Respond Project Fault Level Report for Electricity North West Ltd

ENWL Fault Level Report 3 V1, 15/11/2016

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Change record		
Date	**Edited by**	**Reason**
17/11/2016	J.D.Outram	

Contents

Introduction

This report documents the results obtained from Fault Level Monitors installed at two ENWL sites in summer 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 4th November 2016, data was received from ENWL for the FLMs at each of the two substations. These are:

FLM serial No	Installed at	Recording Start Date	Recording End Date
0887	Bamber Bridge Primary	30/06/2015	31/10/2016
0888	Littleborough Primary	30/06/2015	31/10/2016

Connection checks

Connection checks were made on both sites by examination of phases of typical waveforms obtained during the recording. Both 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[1]
0887	Bamber Bridge Primary	17.76	1.931	7.313	19.691
0887	Bamber Bridge Primary [2]	9.574	N/A	4.007	N/A
0888	Littleborough Primary	34.51	3.337	12.79	37.847
0888	Littleborough Primary [3]	18.2	3.337	7.14	21.57

[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.

[2] From ~8am to ~11am on 28/9/16 and from ~9am to ~10pm on 12/10/16

[3] From start to ~17:30 on 5/7/16, and from ~13:30 on 20/8/16 to ~11:30 on 7/9/16

General comment on results

Results at Bamber Bridge were generally tight, with little scope for manipulation. On two occasions the Fault Level distinctly changed to a lower value, as listed in the table above. Littleborough results at 10ms were also very tight, and also revealed two distinct Fault Level regimes, but the 90ms RMS results were widely distributed, possibly because although there were many useful disturbances to work on, they were predominantly very short, with little disturbance energy left at 90ms.

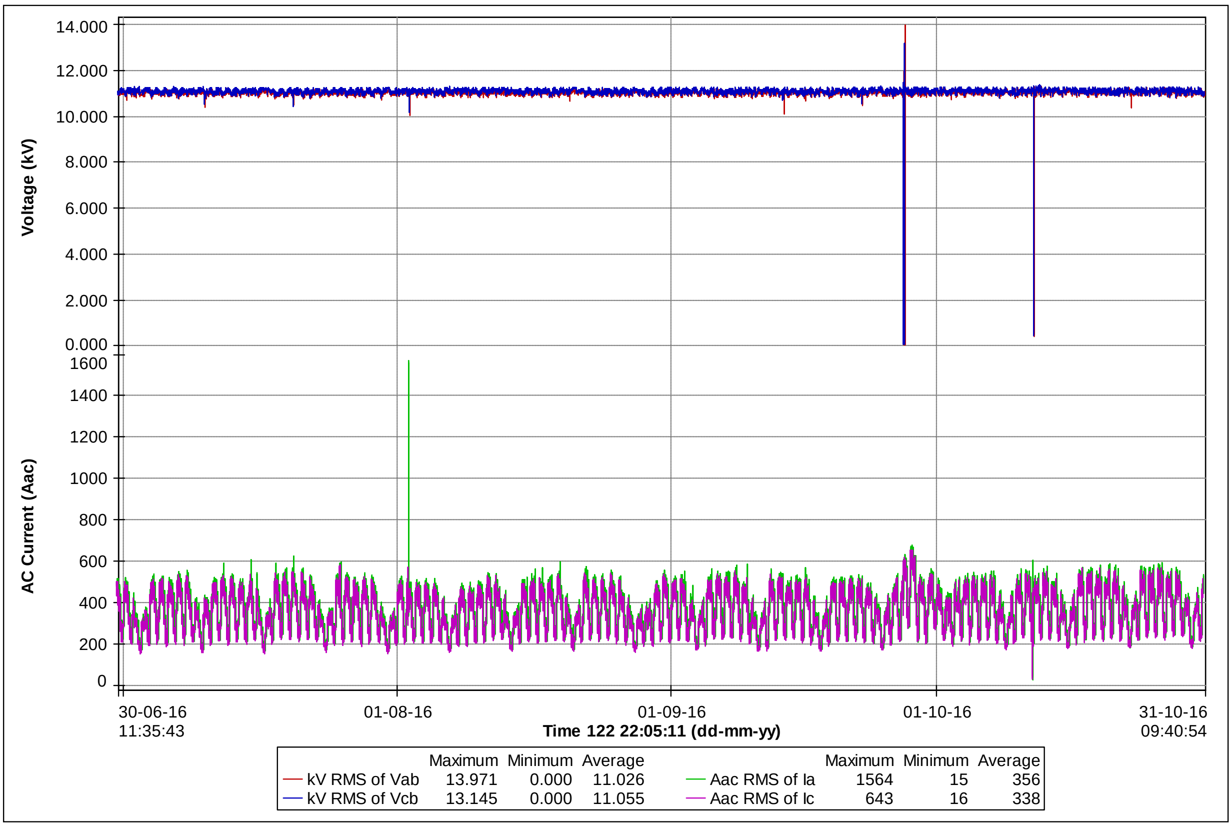
Appendix 1. : Bamber Bridge Primary. FLM Serial No 887

Sources of error

The overall results for Bamber Bridge over the 4 month period are good. 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.

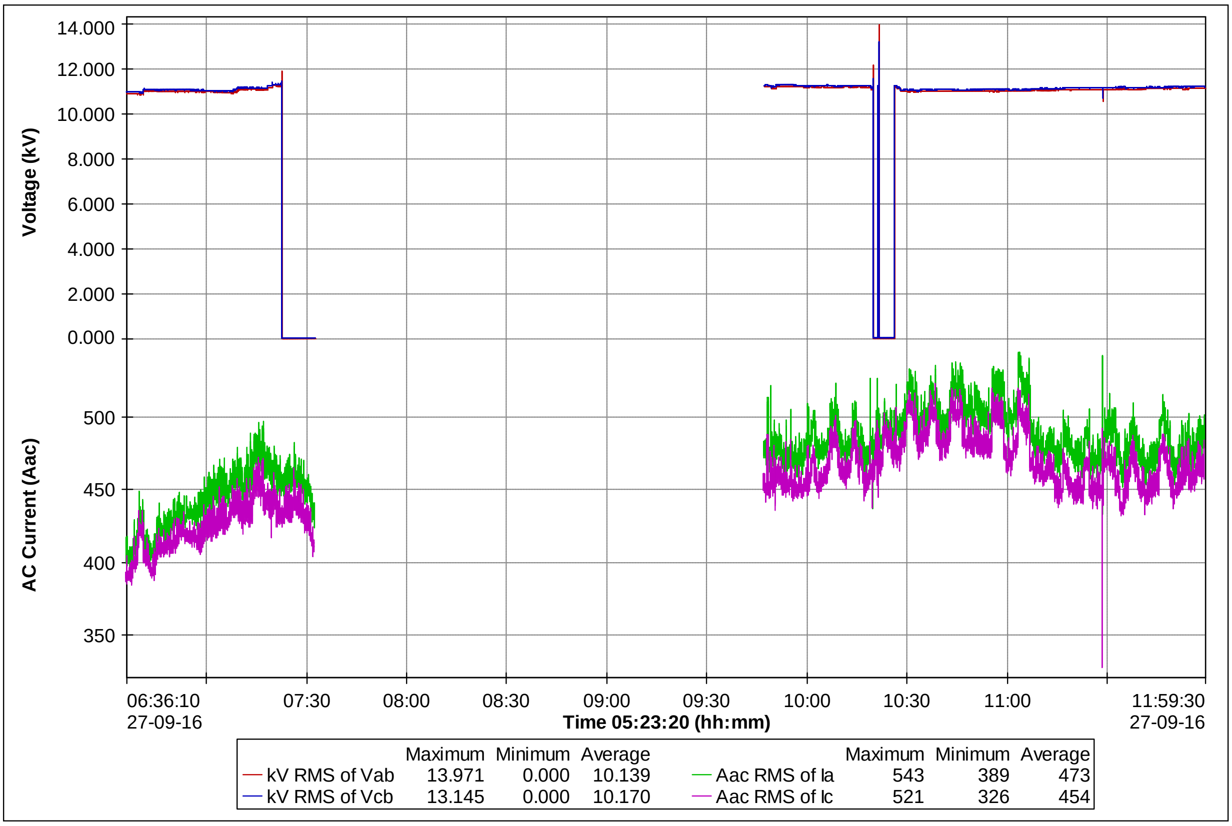
Bamber Bridge results, General observations

