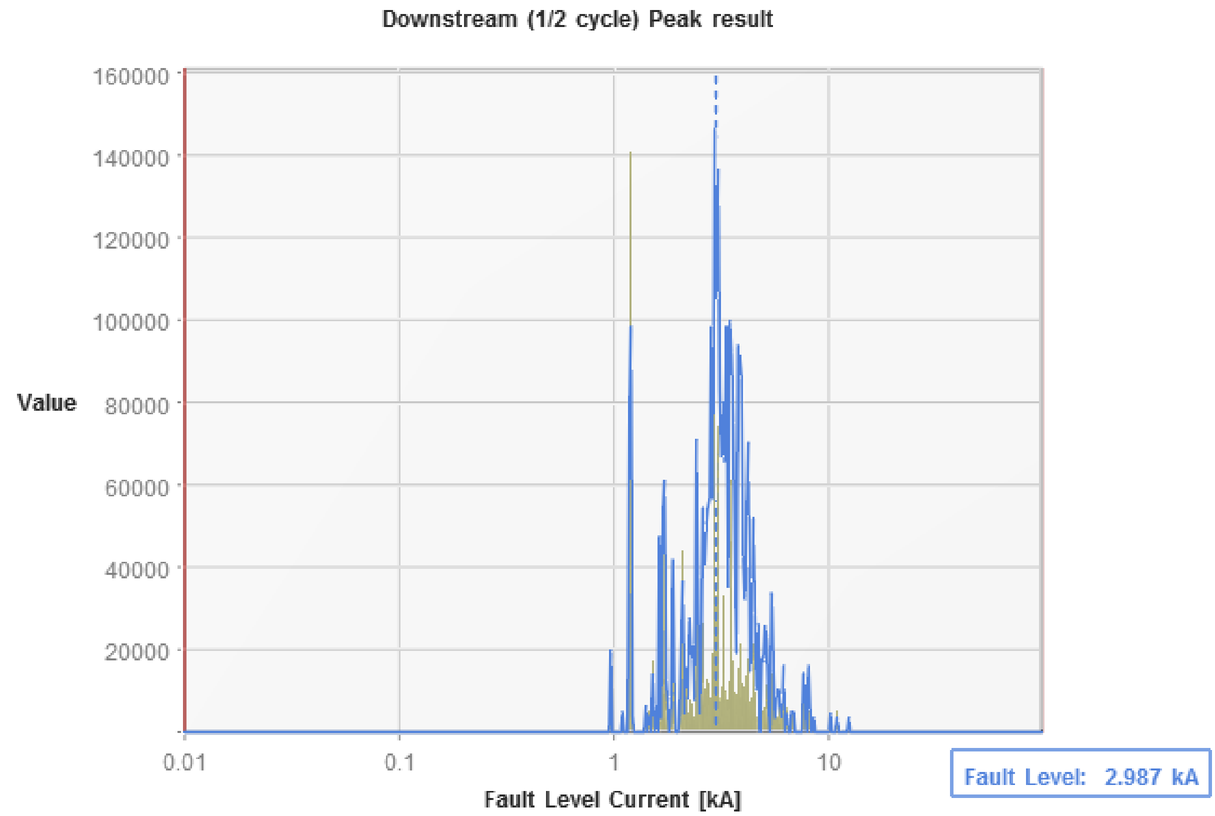
Extending the averaging period out to 7 days and adding 1% filtering, there does not appear to be much variation over the recording. See graph 18.



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

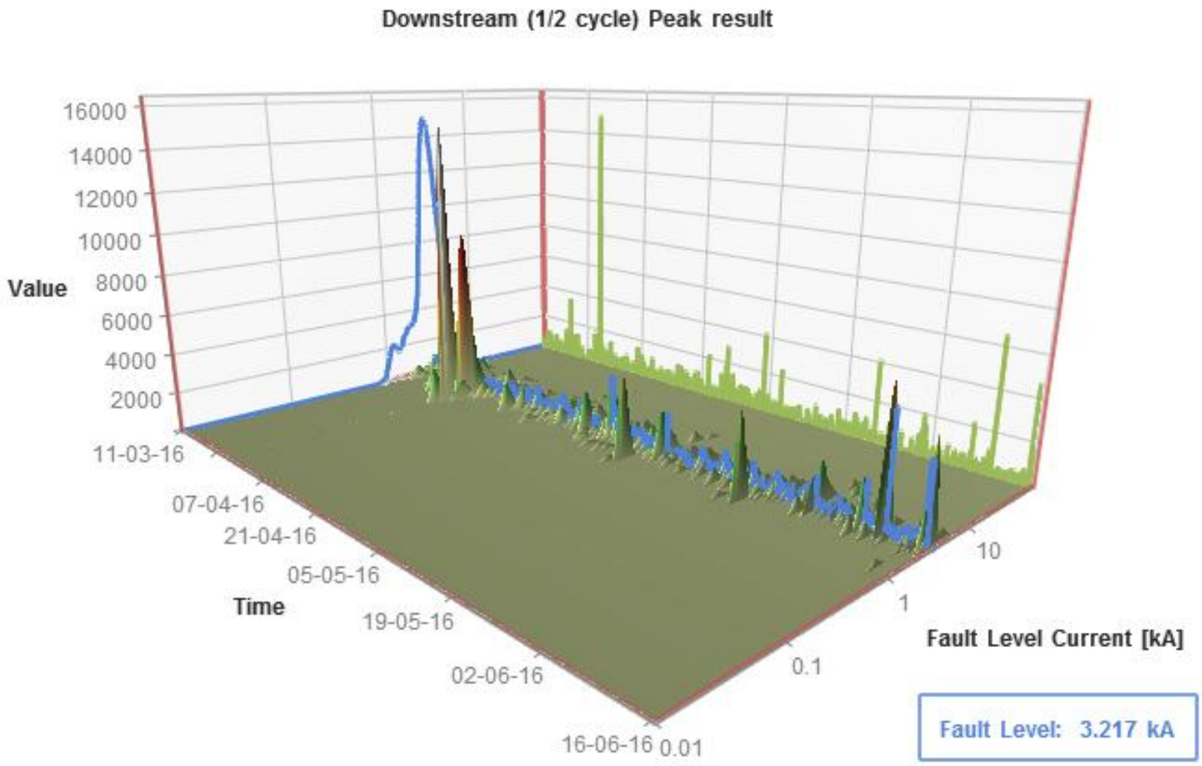
Downstream Fault Level contribution

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

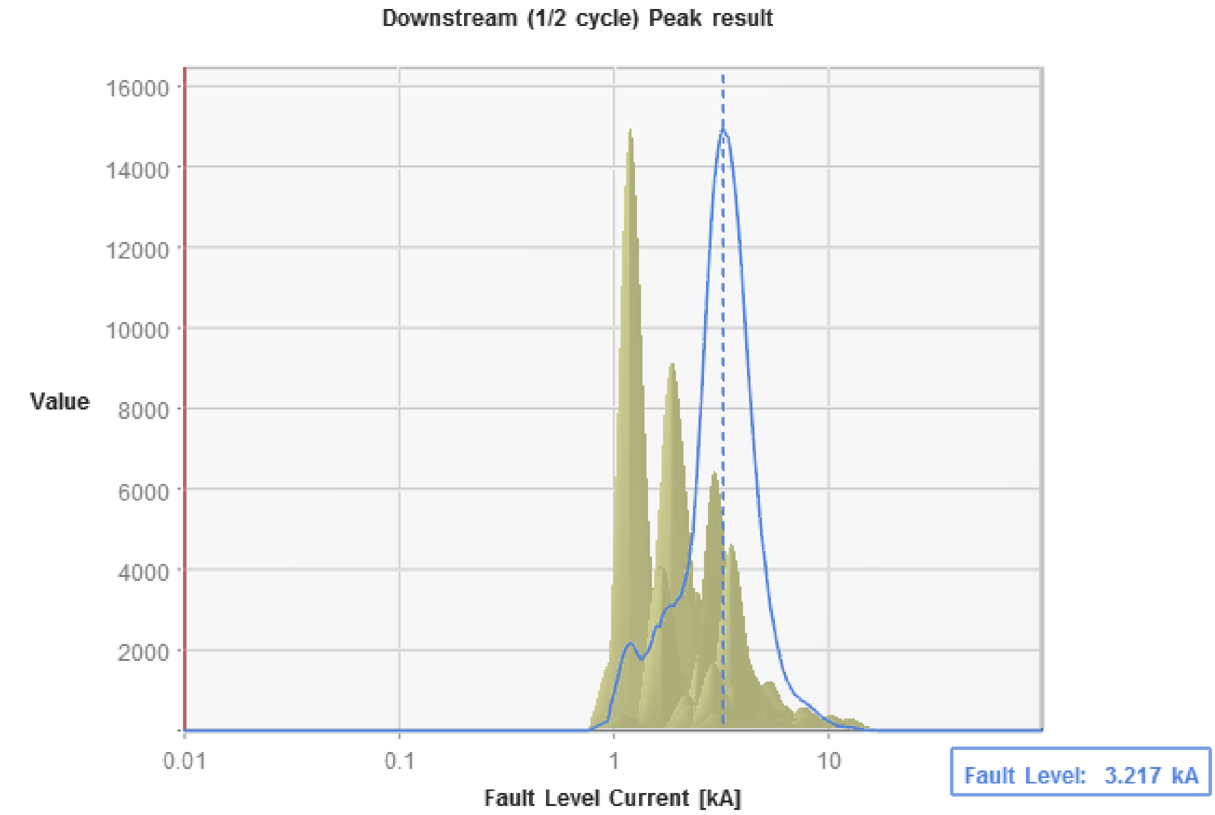


Graph 19. Downstream Peak Fault Level contribution at ½ cycle. 2D representation without filtering.

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

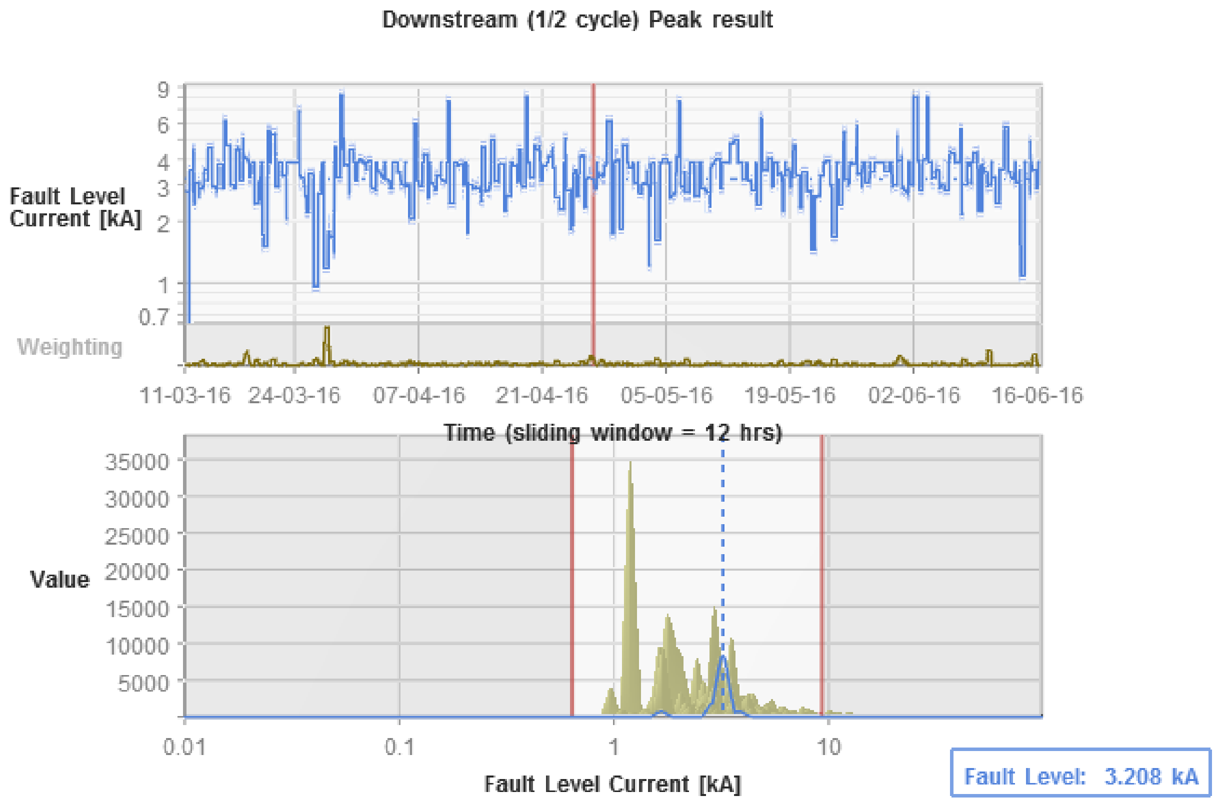


Graph 20. Downstream Peak Fault Level contribution at ½ cycle. 3D representation with 7% filtering.



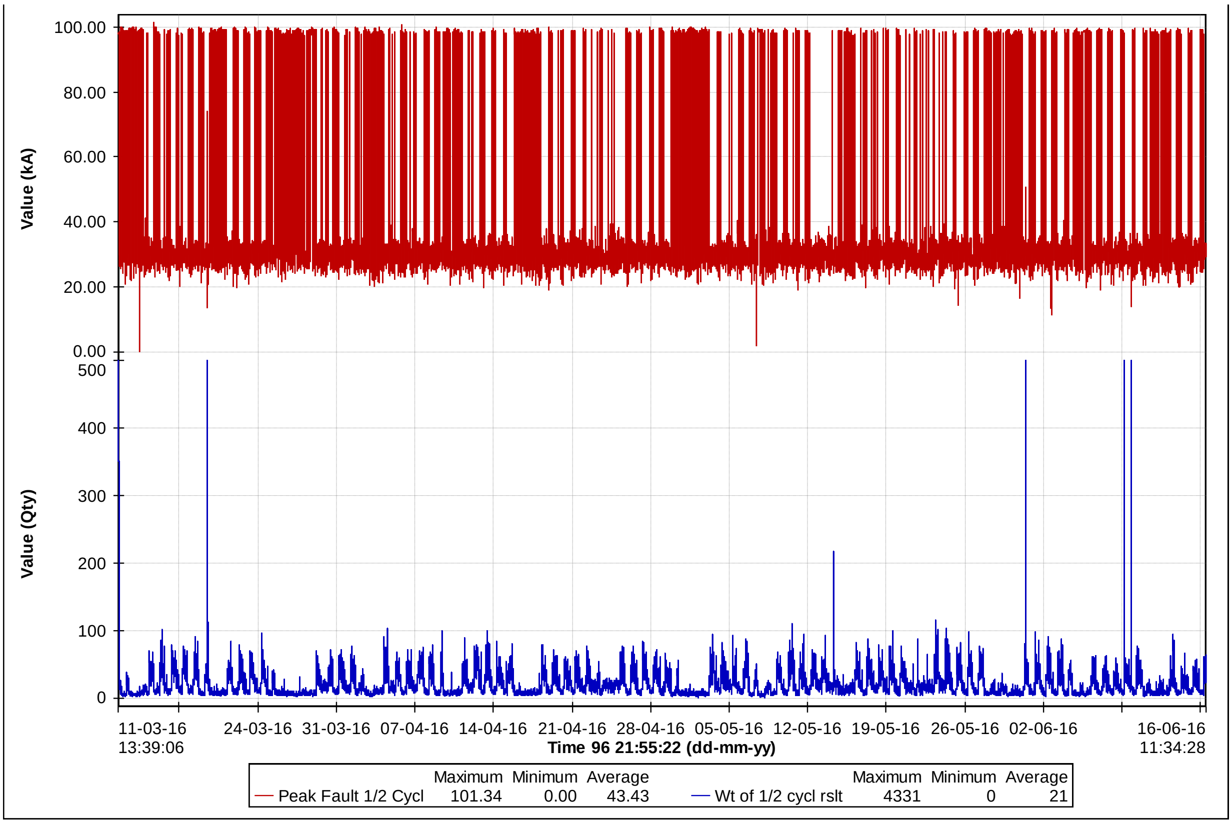
Graph 21. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 7% filtering.