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

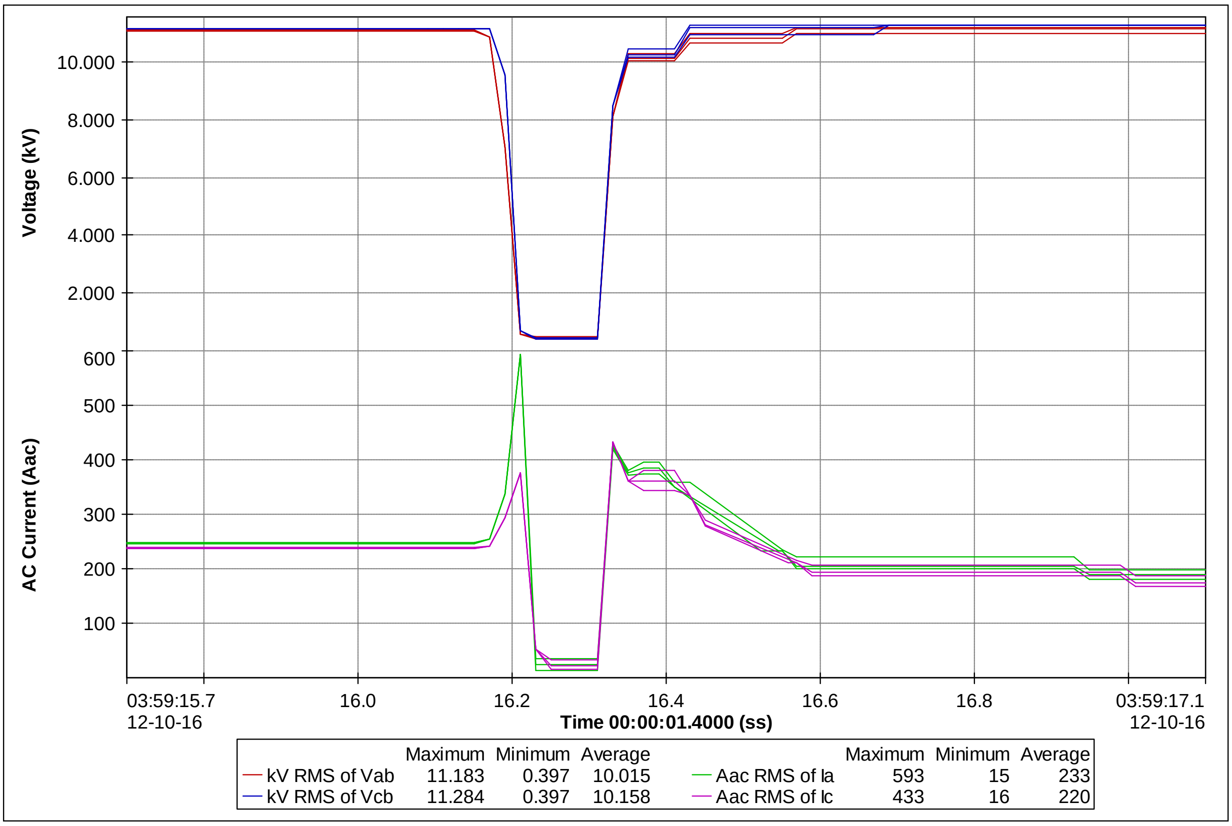


Graph 1. Volts and Current for the full recorded period.

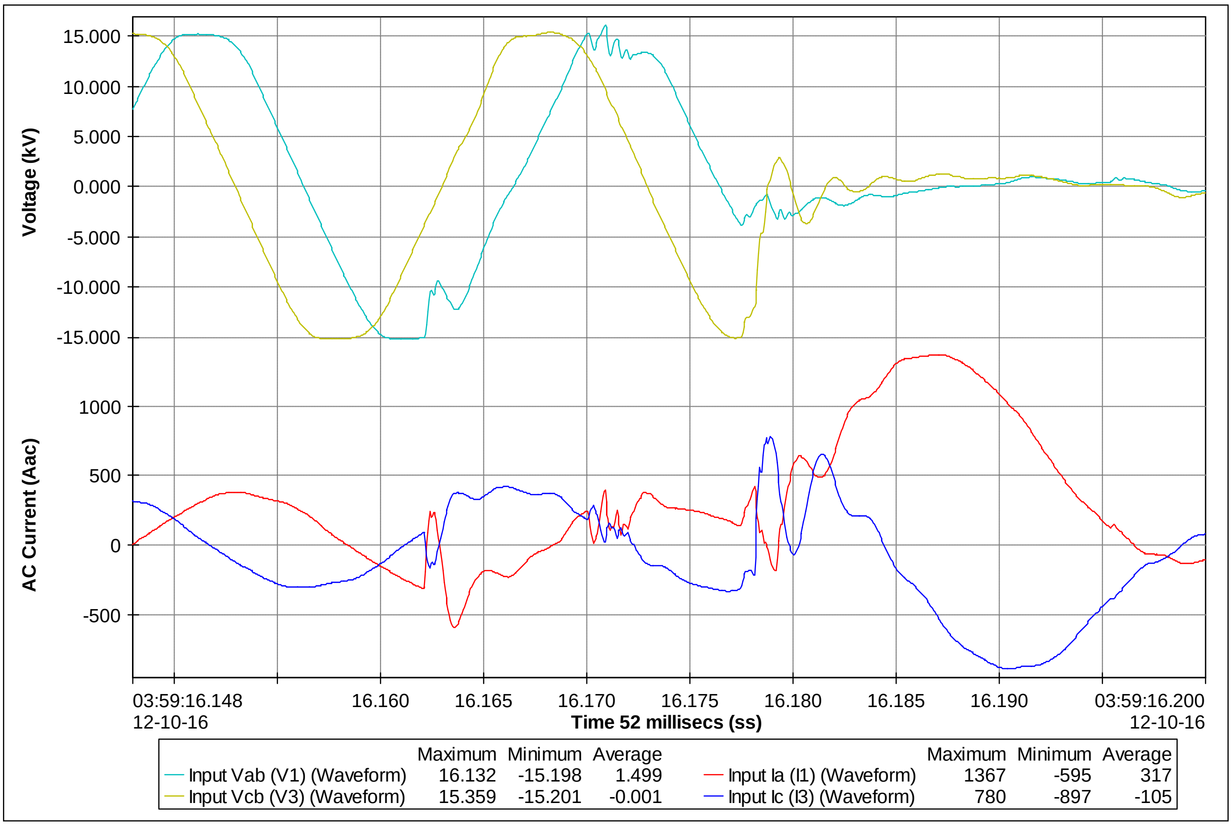
There appear to have been three voltage interruptions. None of them ostensibly appear to have been caused by a load downstream of this substation/feeder, though the waveforms immediately before the short interruption on 12th October may be relevant. There was a short series of high current events on 2nd August, the worst of which pulled the 11kv down by approximately 1000V. Graphs 2, 3, 5 show the RMS detail, and Graph 4 shows the waveforms ahead of the 12th October event.



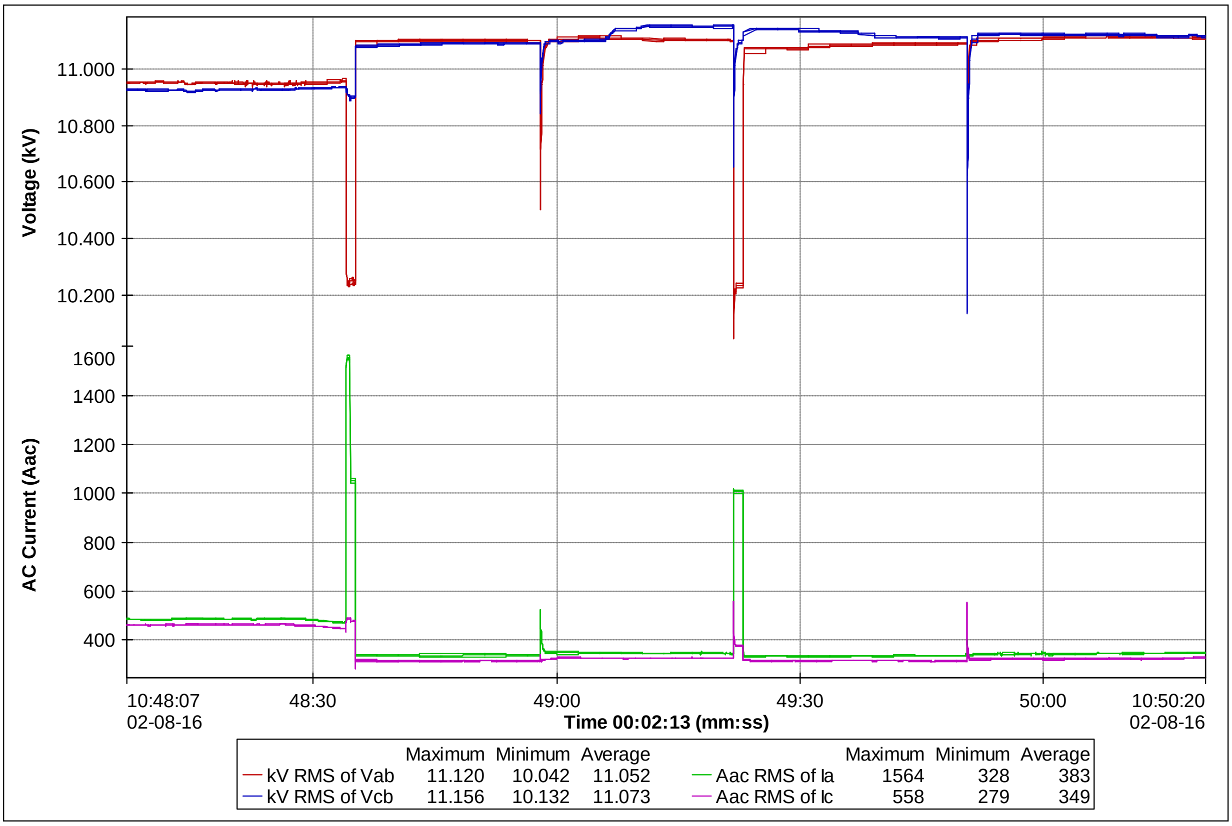
Graph 2. Interruptions over ~3 hours on 27th September 2016.