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

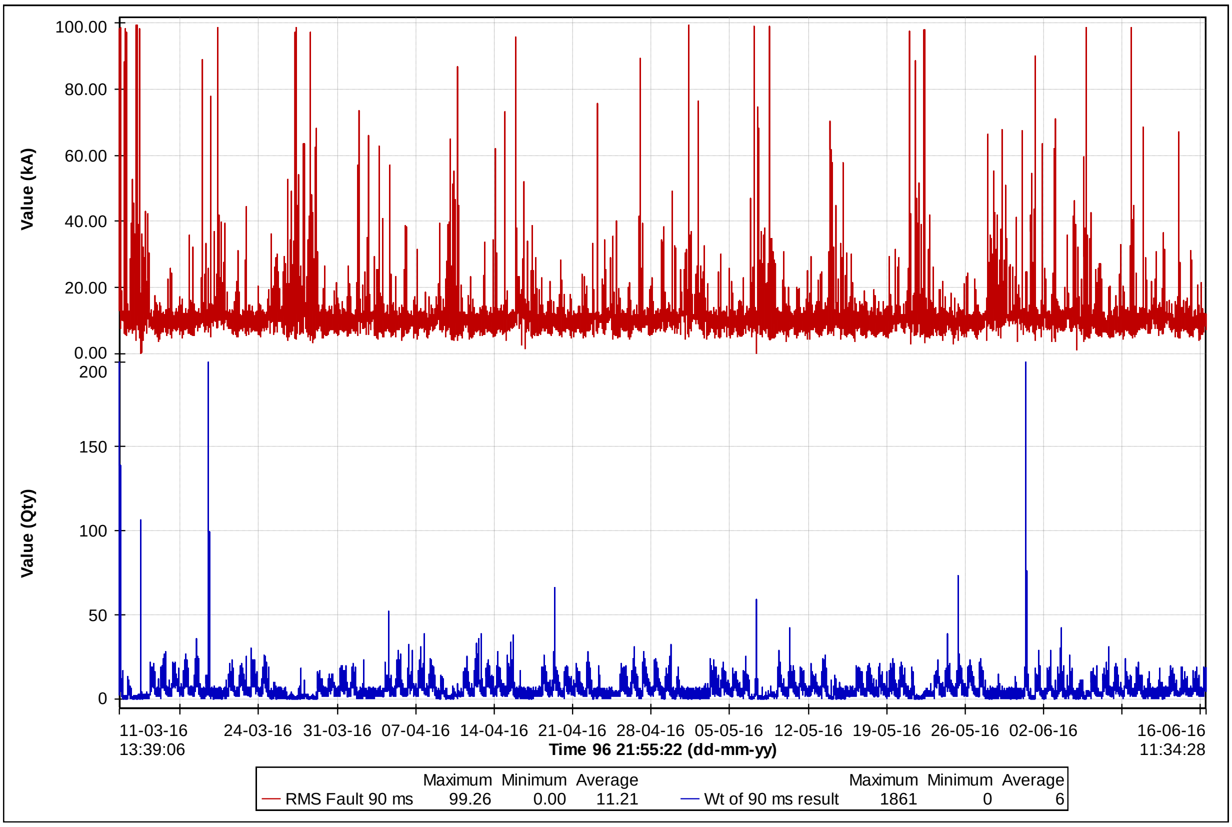


Graph 22. Downstream Peak Fault level at ½ cycle. 12 hr Time varying result shown with 3% filtering.

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. Atherton Town Centre. FLM Serial No 0889

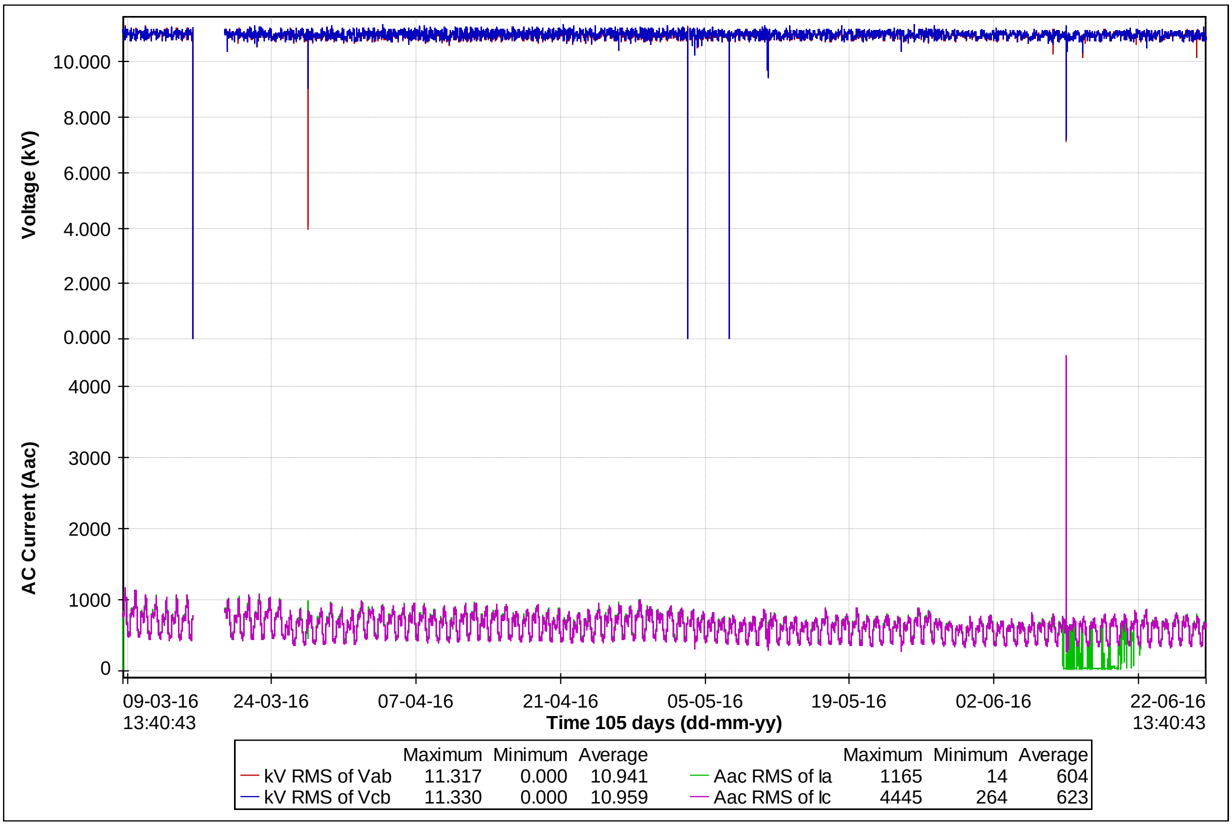
Sources of error

As discussed below, five distinct periods were identified covering (as seems likely) three different Upstream Fault Level conditions. These are shown in Graph 6 below. From the Voltage –Time graph 1 it is clear that there were events of some sort during the period, and whatever caused these may have also caused the Fault Level to be altered. Three of the five periods yielded Upstream Fault Levels within 4% of each other (~9.3kA RMS at 90ms). This might suggest that this is the normal condition for the site. The two other periods had lower Fault Levels (~5.4kA, ~7.8kA RMS at 90ms).

Disturbances were not as plentiful as for other sites, but nevertheless the result distributions, particularly for periods 4 and 5 (quite the longest) are tight and need only light filtering (except period 3).

Atherton Town Centre results, General observations.

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

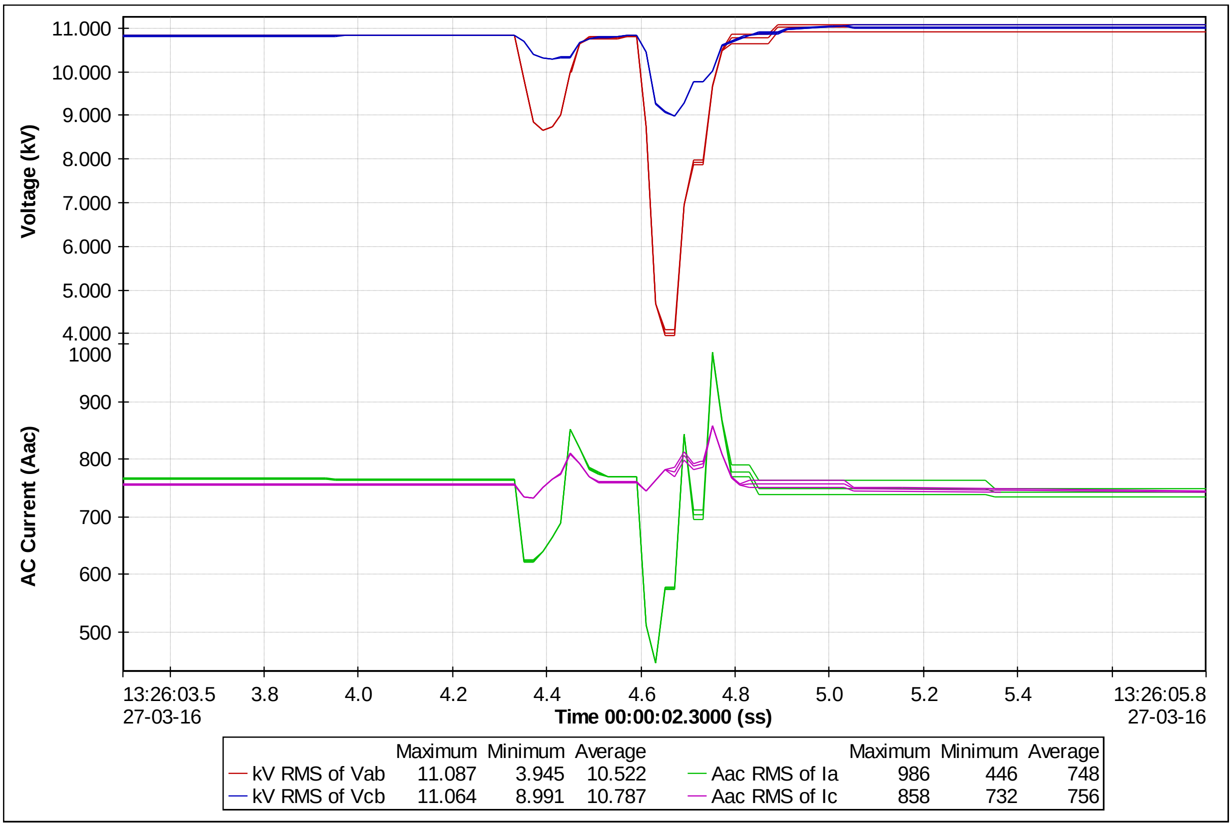


Graph 1. Volts and Current for the full recorded period.

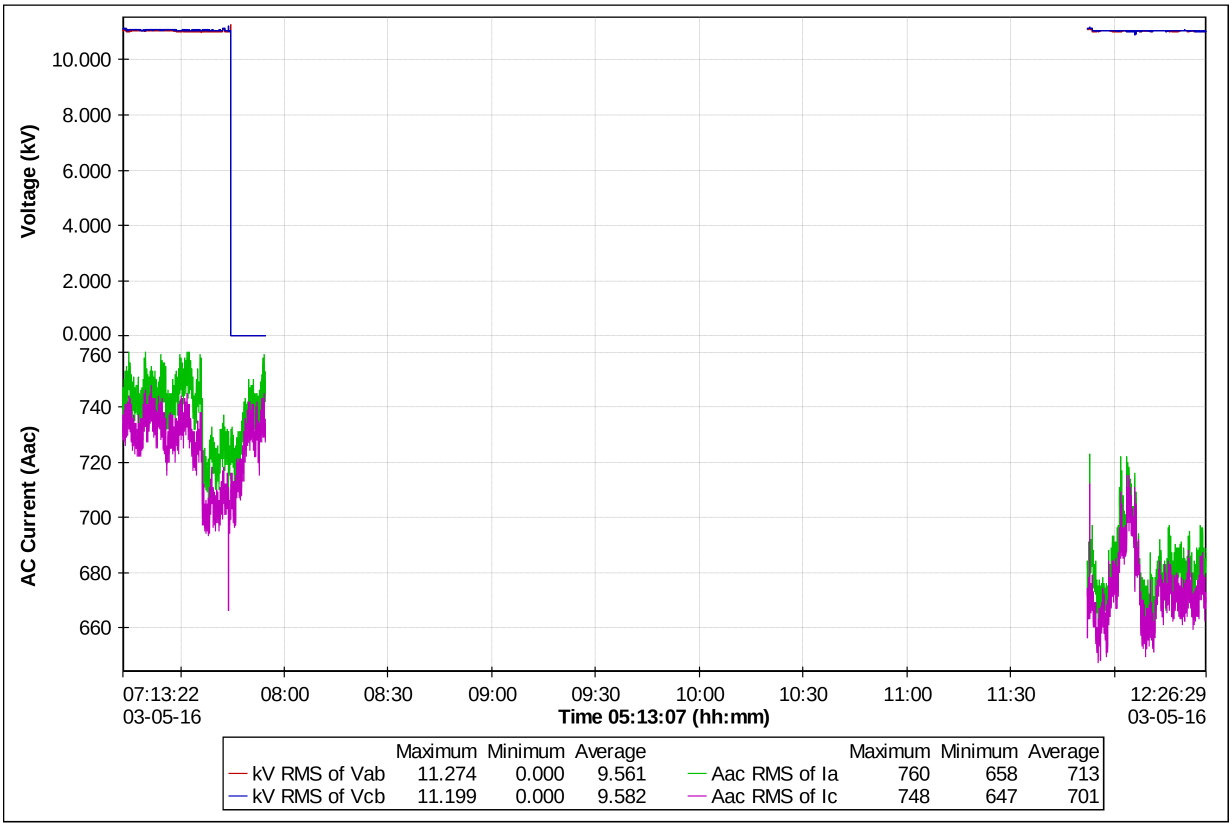
The missing recording section in March and the poor Ia connection in June are clearly shown in Graph 1. The Fault Level results described below are taken from the 11 weeks between these two periods, from 20/3/2016 to 8/6/2016.

There appear to have been several major voltage events and a few smaller ones. In addition to the outage in March, another lasting about 4 hours apparently occurred on 3rd May, but current continued to flow after the voltage (both Vab and Vcb) collapsed.

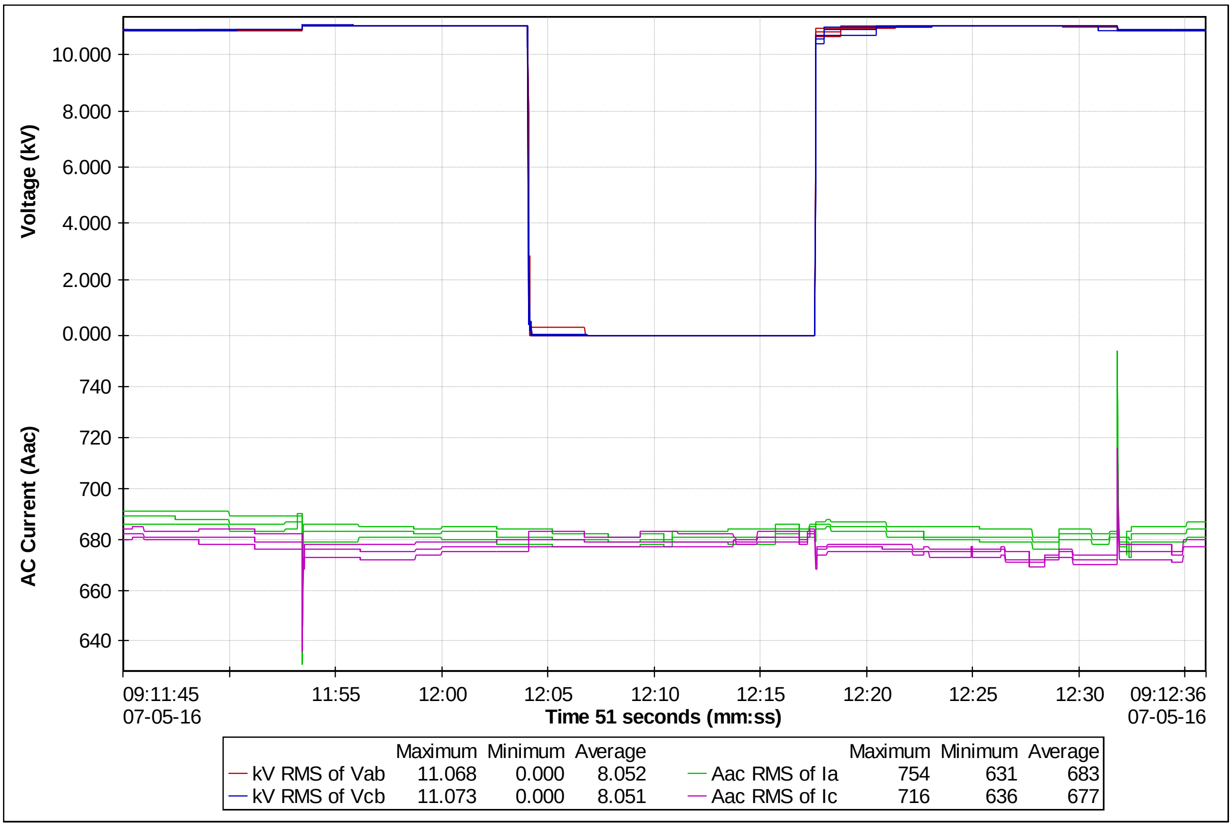
Graphs 2-5 show the RMS detail.