Graph 3. 100msec interruption on 12th October 2016.



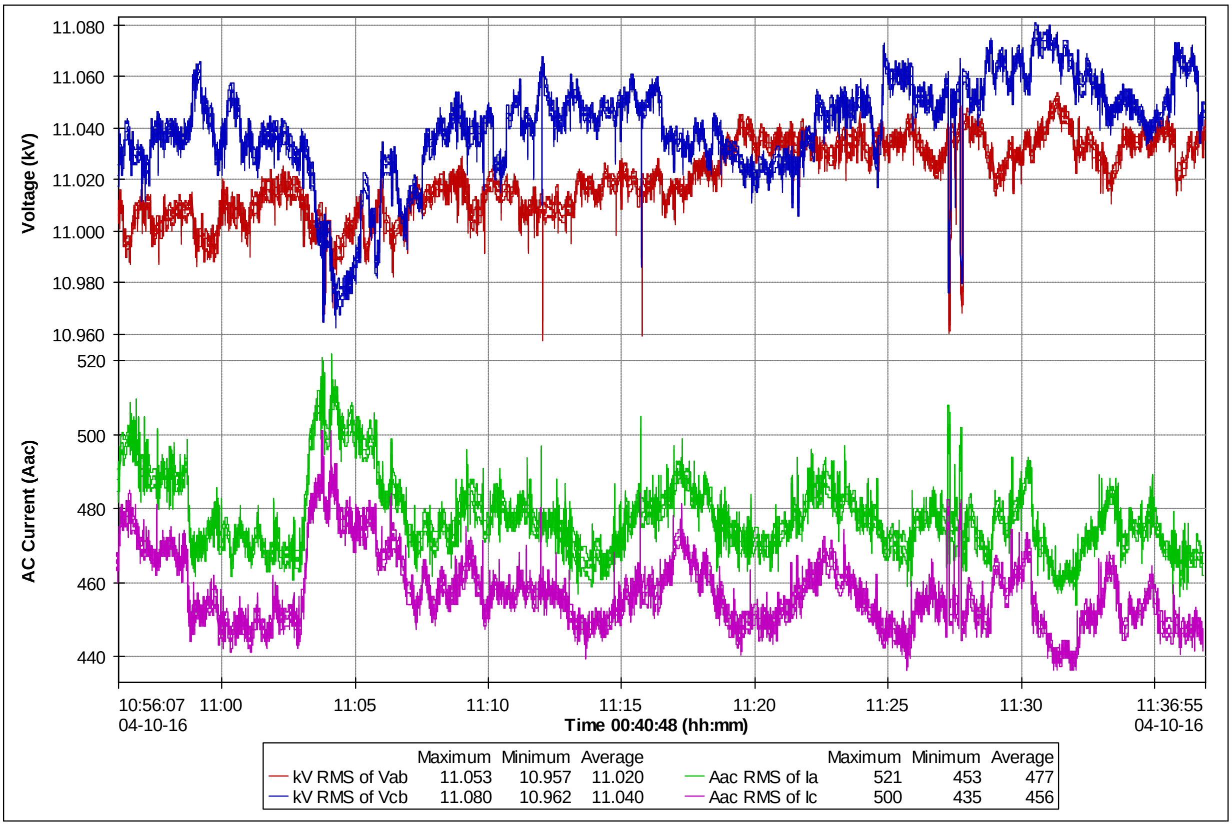
Graph 4. Waveforms ahead of the 100msec interruption on 12th October shown in Graph 3.



Graph 5. Current spikes and associated voltage dips on 2nd August 2016.

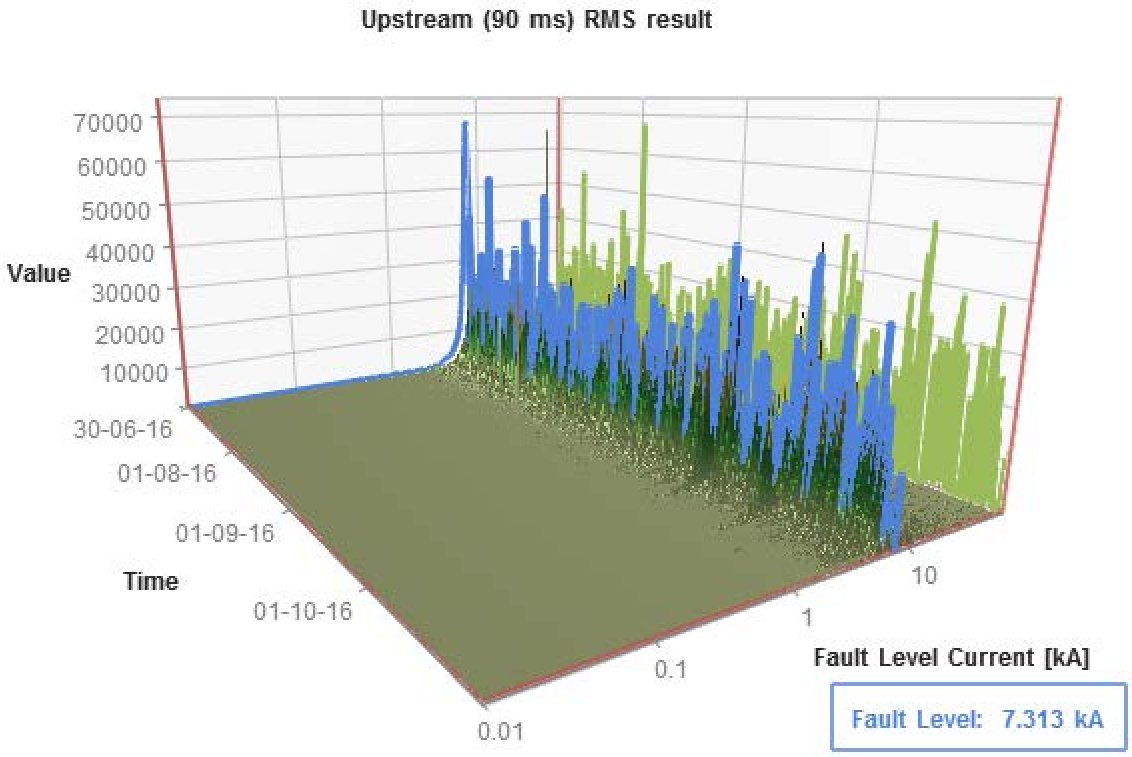
Useful Fault Level type disturbances.

Apart from the major events noted above, there was nothing of great magnitude, but plenty of modest disturbances. Graph 6 below shows examples of the best of these.



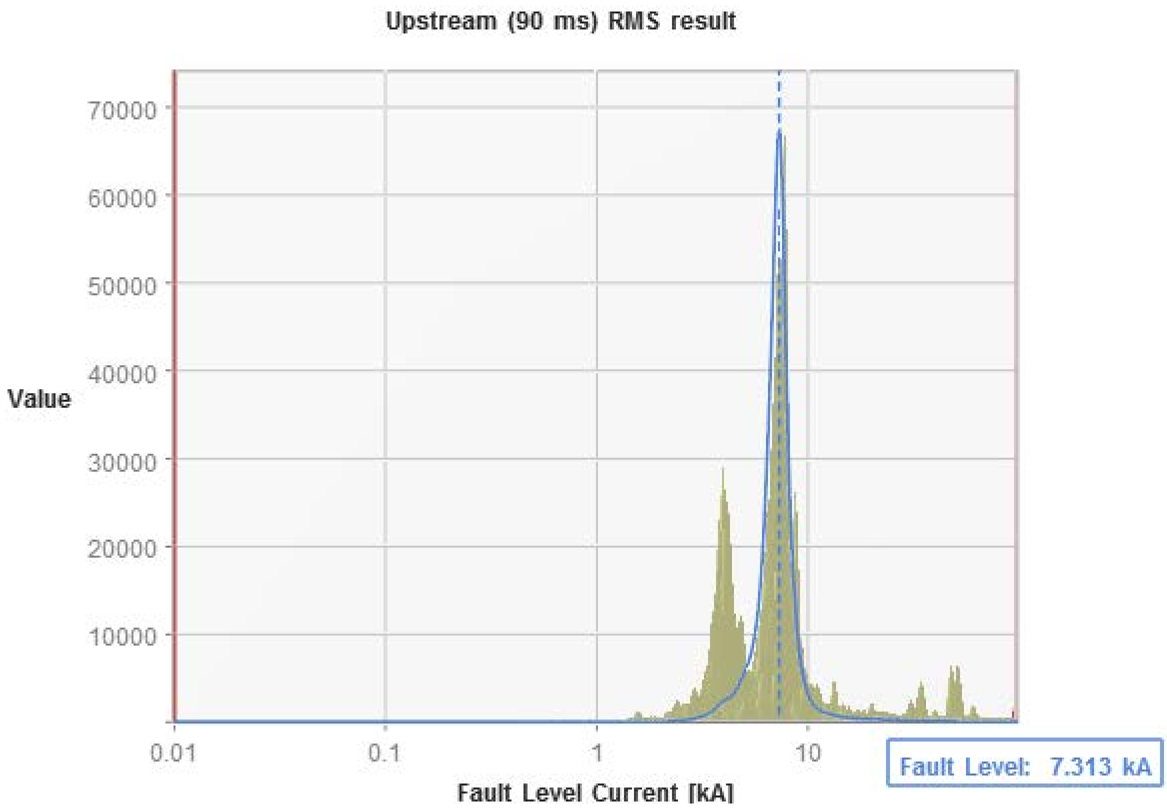
Graph 6. Examples of typical disturbances.

Fault Level Results



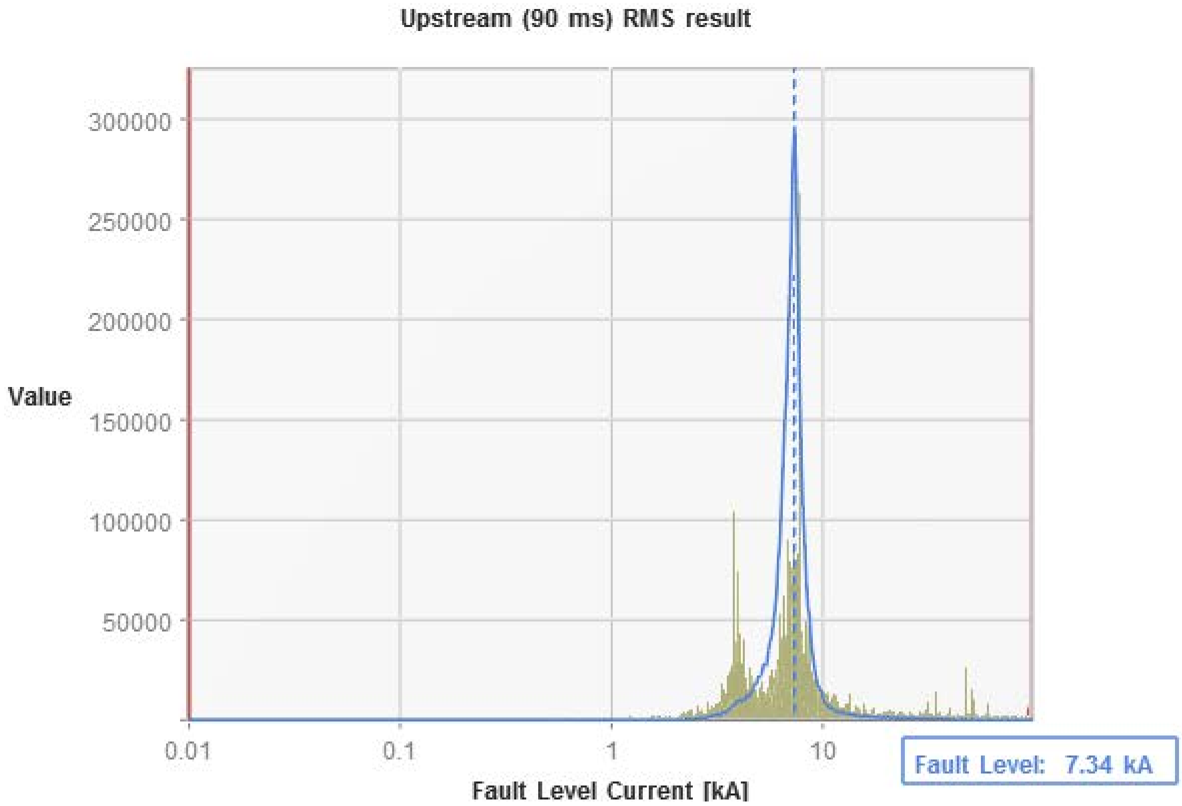
Graph 7. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.

Graph 7 shows that the mean Upstream 90ms RMS Fault Level for the period was 7.313 kA. Graph 8 shows the same thing in 2 dimensions.



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

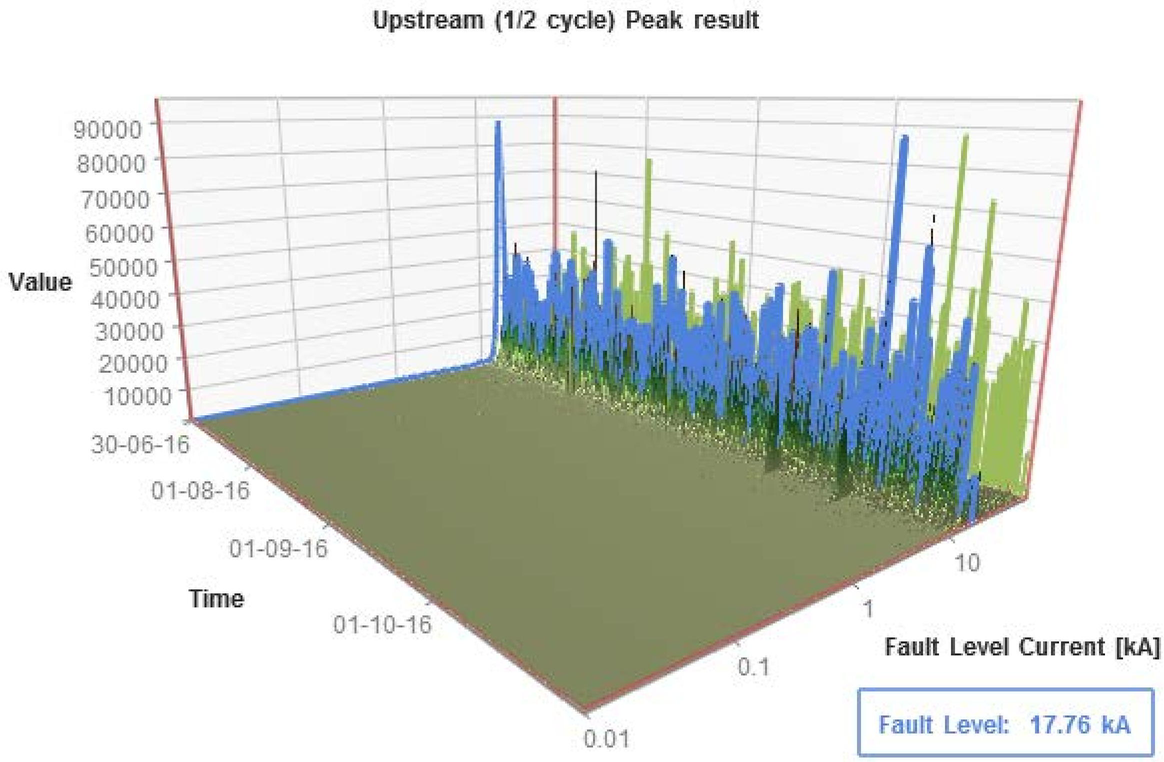
A modest degree of filtering was used to extract this peak, but even without it, the nose of the distribution is in almost exactly the same place, as shown in Graph 9 below.



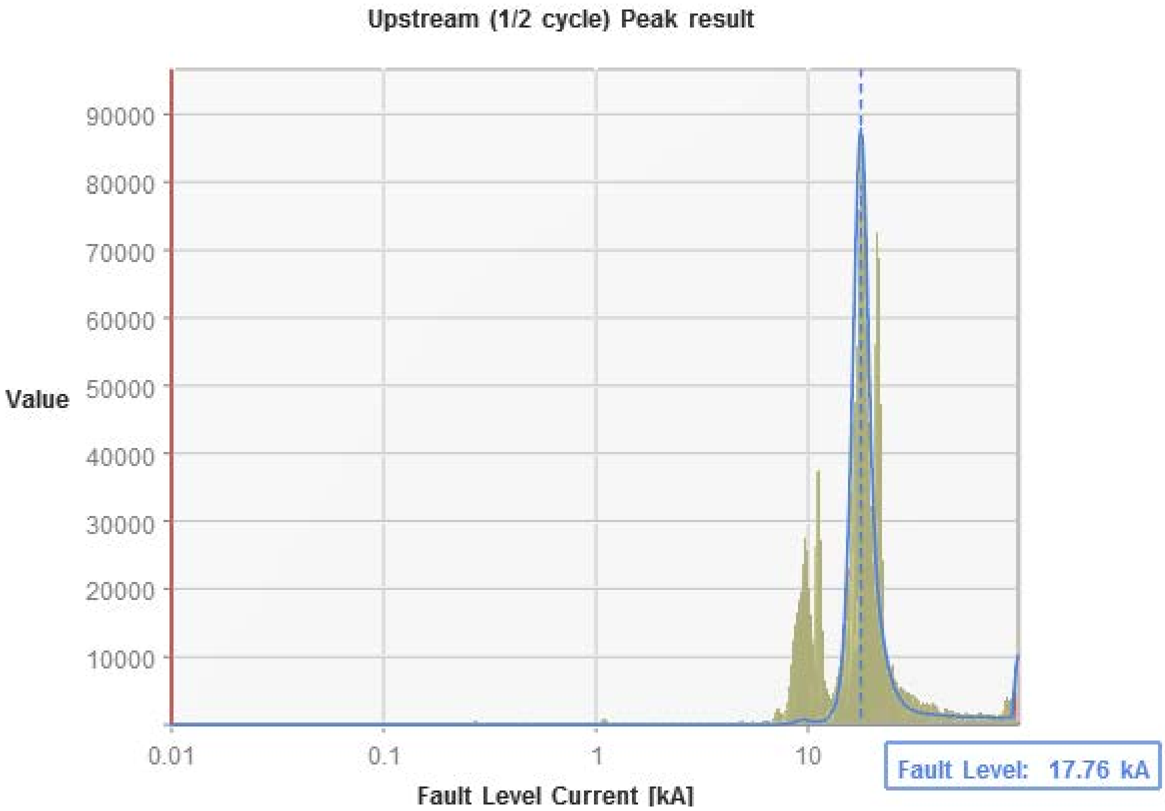
Graph 9. Upstream RMS Fault level at 90ms. 2D Distribution shown with no filtering.