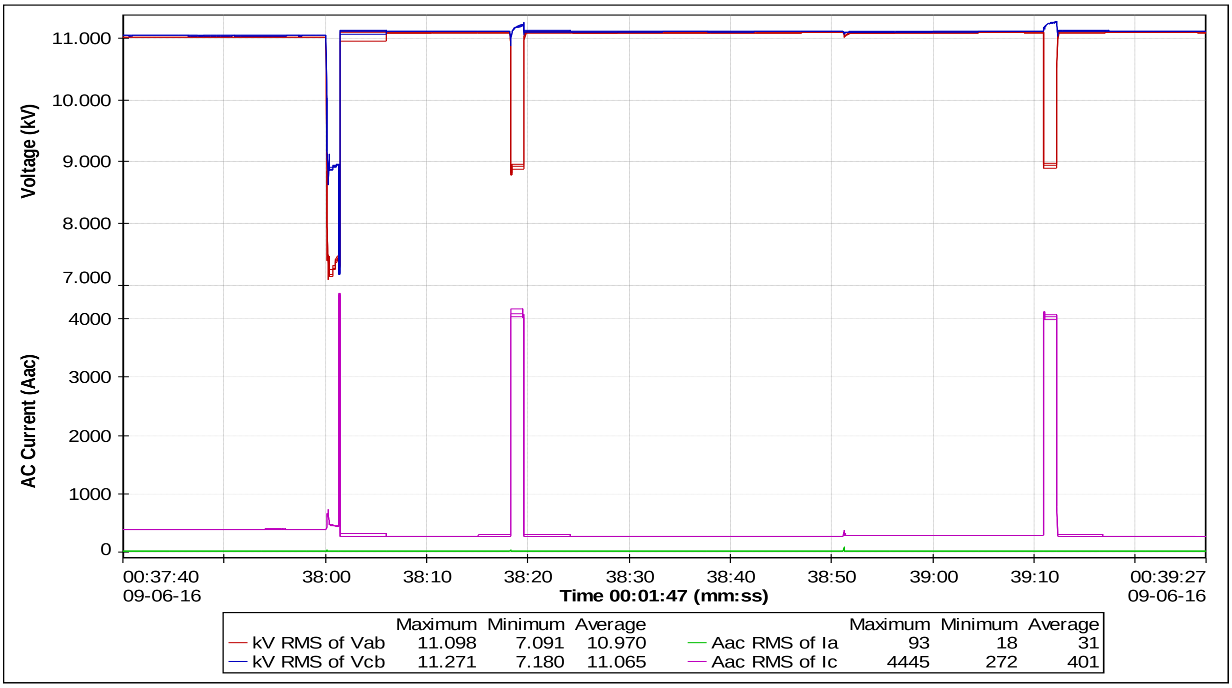
Graph 2. Upstream disturbance on 27th March.



Graph 3. Four hour outage on 3rd May.



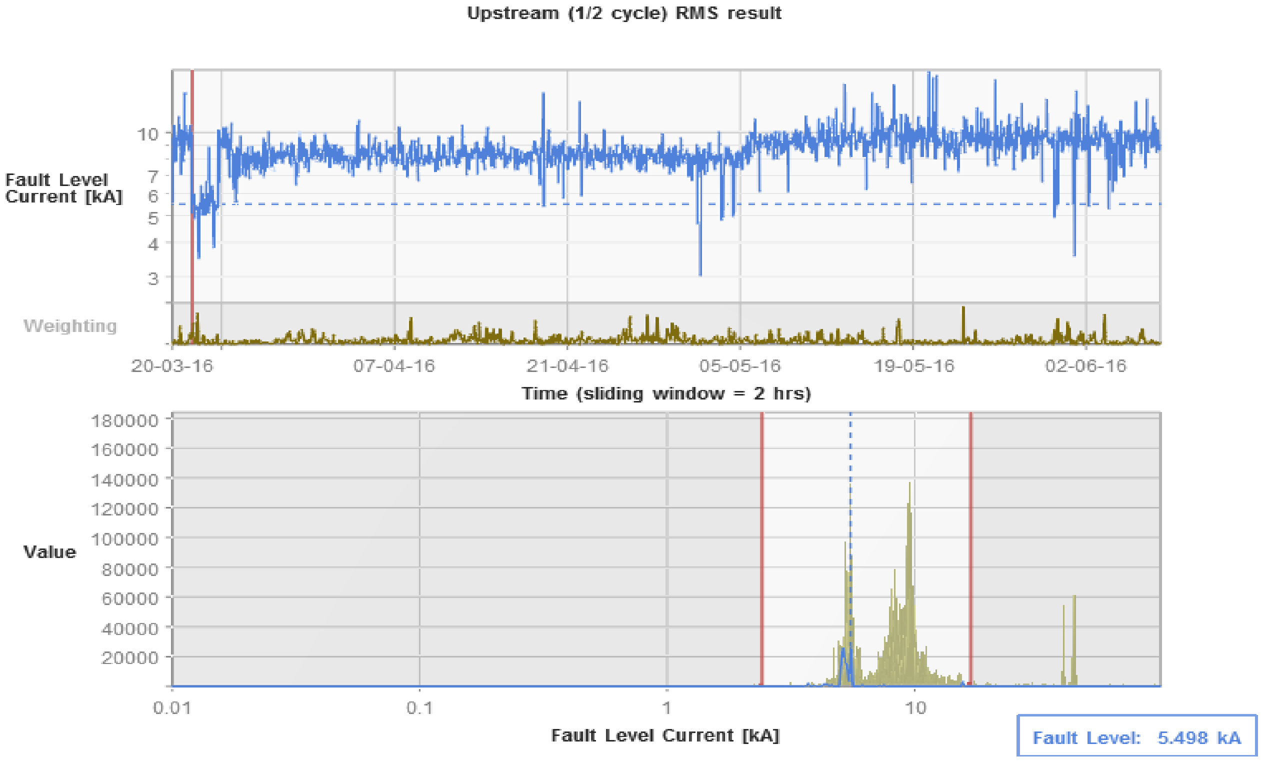
Graph 4. Interruption on 7th May. Note that although on the same day and very similar, this is not the same as the one recorded at Broadheath. The durations are 12.72 secs (Broadheath), and 13.52 secs (Atherton). The Atherton one occurs approximately 35 minutes before Broadheath.



Graph 5. Downstream disturbances on 9th June.

Fault Level Results

Fault Level appears to have changed significantly during the course of the recording. To try to see when changes occurred, Graph 6 below shows the upstream 90ms RMS Fault Level in the period from 20th March to 8th June, using a 2 hour sliding box car and filtering of 2%. The discrete periods have been listed in the table below Graph 6.



Graph 6. RMS Fault Level at ½ cycle, 2 hour sliding box-car with no filtering.

Beginning	End	10ms Peak Upstream	10ms Peak Downstream	90ms RMS upstream	Combined 10ms Peak
20th Mar 0:00	21st Mar 14:00	23.35	2.416	9.531	25.77
21st Mar 14:00	23rd Mar 17:00	12.85	2.416	5.401	15.27
23rd Mar 17:00	24th Mar 17:00	23.25	2.416	9.537	25.67
24th Mar 17:00	5th May 4:30	18.9	2.416	7.816	21.32
5th May 4:30	8th June 0:00	22.38	2.416	9.317	24.80

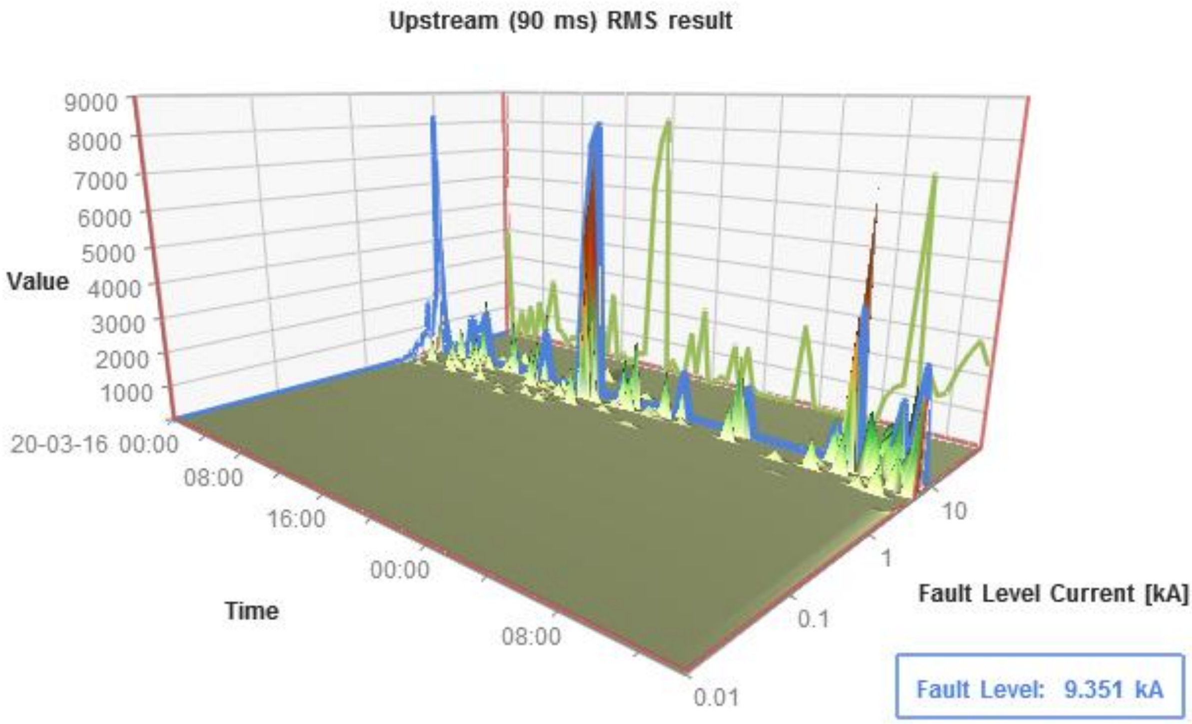
The precise moments when Fault Level changed can be determined more closely from the following graphs. The early transitions appear to have been quite abrupt. The transition around 5th May is more gradual.

Graphs 7 to 16 show Upstream RMS at 90ms and Peak Fault Level at ½ cycle for each of the five periods identified. The downstream result appears common to the whole interval, and is shown in Graph 17.

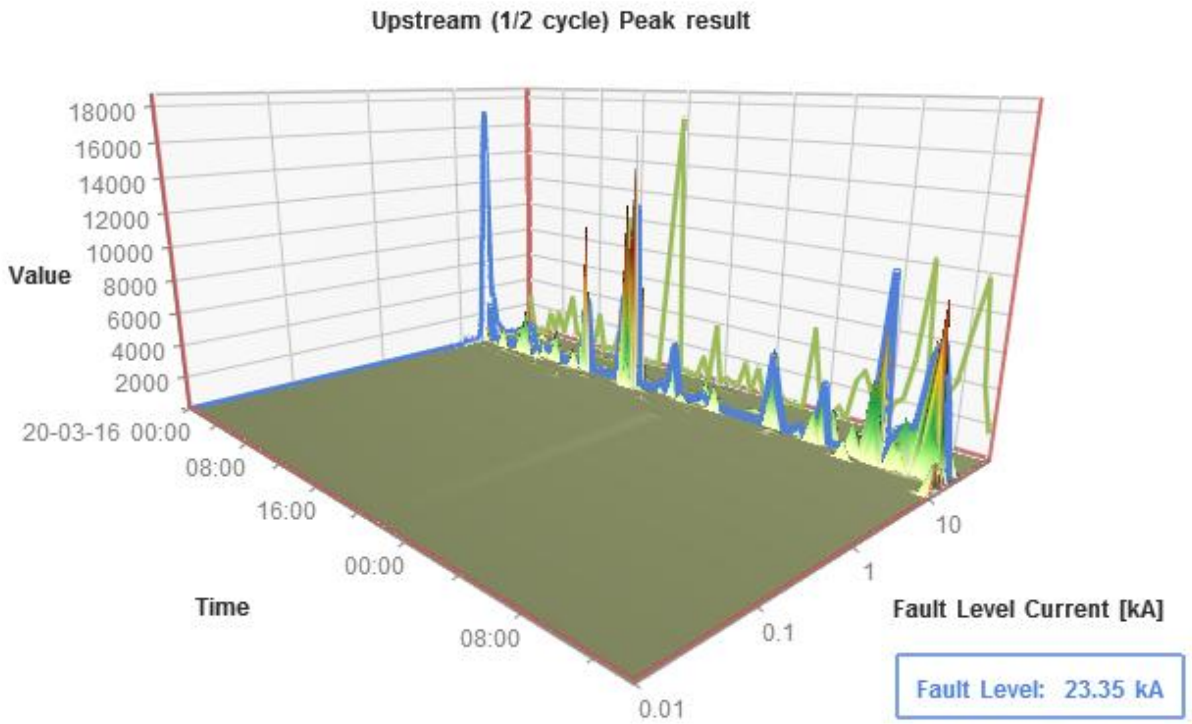
Period 1.

20th Mar 0:00	21st Mar 14:00

Graphs 7 and 8 show the RMS and Peak results respectively for this 38 hour period.



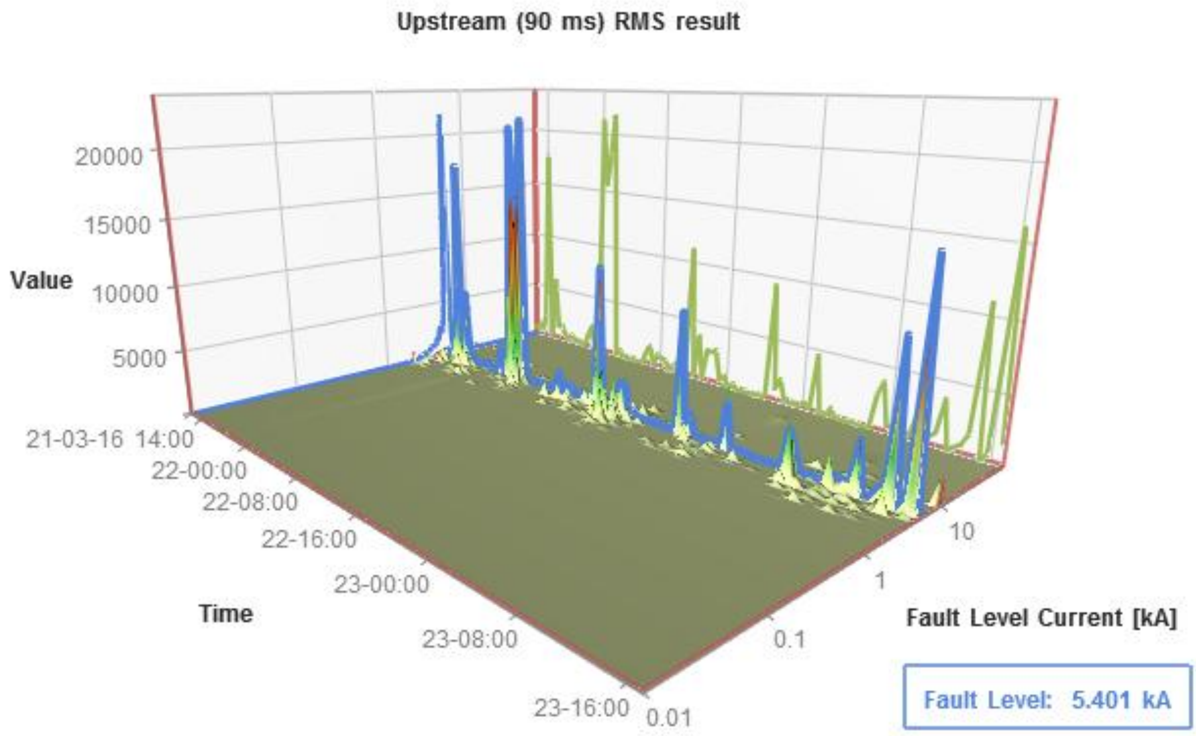
Graph 7. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.