In fact the main distribution is relatively narrow so that there is very little variation between the two. There is some disturbance energy forming a population at a lower Fault Level, but this is very short lived. This is examined later.

Graphs 10 and 11 show the Peak Upstream Fault Level for the whole period.

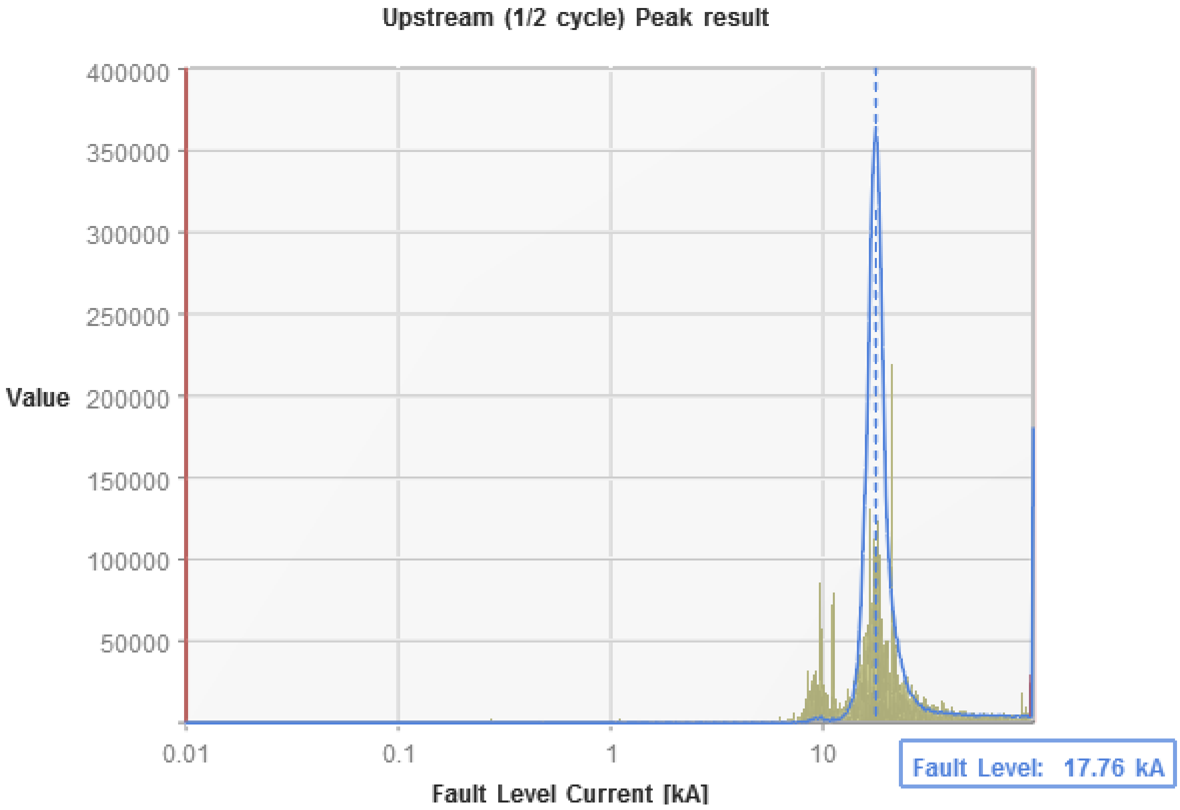


Graph 10. Upstream Peak Fault level at ½ cycle. 3D Distribution shown with 2% filtering.



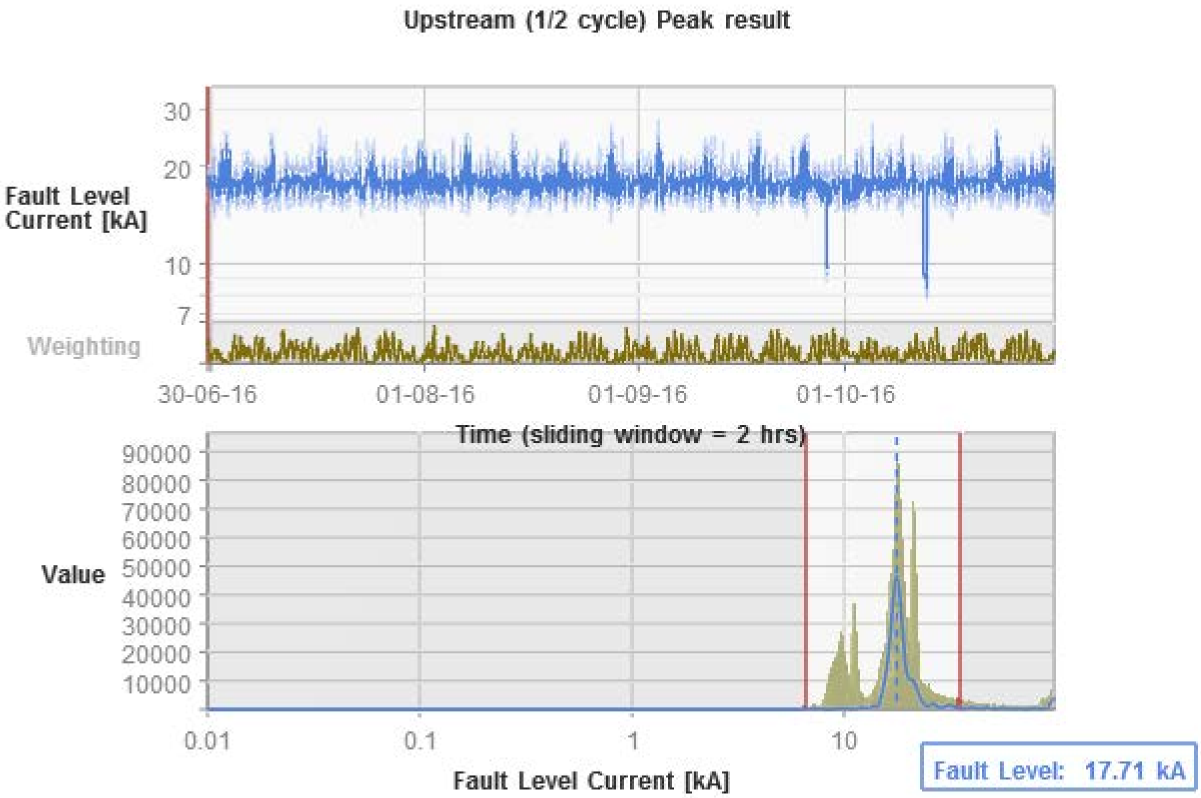
Graph 11 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with 2% filtering.

Exactly the same result is obtained without filtering as shown in Graph 12.