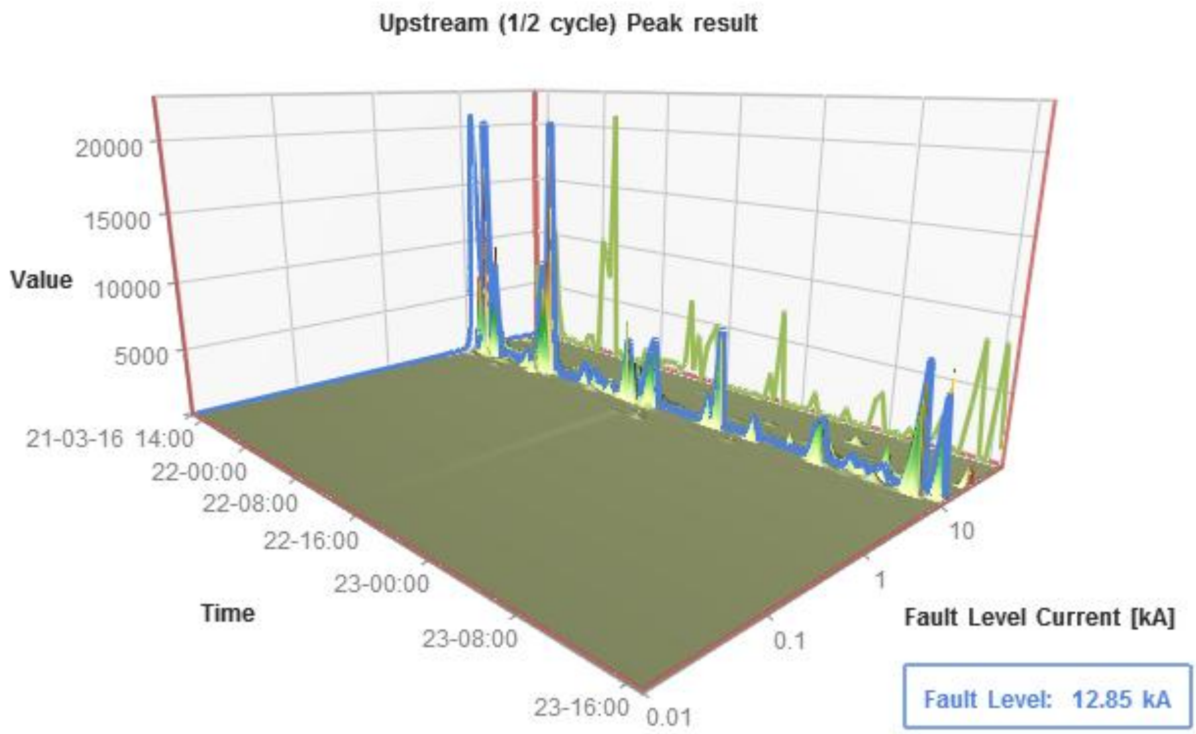
Graph 8. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 2% filtering.

Period 2.

21st Mar 14:00	23rd Mar 17:00



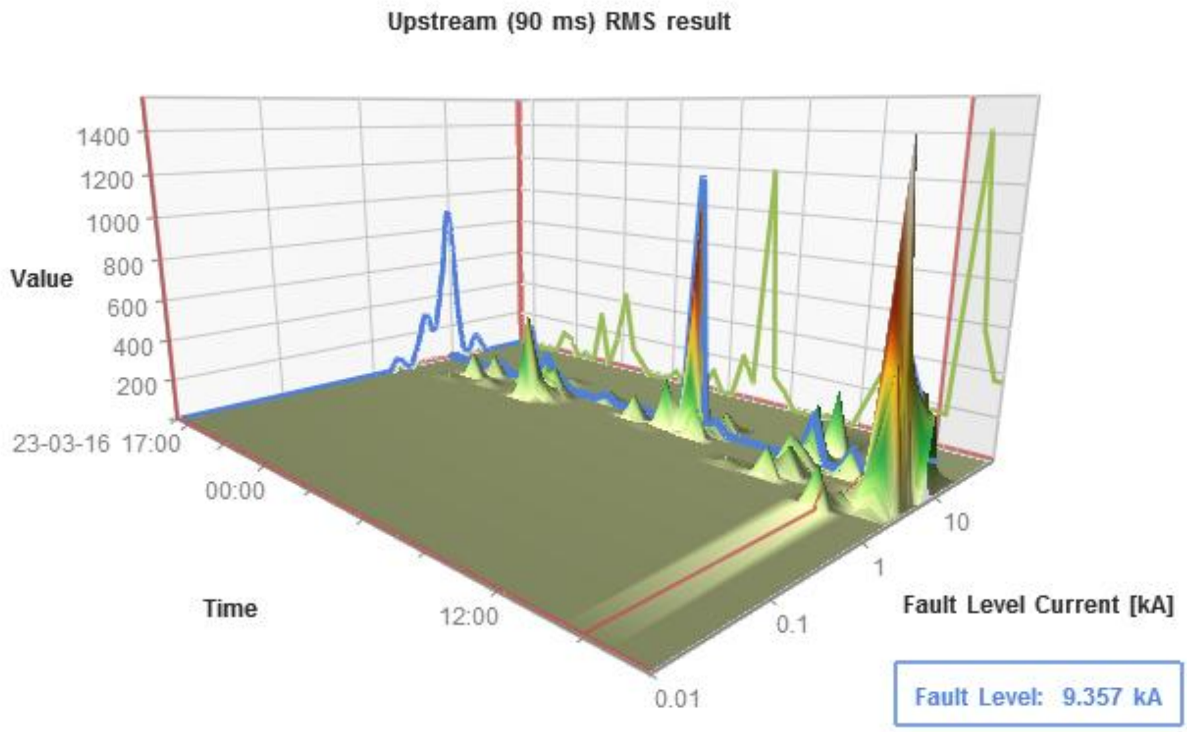
Graph 9. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.



Graph 10. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 3% filtering.

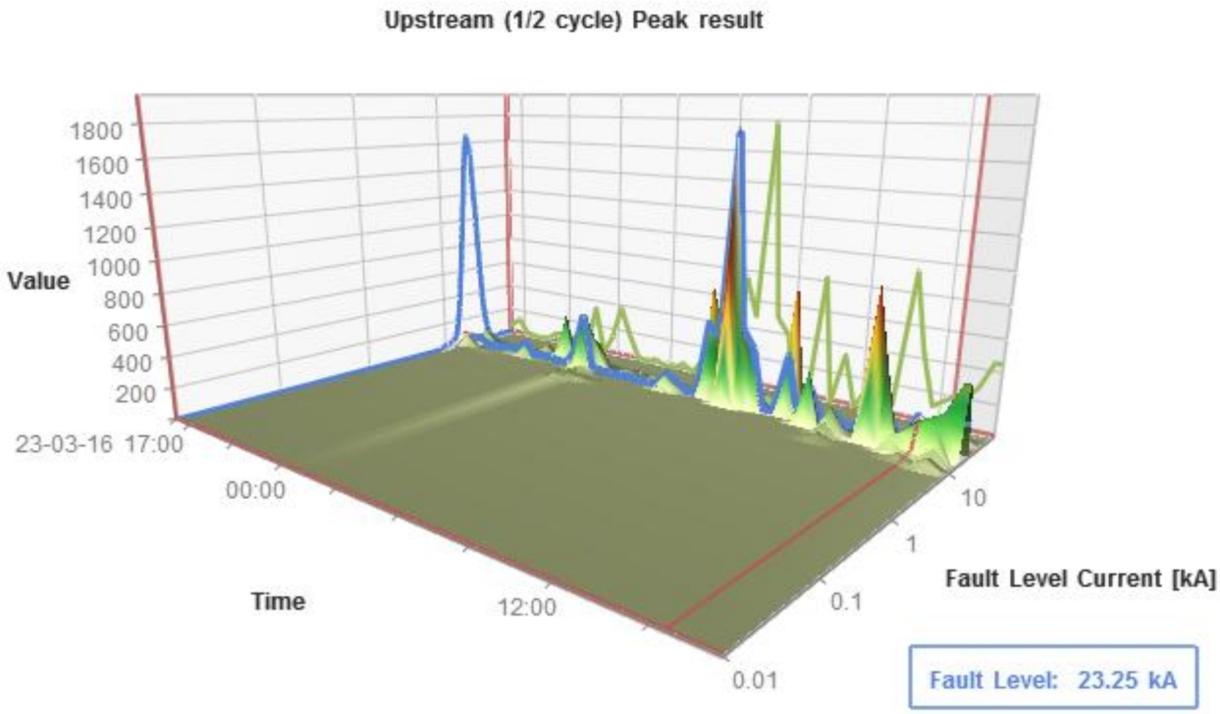
Period 3.

23rd Mar 17:00	24th Mar 17:00



Graph 11. Upstream RMS Fault level at 90ms. 3D Distribution shown with 7% filtering.

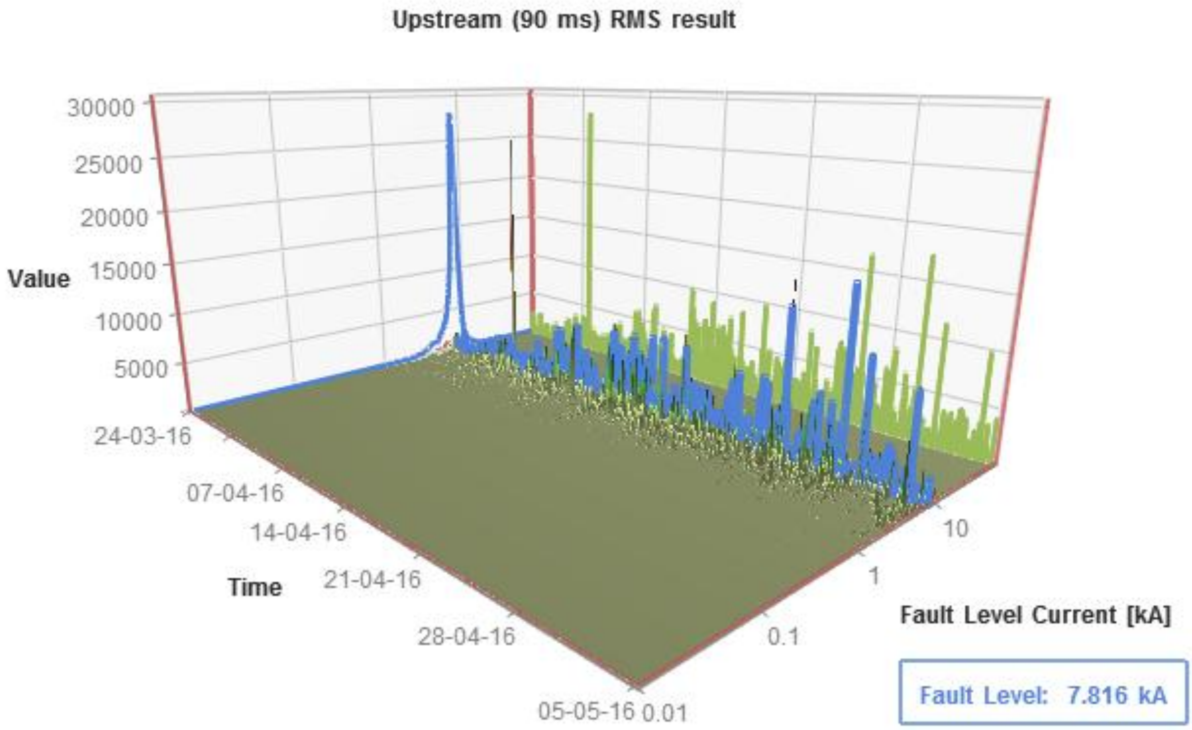
Graph 11 above shows that the ending transition was probably a little earlier than 17:00. There was not a great deal of disturbance energy during this relatively short 24 hour period and heavy filtering is required, but from this, the ½ cycle RMS and Peak results, the approximate result is reasonably unequivocal, and very similar to the first period.



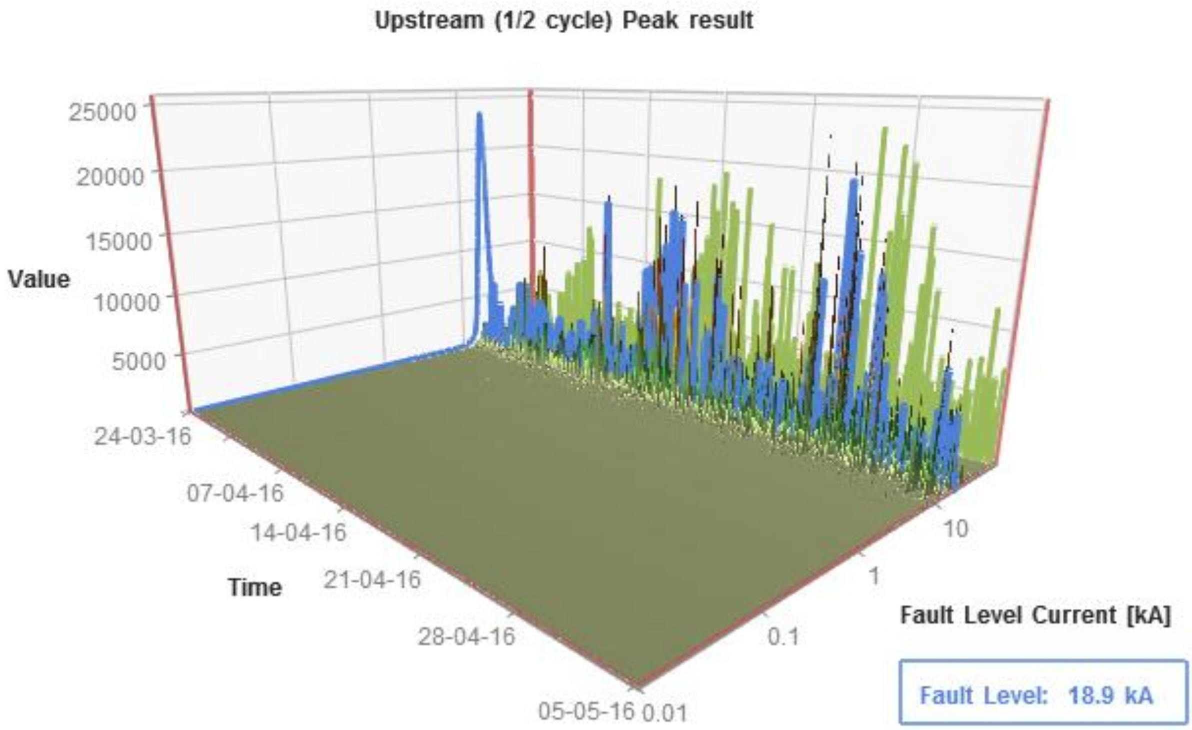
Graph 12. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 7% filtering.

Period 4.