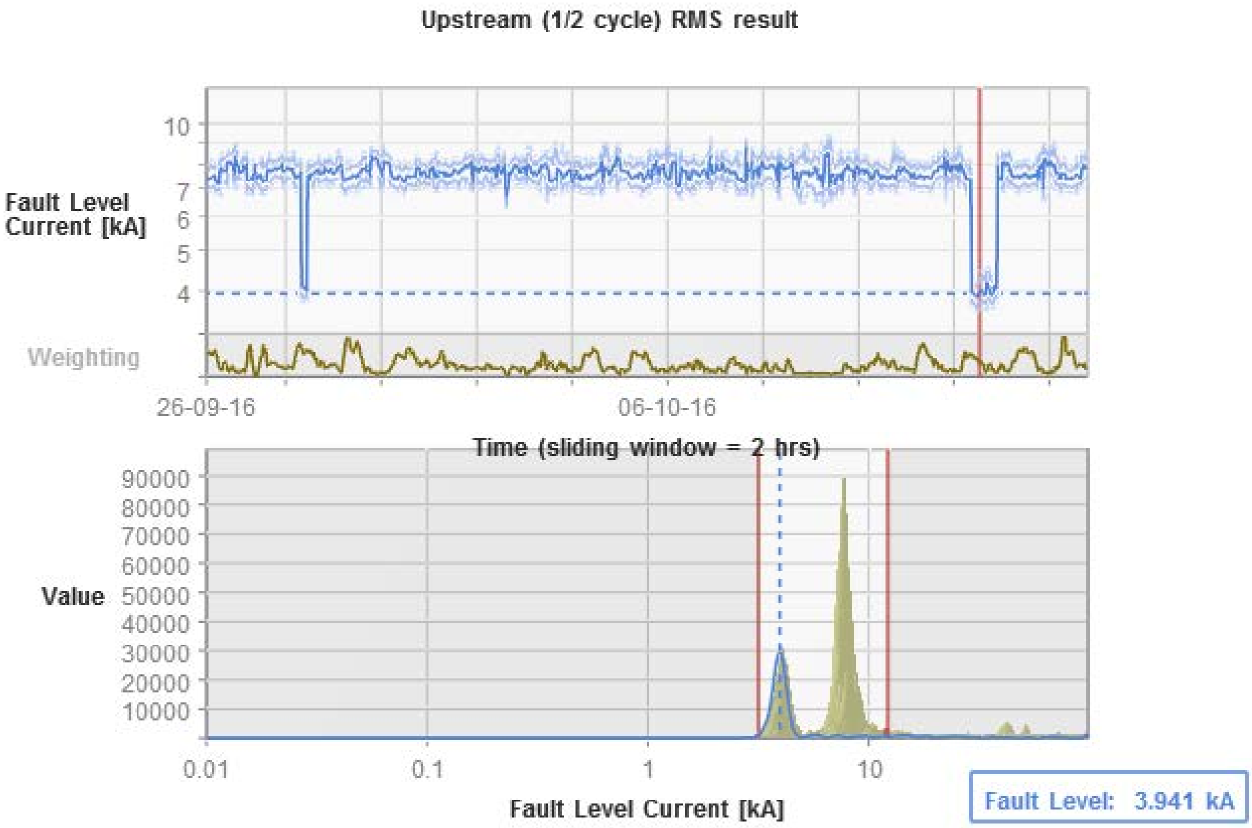
Graph 12 Upstream Peak Fault level at ½ cycle. 2D Distribution shown with no filtering.

Examining the ½ cycle RMS result, on the grounds that it should be the cleanest and any anomalies most easily seen on it, we can see that if the time period for results accrual is reduced to 2 hours, there are two regions for which a lower Fault Level appears to apply. Graph 13 applies.



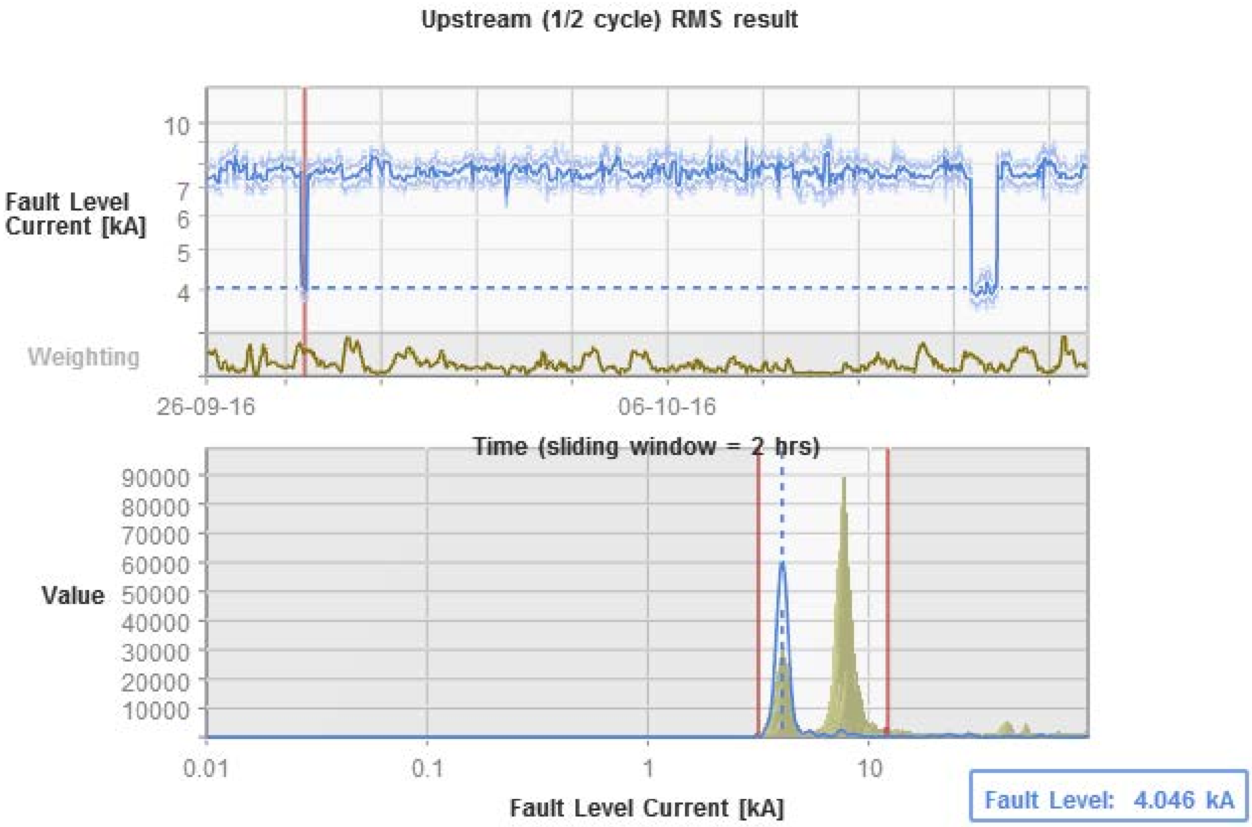
Graph 13. Upstream RMS Fault level at ½ cycle. Time plot and 2D Distribution shown with 2% filtering.

Both these regions are discernible on both graphs 7 & 10, but we need to graph the data over a much shorter period in order to establish whether these are truly different Fault Level conditions. Graph 14 shows the two regions.



Graph 14. Upstream RMS Fault level at ½ cycle. Reduced Time plot and 2D Distribution shown with 2% filtering.

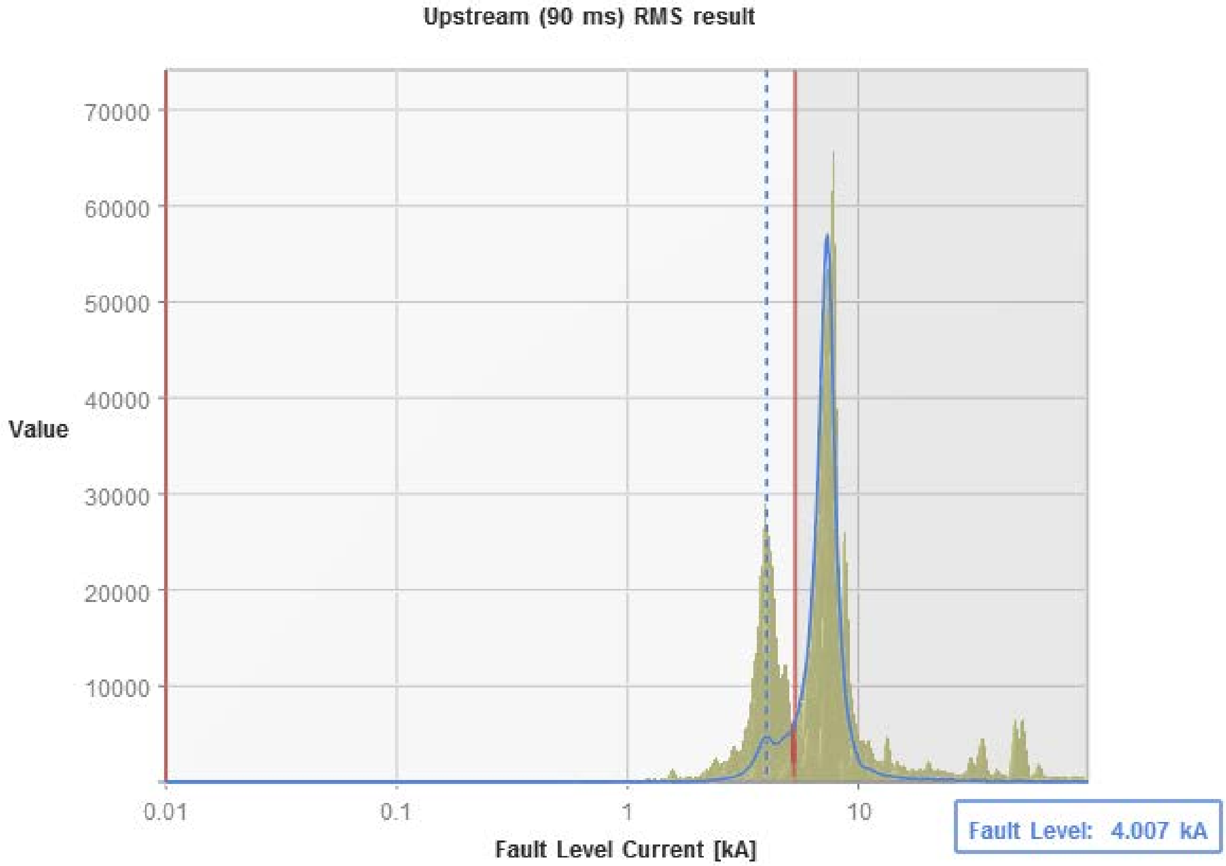
Although it is clear from the time graph (the upper graph) that the lower Fault Level region on the right has unambiguously moved from 7-8kA to 4kA, it is less clear that the same applies to the left hand region. By looking at the blue line in the population part of graph 14 (the lower of the two graphs above), we can see that there is no contribution from the higher Fault Level population during the relevant period. We conclude that for the ~13 hour period on the 12th October, some significant generation was lost. The same applies to the earlier period, though this was much shorter. By moving the time slide bar to obtain the relevant population during that earlier region, we can again confirm that the reduction in Fault level is genuine and unambiguous. See Graph 15.