24th Mar 17:00	5th May 4:30



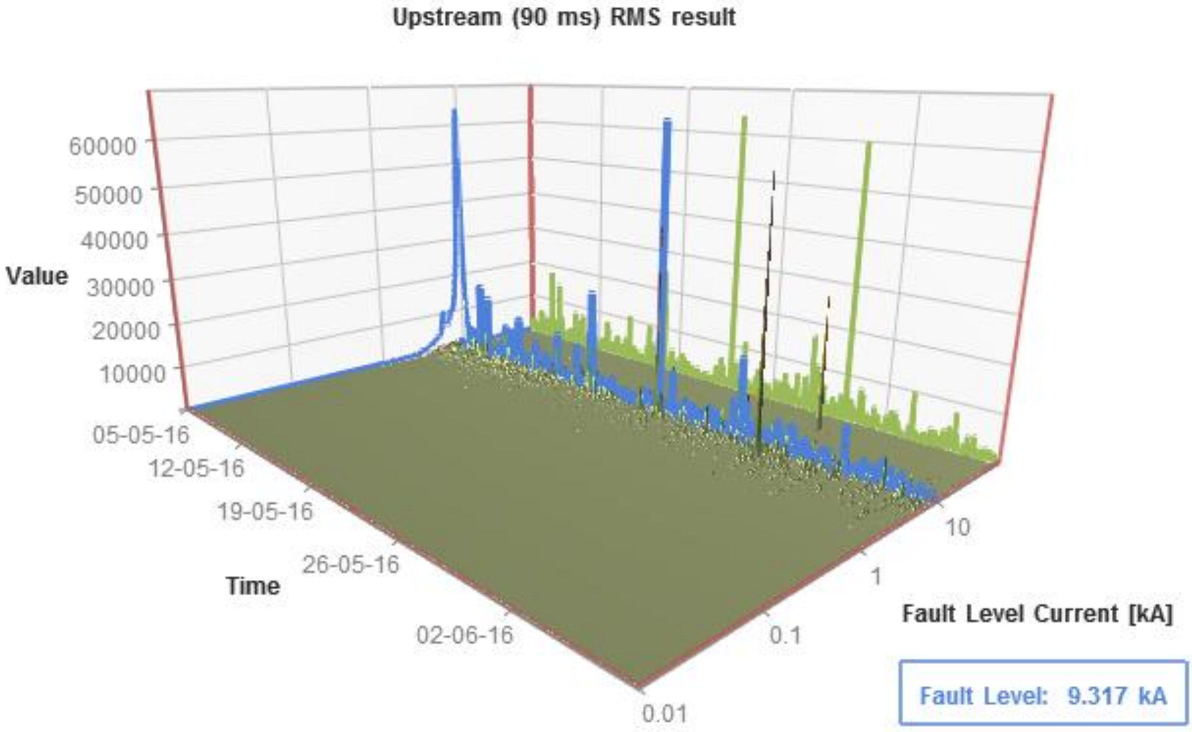
Graph 13. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.



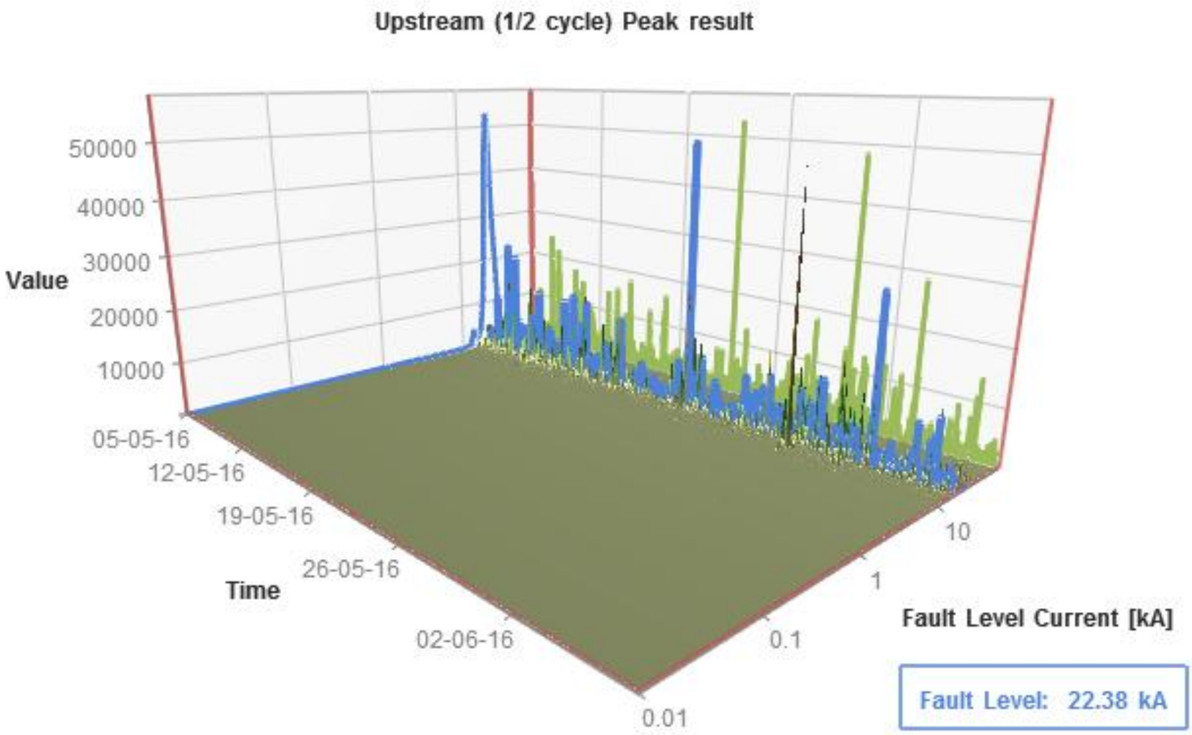
Graph 14. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 2% filtering.

Period 5.

5th May 4:30	8th June 0:00



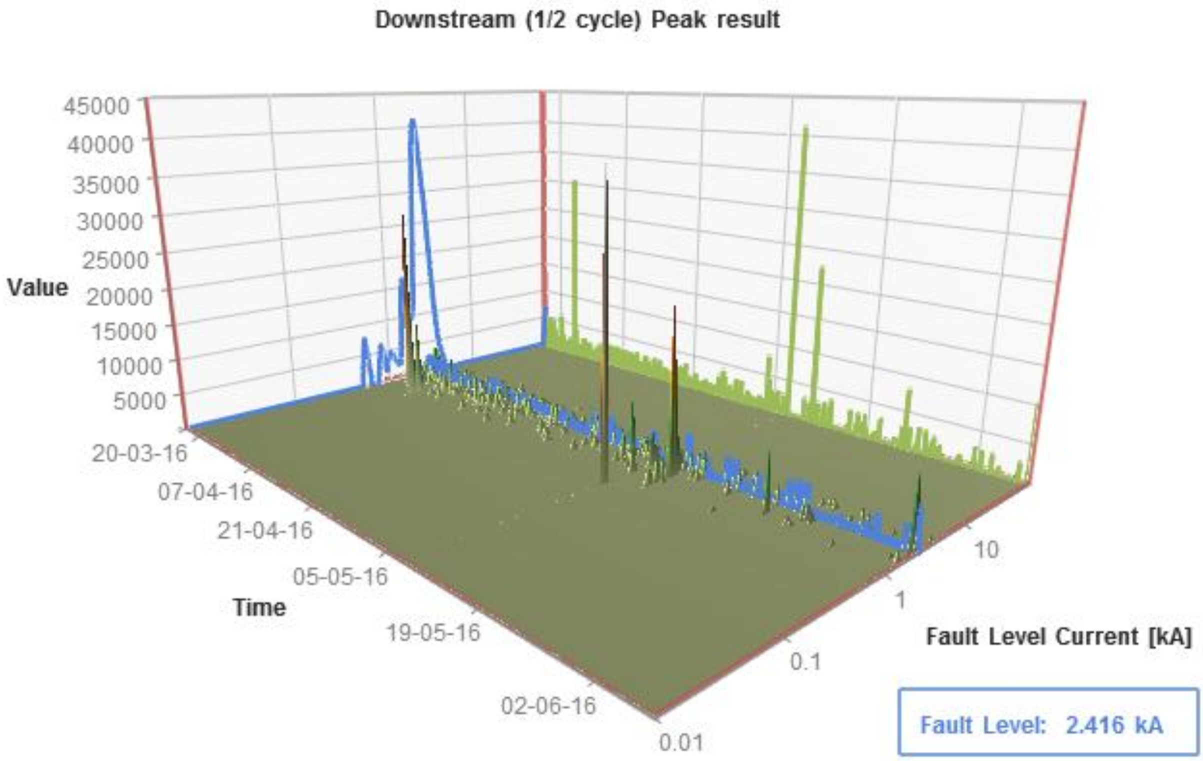
Graph 15. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.



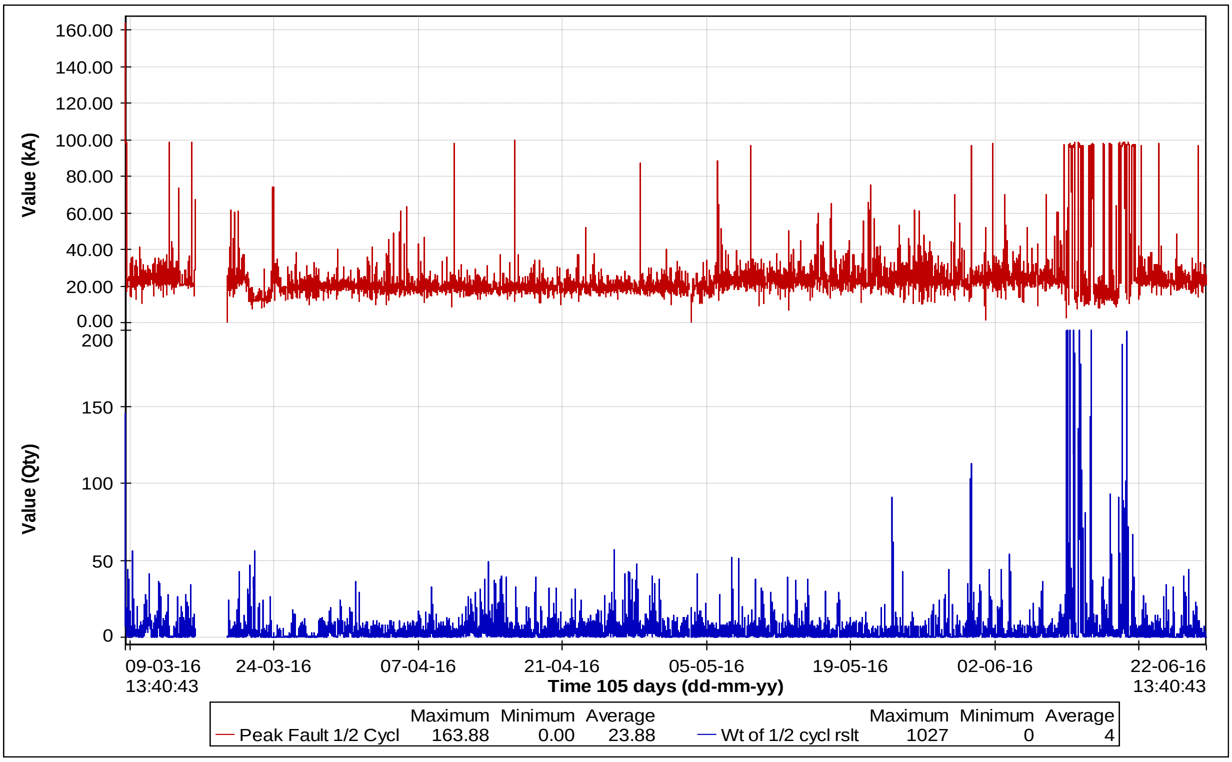
Graph 16. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 2% filtering.

Downstream Fault Level contribution.

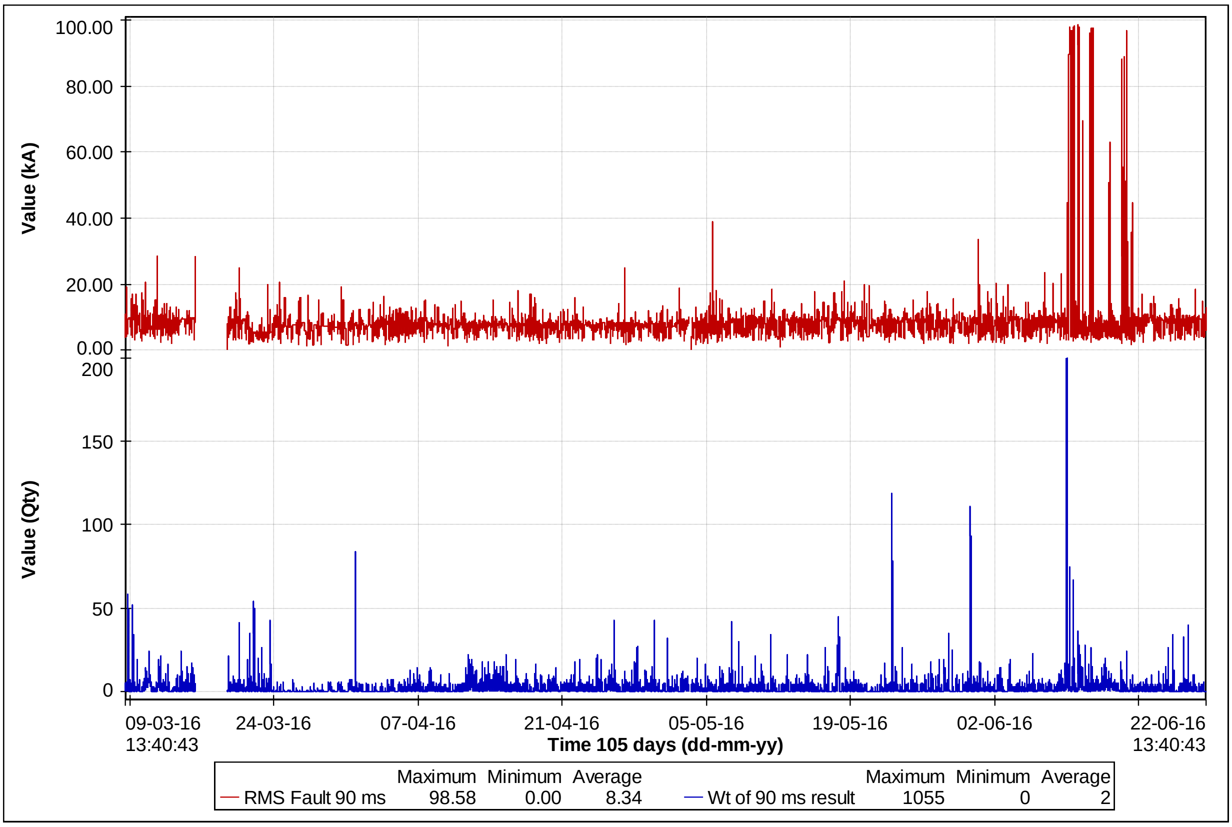
The Downstream contribution does not appear to vary with the periods defined above. Graph 17 shows the result for the full 11+ week period with 3% filtering.



Graph 17. Downstream Peak Fault level at ½ cycle. 3D Distribution shown with 3% filtering.



Graph 18. Peak upstream results and weighting present at ½ cycle.



Graph 19. RMS upstream results and weighting present at 90ms.