Graph 15. Upstream RMS Fault level at ½ cycle. Reduced Time plot and 2D Distribution shown with 2% filtering. Population shown for earlier reduced Fault Level region.

In both cases, the reductions occurred largely during the day when there were plenty of disturbances to evaluate, and the weighting graph confirms this.

The combination of these two regions together and the likely Fault Level arising can be obtained by expanding out the accrual time from the two hours used above to the full interval shown, then deliberately excluding contributions from the upper population in the evaluation process. Graph 16 shows this process applied to the 90ms RMS Upstream result.

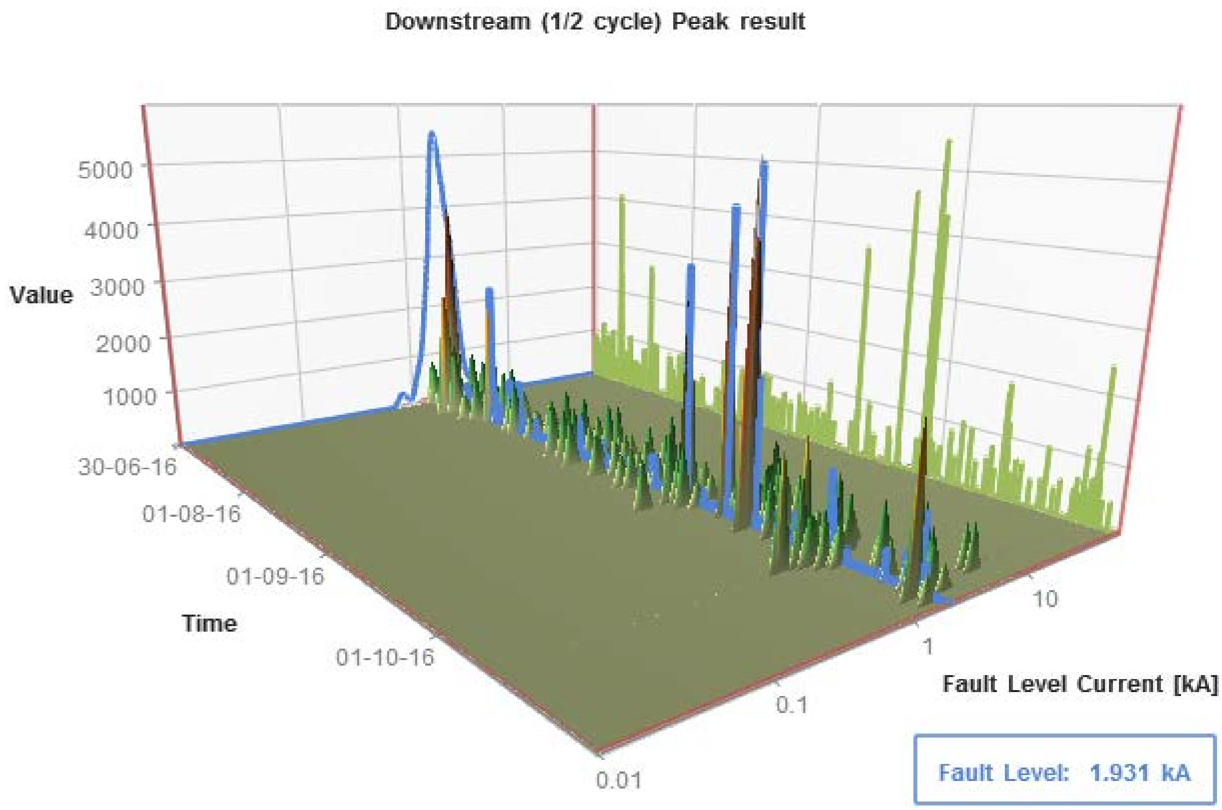


Graph 16. Showing Upstream RMS 90ms result for the combined reduced Fault Level periods.

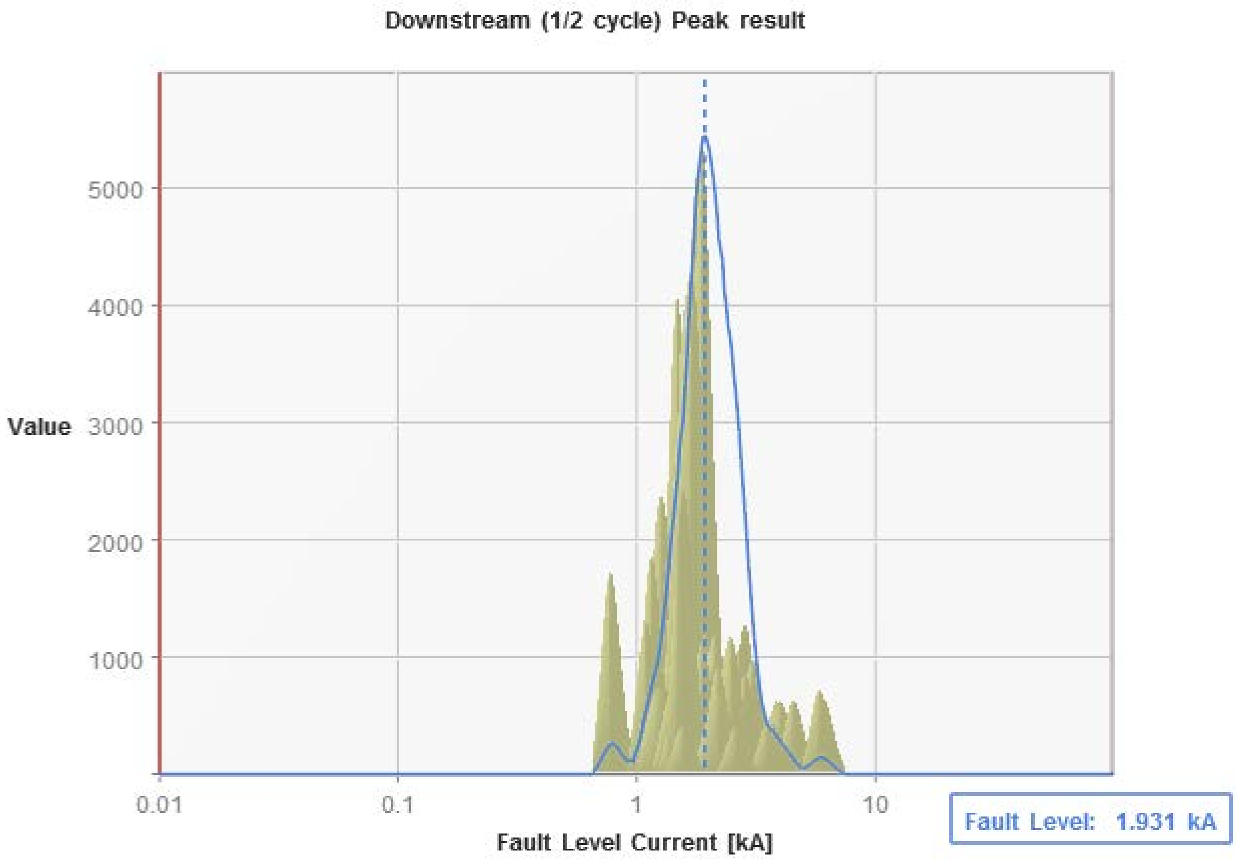
In this case the Fault Level Span (Upper side) is reduced to below the main population so that the peak associated with it (the main population) is excluded. Even so, such is the weight of the predominant population above the fault level span position (the red line), that it is necessary to use the time restriction function as well in order to isolate the required peak. In this case the accrual period contributing is 23rd Sept 6am to 14th October 10am (enough to embrace both reduced FL periods), the filtering is 2%, and now the peak associated with the little bump below the red line can be found. It is well centred between the two individual results shown in graphs 14 & 15.

Downstream Fault Level contribution

There is very little downstream disturbance energy, but what there is, is fairly consistent. Graphs 17 and 18 show the Peak half cycle Fault Level detected for downstream contribution with 5% filtering.