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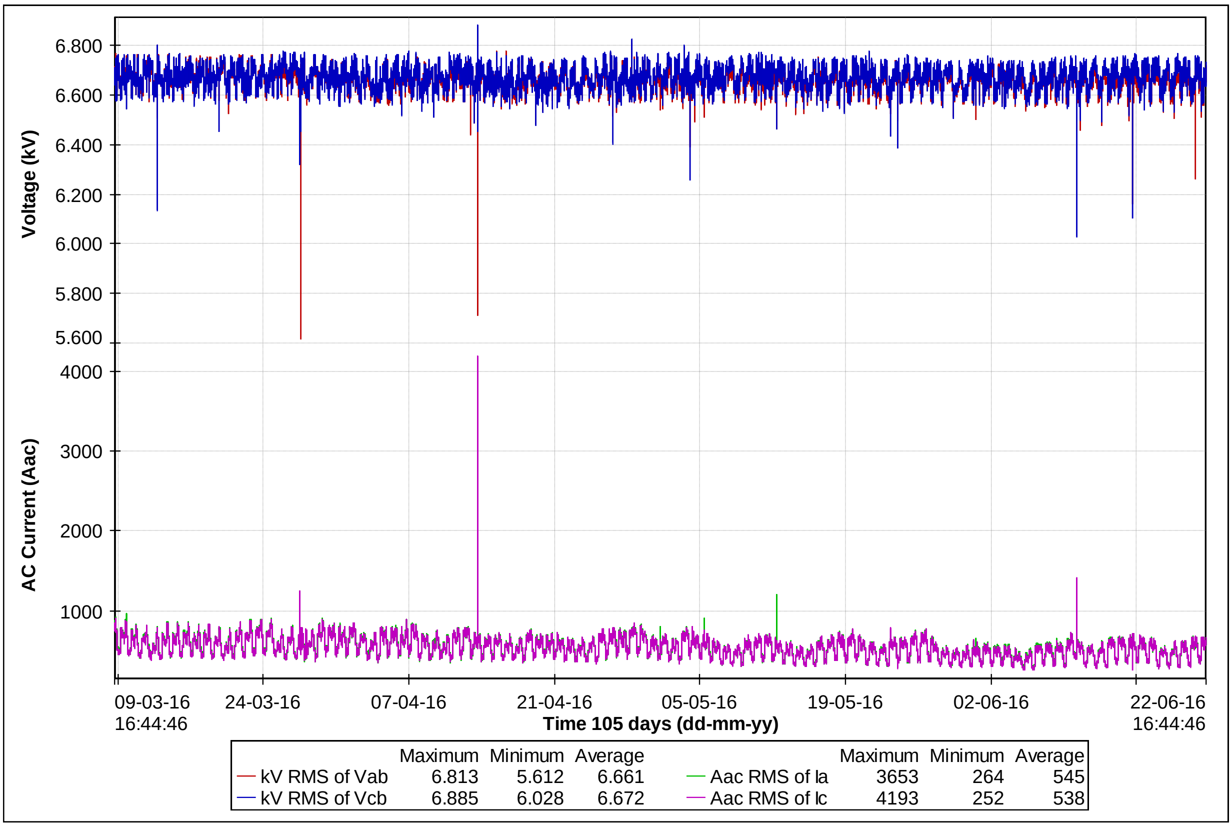
Appendix 4. Longridge. FLM Serial No 0890

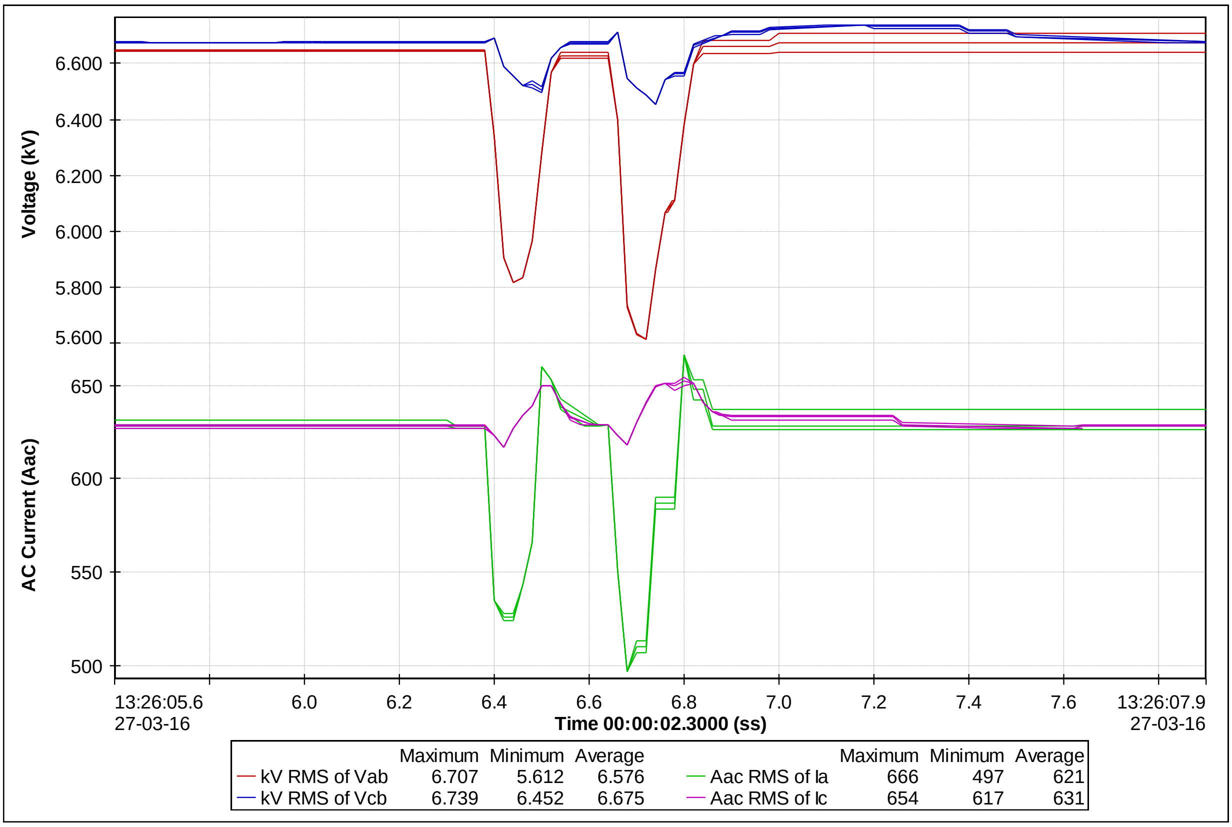
Longridge results, General observations
Graph 1 shows the voltage and current for (almost) the full recording period.

Though there is a good degree of current variation, it is generally occurring over several cycles rather than being abrupt. Consequently the typical weighting attached to each disturbance is small. Nevertheless, the result distribution populations for the Upstream Fault Level results are unambiguous.

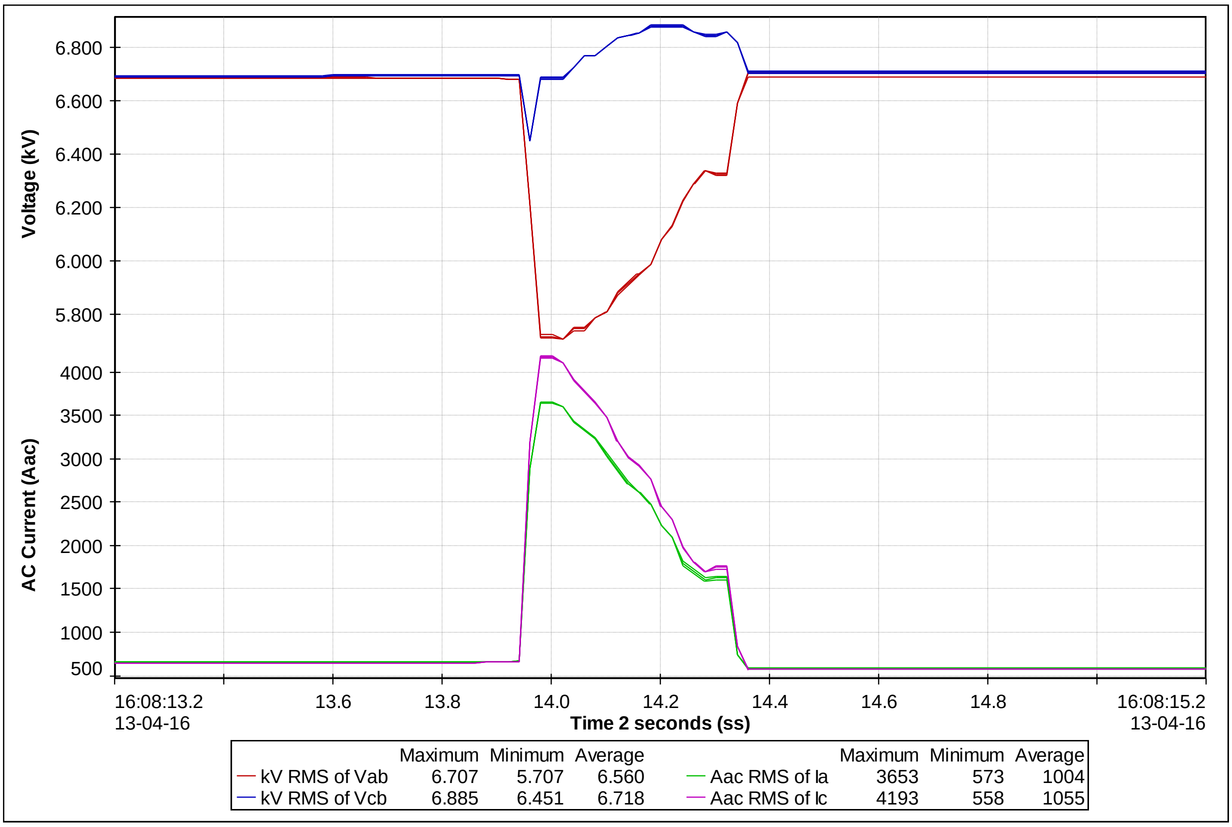


Graph 1. Volts and Current for the full recorded period.

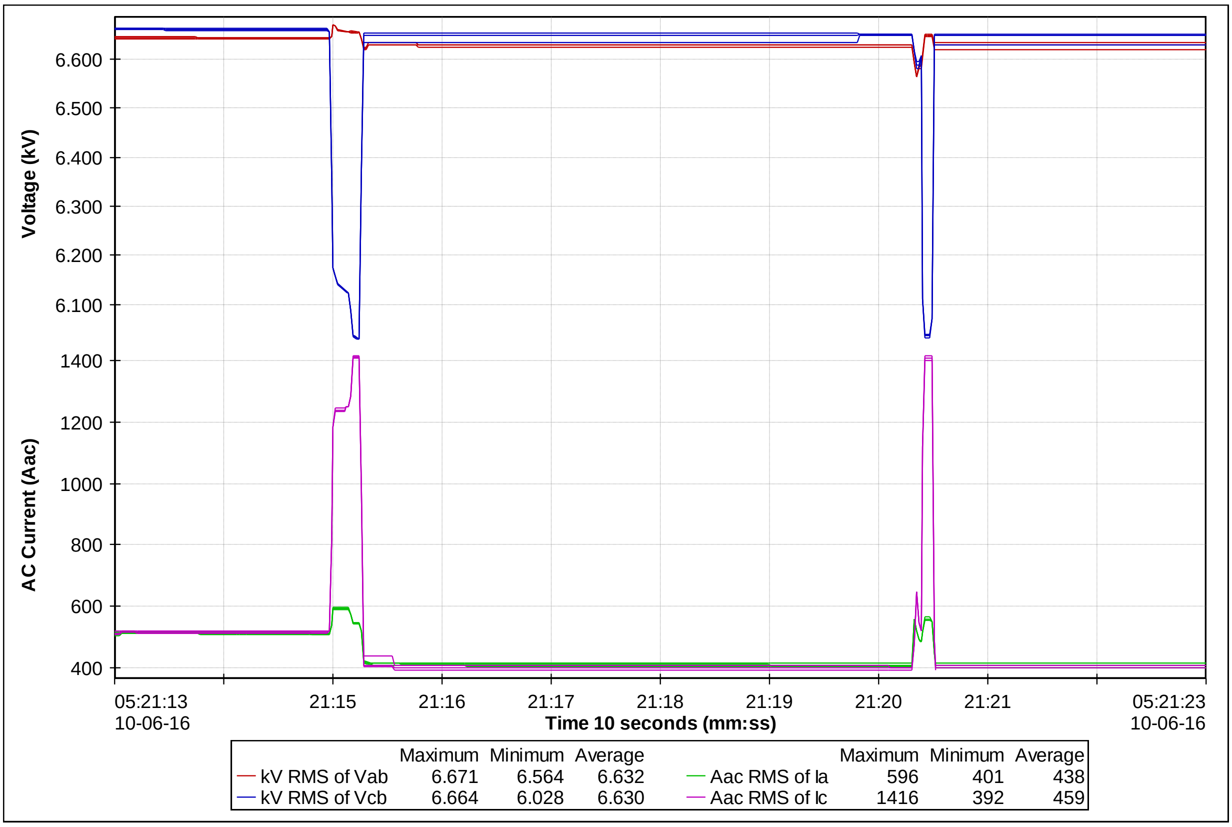
There are some disturbances, which are expanded in the Graphs 2-4 below.



Graph 2. Disturbance on 27th March. Also seen at other sites (offers a good opportunity to check time synchronisation between units).



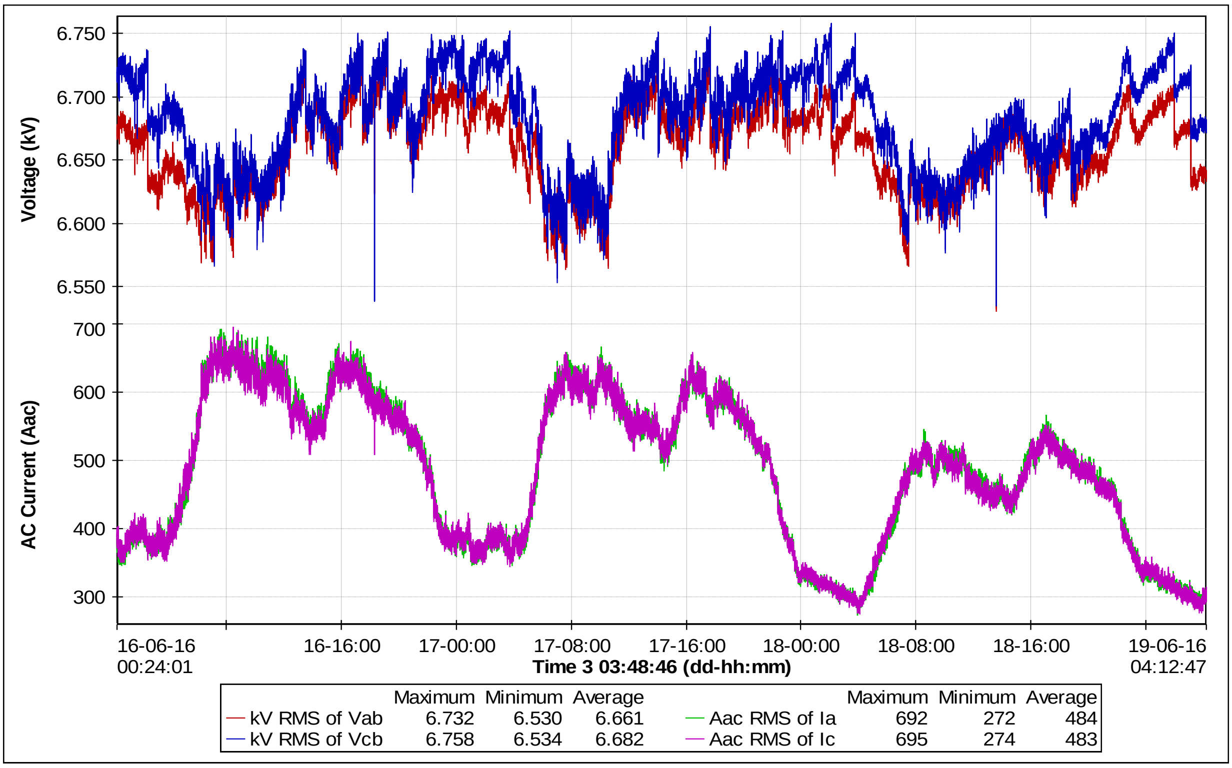
Graph 3. Disturbance on 13th April.



Graph 4. Disturbances on 10th June

Useful Fault Level type disturbances.

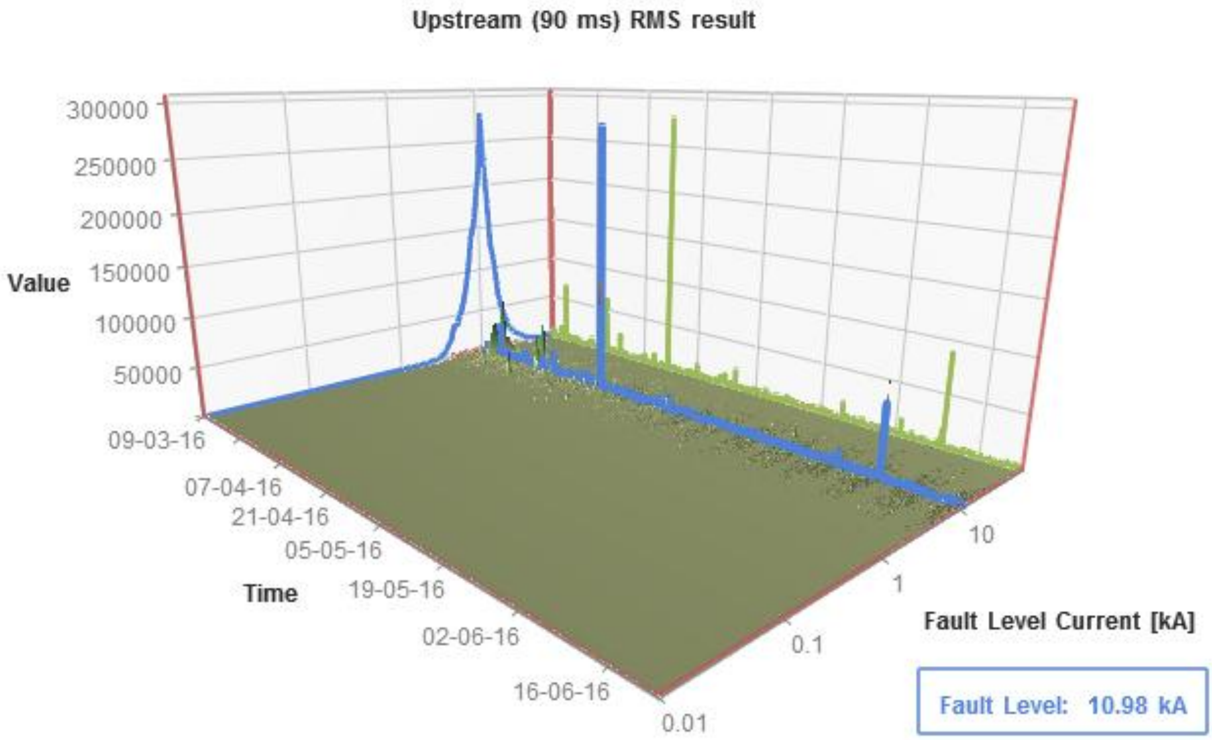
Apart from a few large current disturbances, there doesn't appear to be very much in the way of abrupt current changes. Graph 5 shows a typical 3 day section of the recording.



Graph 5. Typical 3 day section of voltage and current.

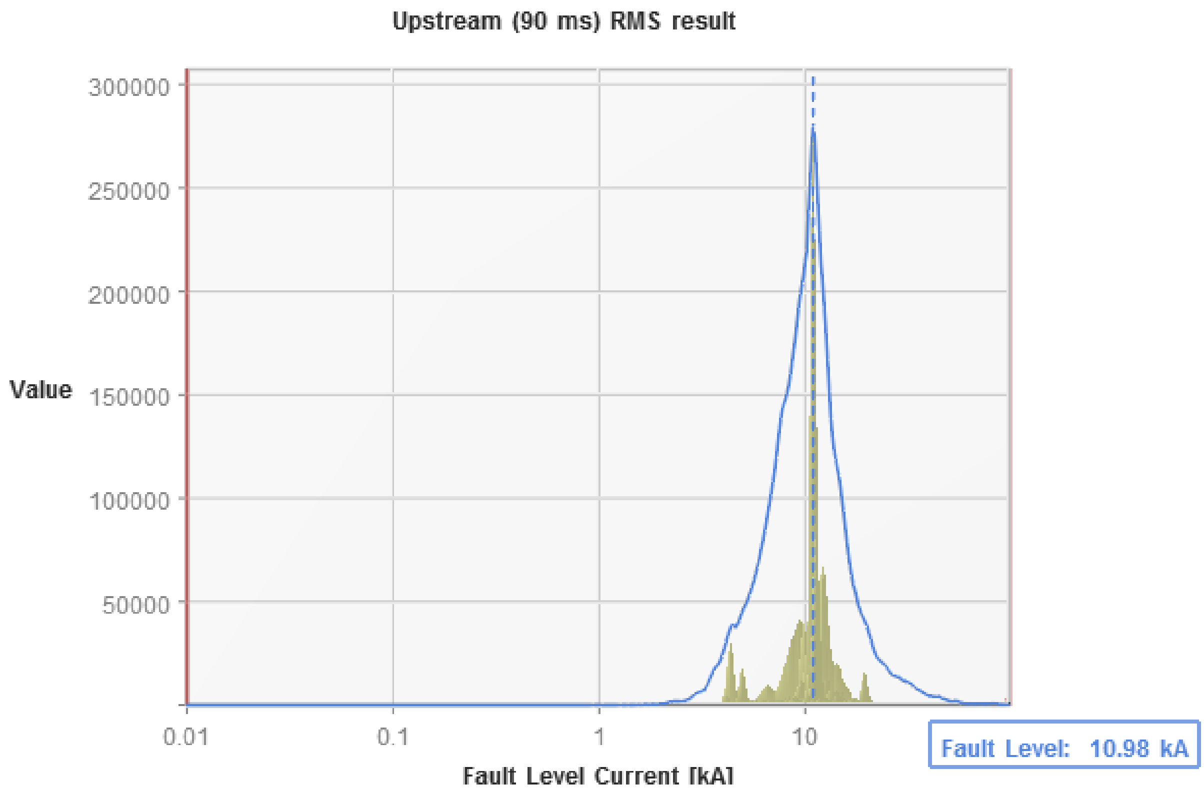
Such current variations as have occurred here are generally gentle and of limited use (for disturbance evaluation purposes).

Fault Level Results

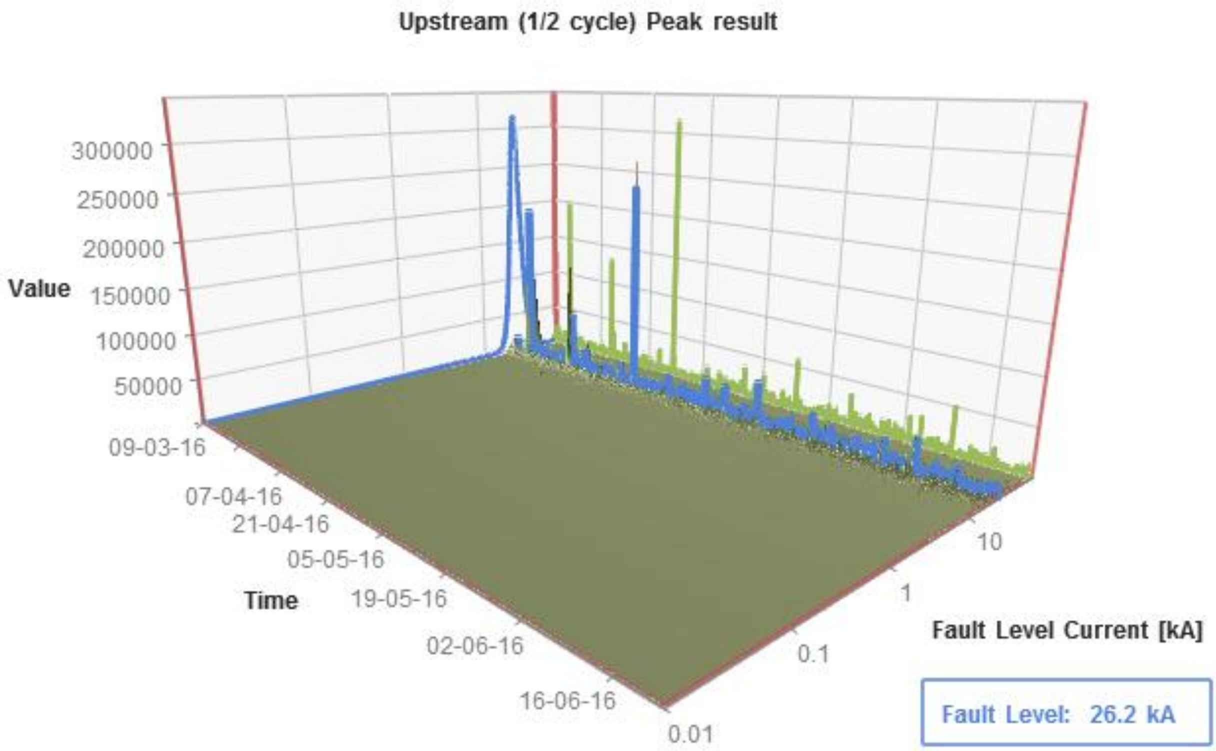


Graph 6. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.

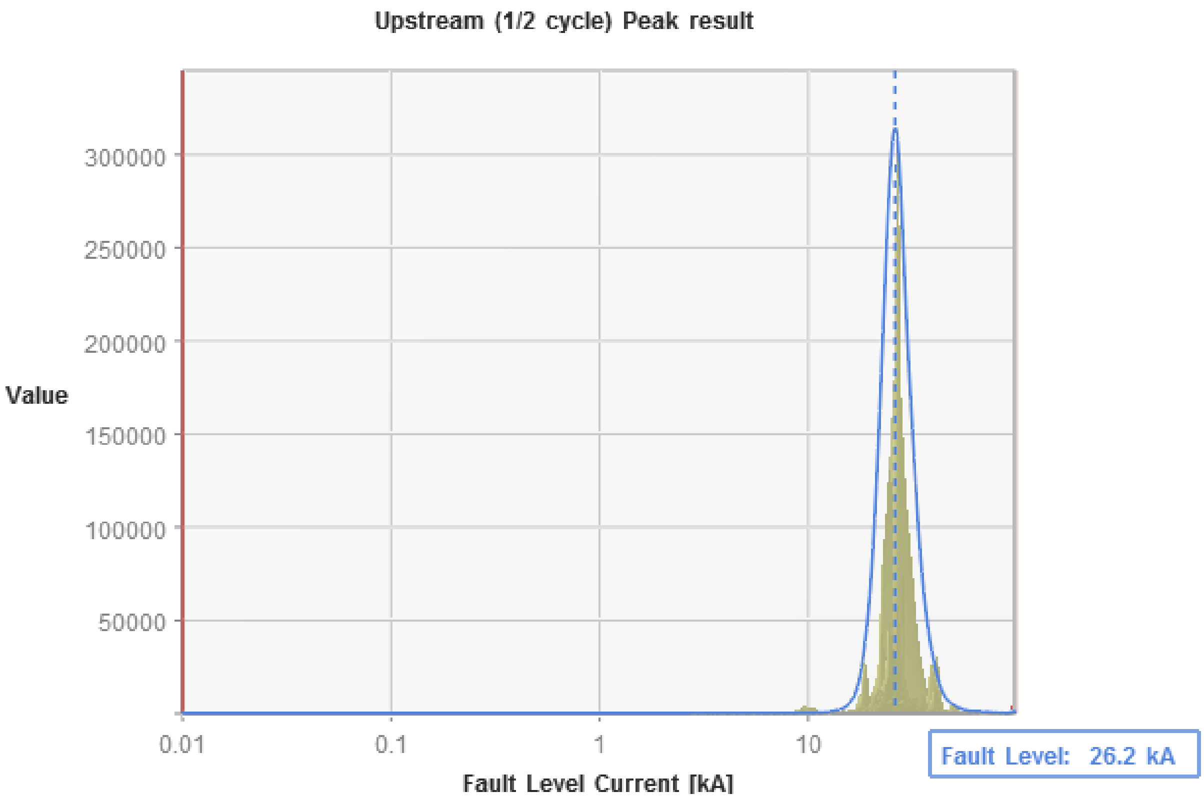
The overall result for Upstream 90ms RMS Fault Level (Graph 6) is heavily driven by the local disturbance on 13th April, but this one result is in line with the rest of the recording. The Fault Level was 10.98kA for the period. Graph 7 shows the same thing in 2 dimensions.



Graph 7. Upstream RMS Fault level at 90ms. 2D Distribution shown with 2% filtering.



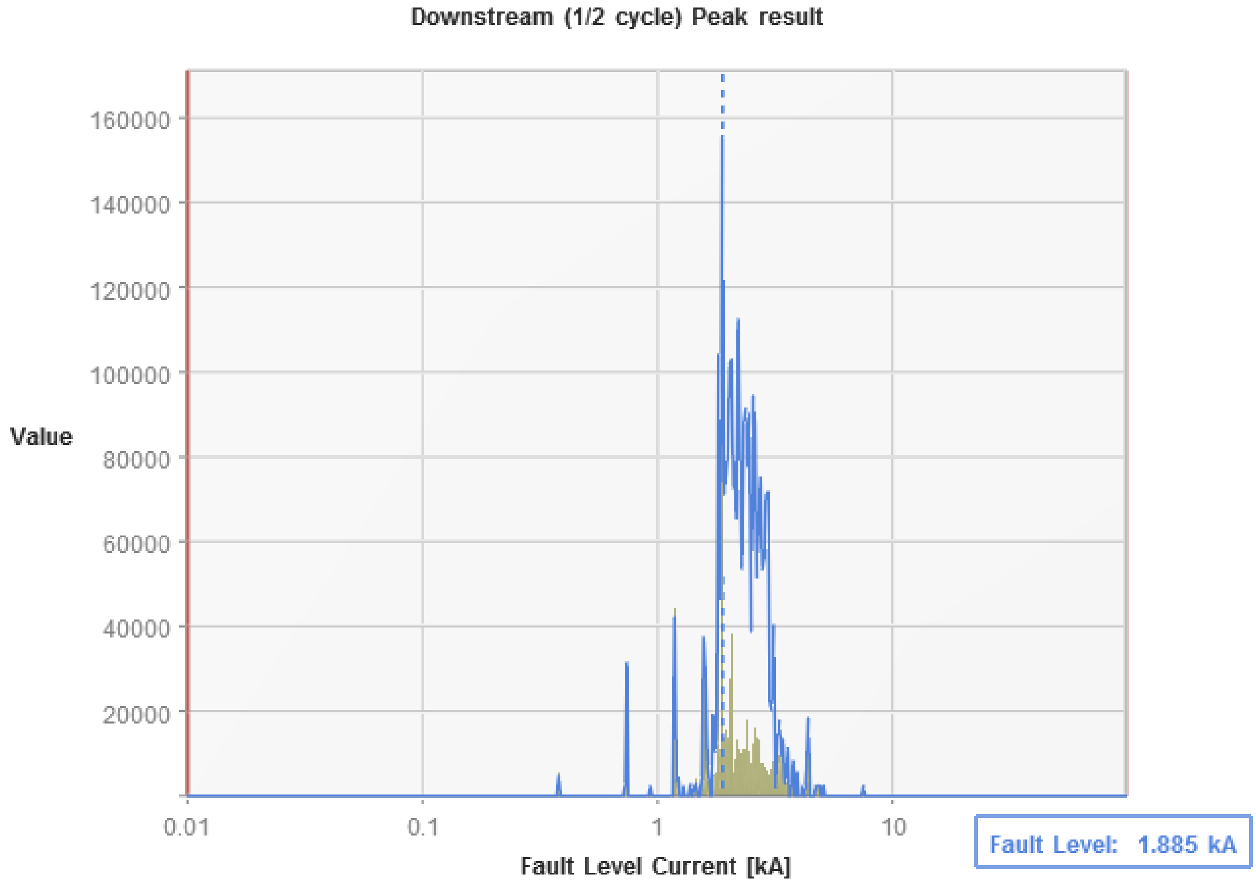
Graph 8. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 2% filtering.



Graph 9. Upstream Peak Fault level at ½ cycle. 2D Distribution shown with 2% filtering.

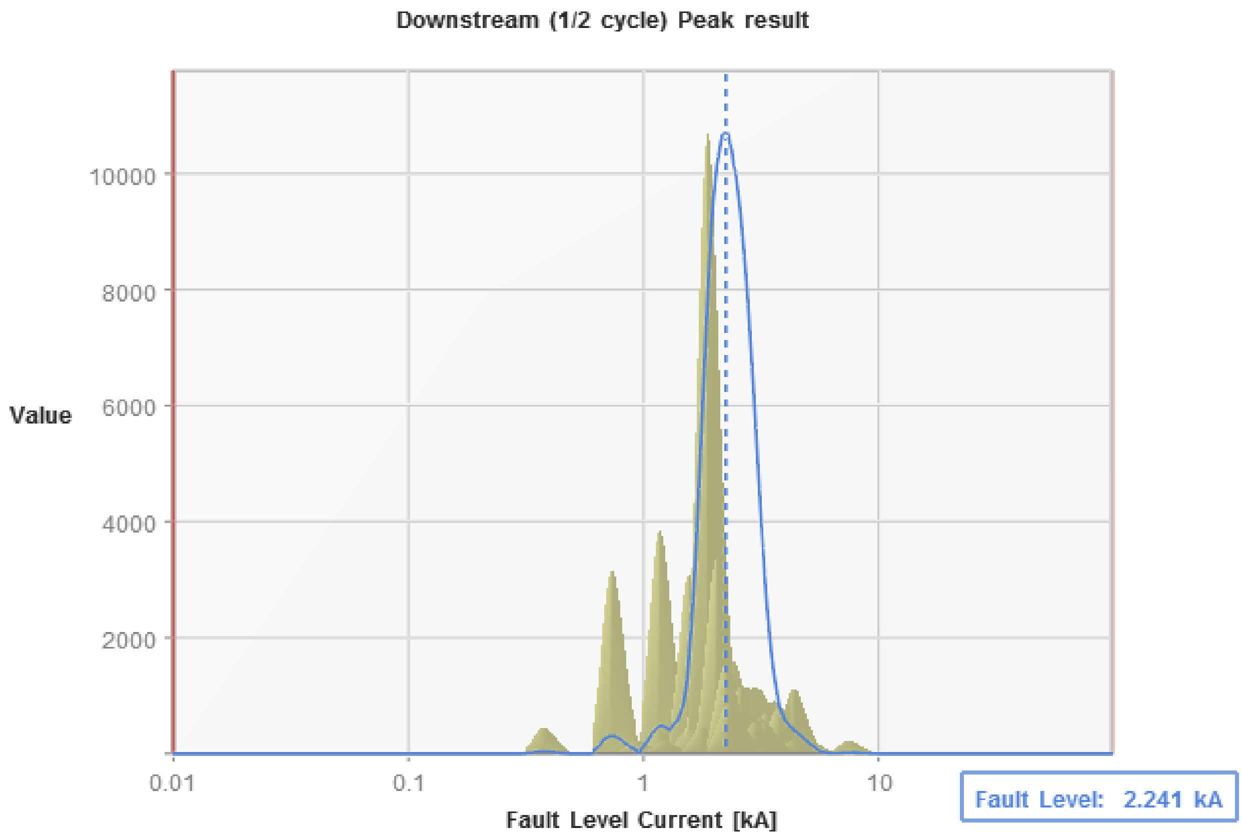
Downstream ½ cycle Peak Fault Level contribution.

Graph 10 below shows the ½ cycle Peak Fault Level contribution. With no filtering this is quite a broad distribution, which may be properly representative of peak downstream contribution seen.



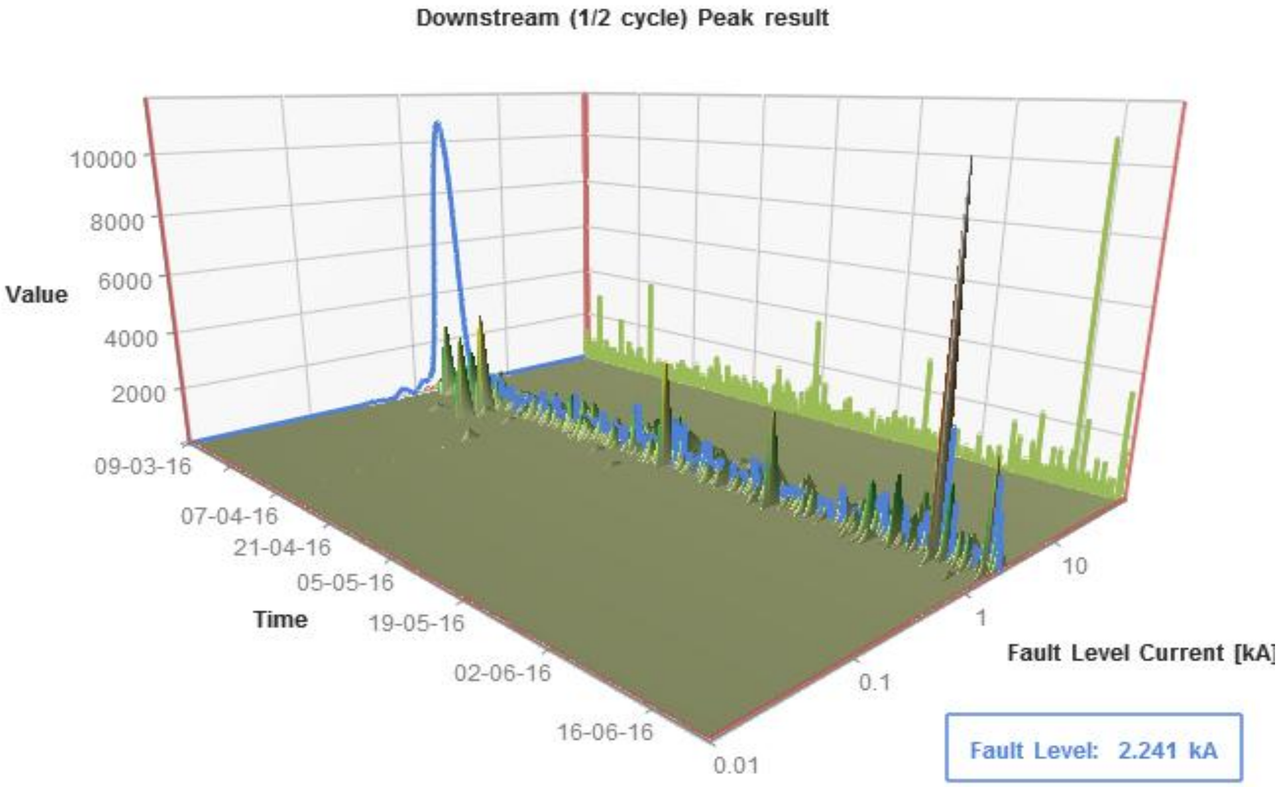
Graph 10. Downstream Peak Fault level at ½ cycle. 2D Distribution shown with no filtering.

To get a representative value for this, 6% filtering is required. Graph 11 below shows the result.



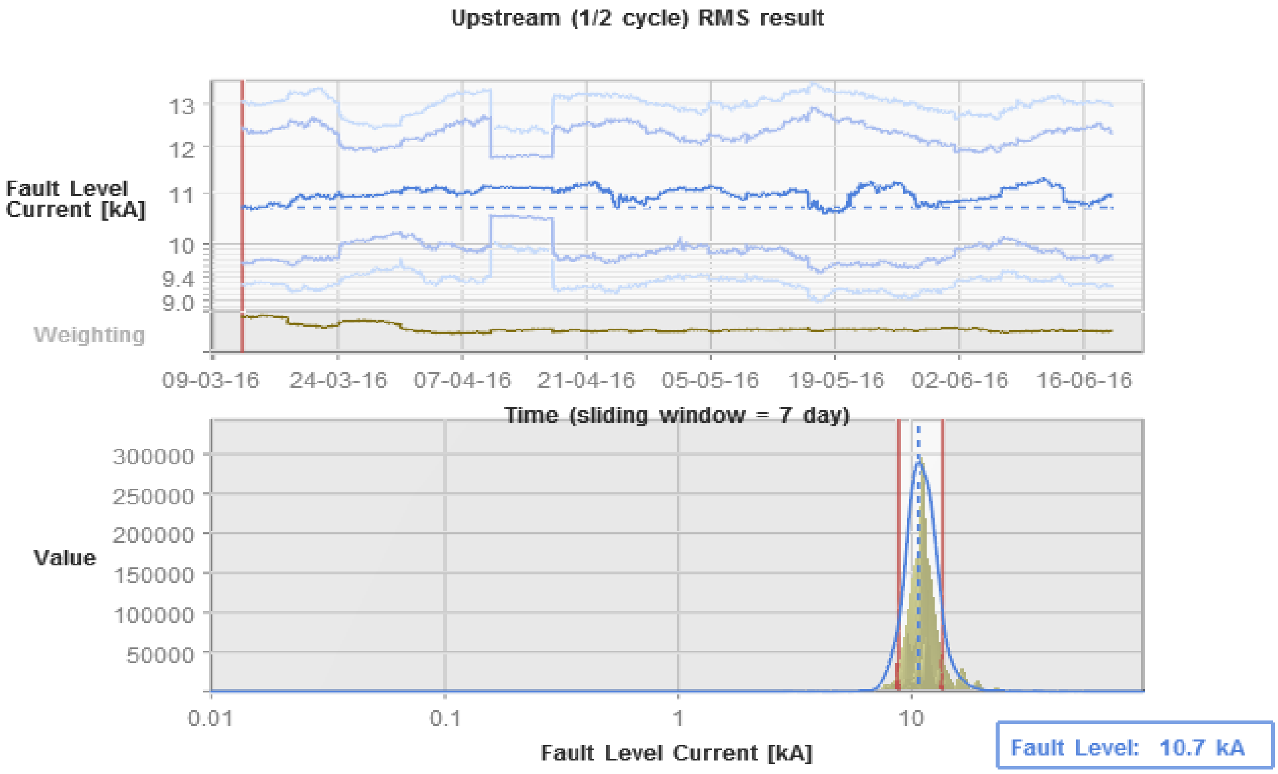
Graph 11 Downstream Peak Fault level at ½ cycle. 2D Distribution shown with 6% filtering.

As shown in the 3D representation in Graph 12 below, this level of filtering sweeps up most of the energy so the 2.24kA Fault Level contribution figure is not unreasonable.



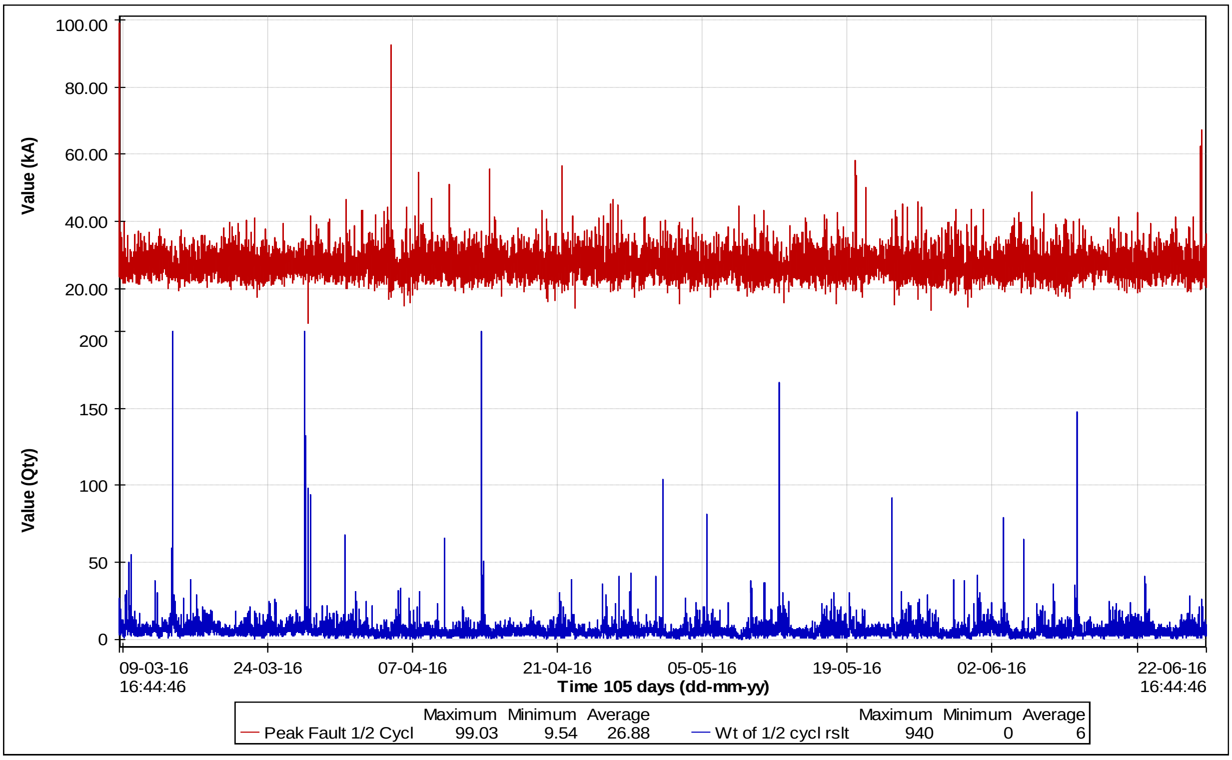
Graph 12 Downstream Peak Fault level at ½ cycle. 3D Distribution shown with 6% filtering.

A review of the upstream ½ cycle RMS result shows that Fault Level appears to remain relatively unchanged throughout the recording. Graph 13 below shows application of a 7 day sliding box-car with 2% filtering.

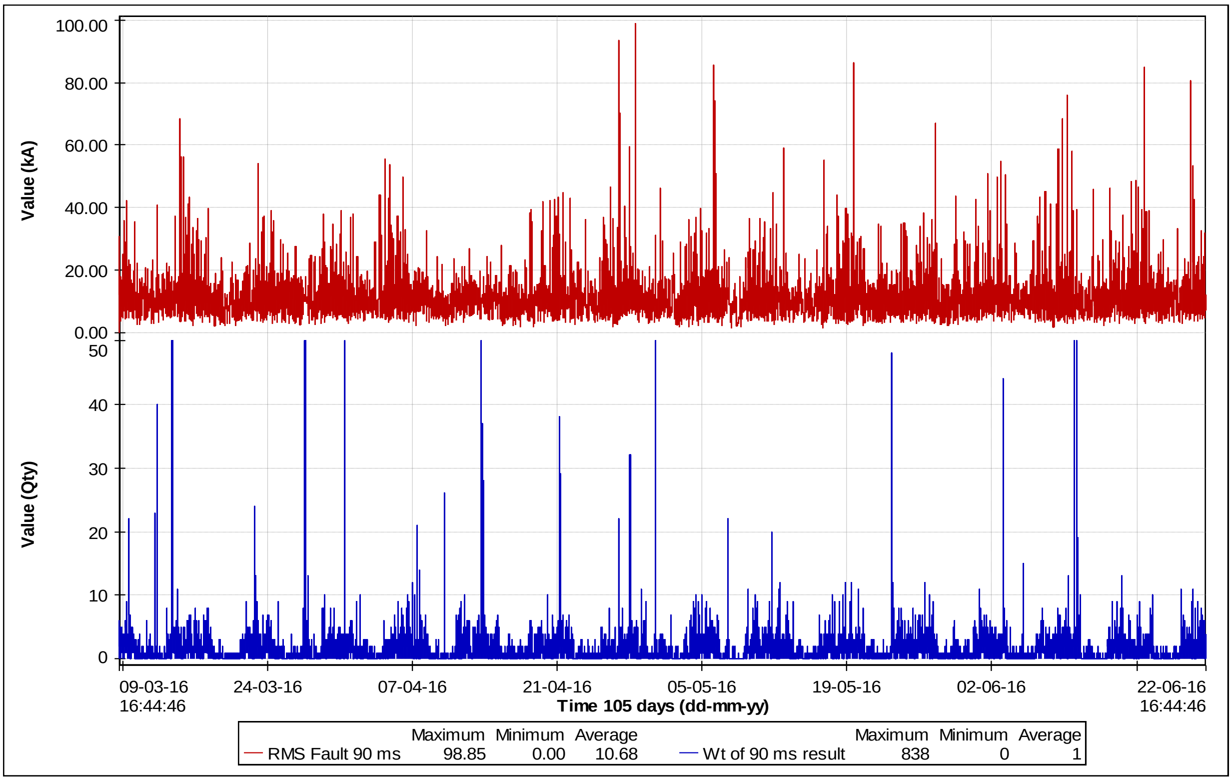


Graph 13. Upstream ½ cycle RMS result treated with 7-day boxcar and 2% filtering.

The following graphs 14 and 15 show the detail results and weighting applied at ½ cycle and 90 ms respectively. The overall average disturbance amplitude is very small.



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



Graph 15. RMS upstream results and weighting present at 90ms.