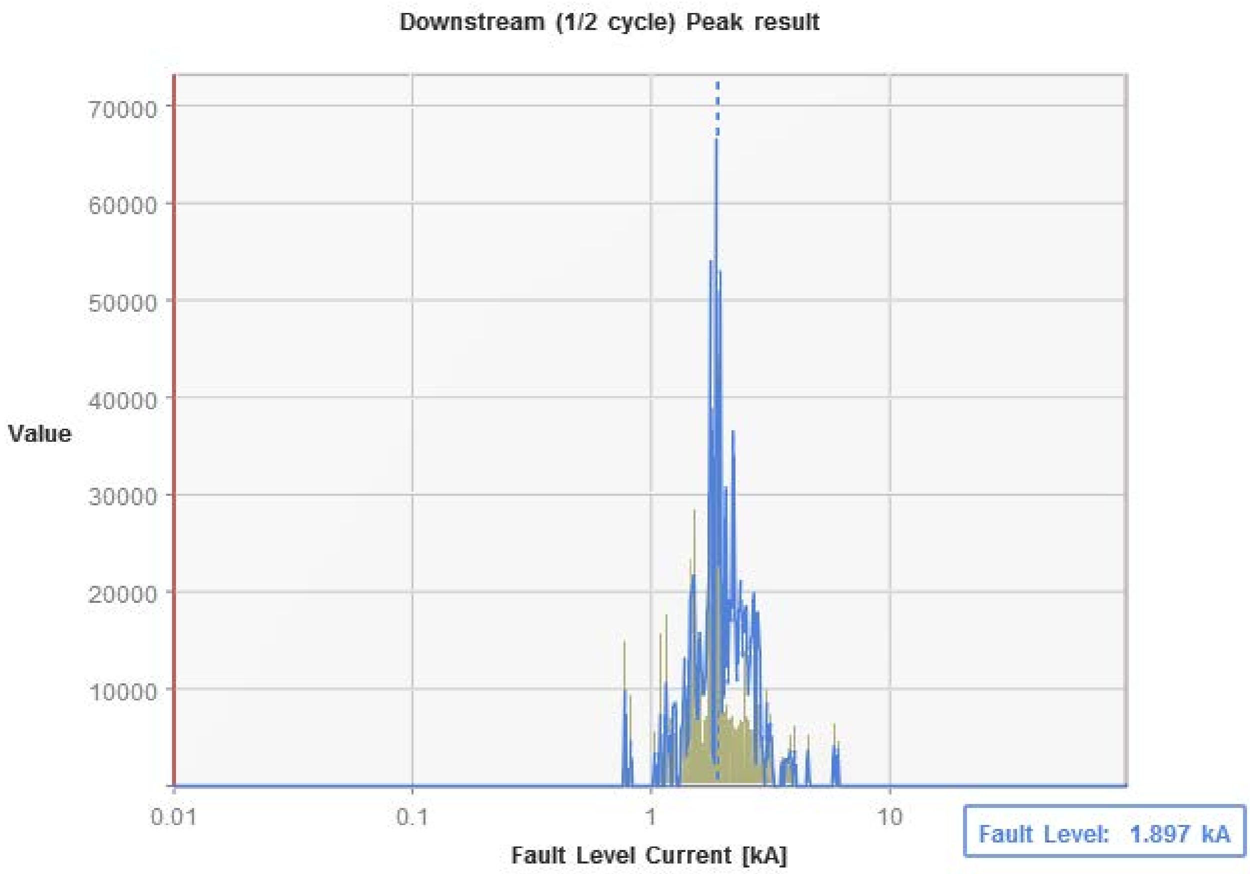


Graph 17. Downstream Peak Fault Level contribution at ½ cycle. 3D representation with 5% filtering.



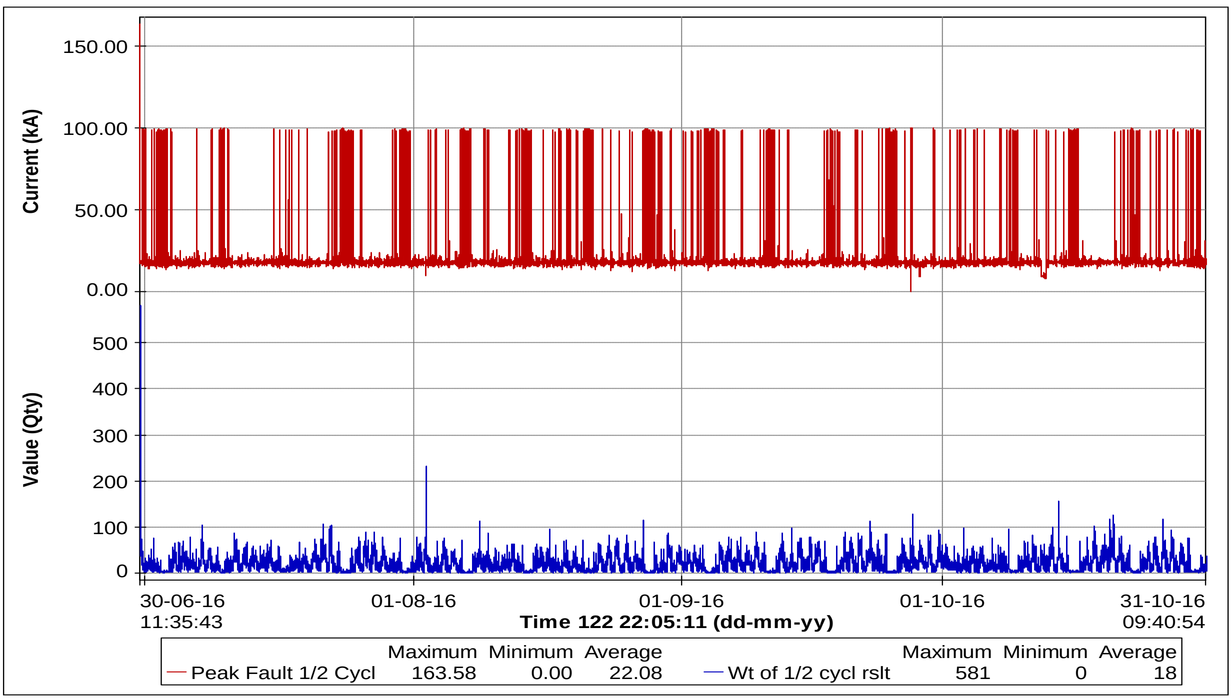
Graph 18. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with 5% filtering.

Without any filtering, the result is very similar. Graph 19 refers.

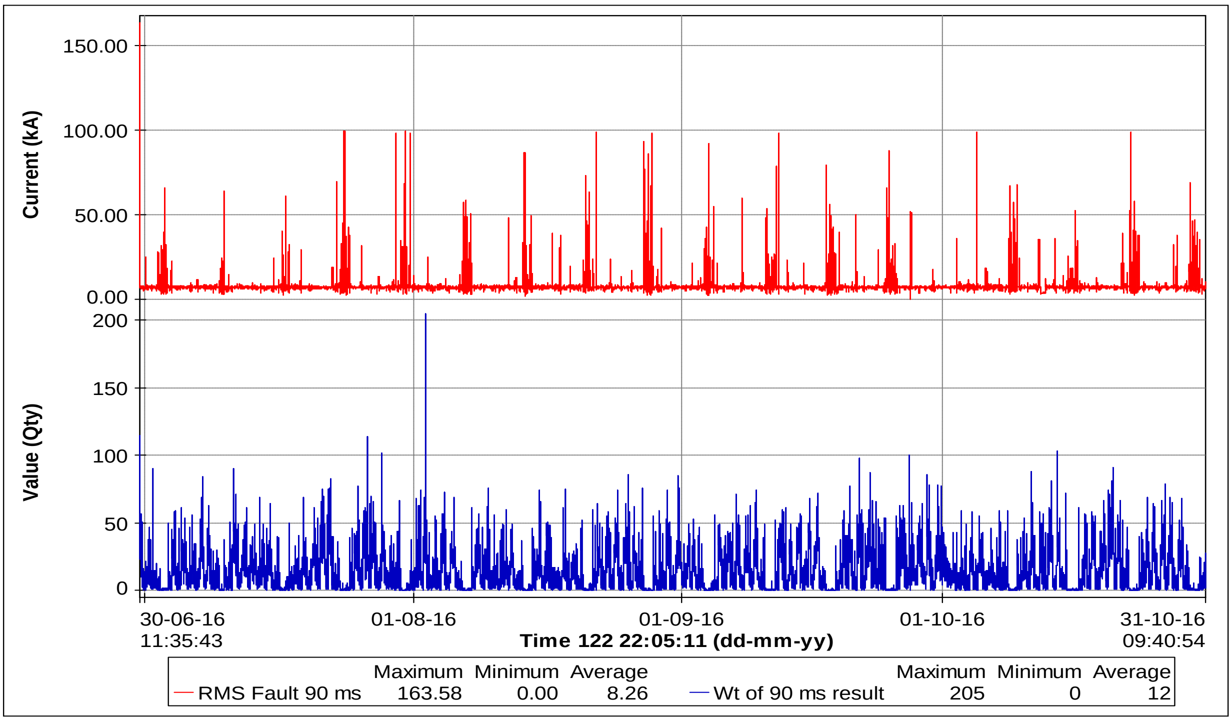


Graph 19. Downstream Peak Fault Level contribution at ½ cycle. 2D representation with no filtering.

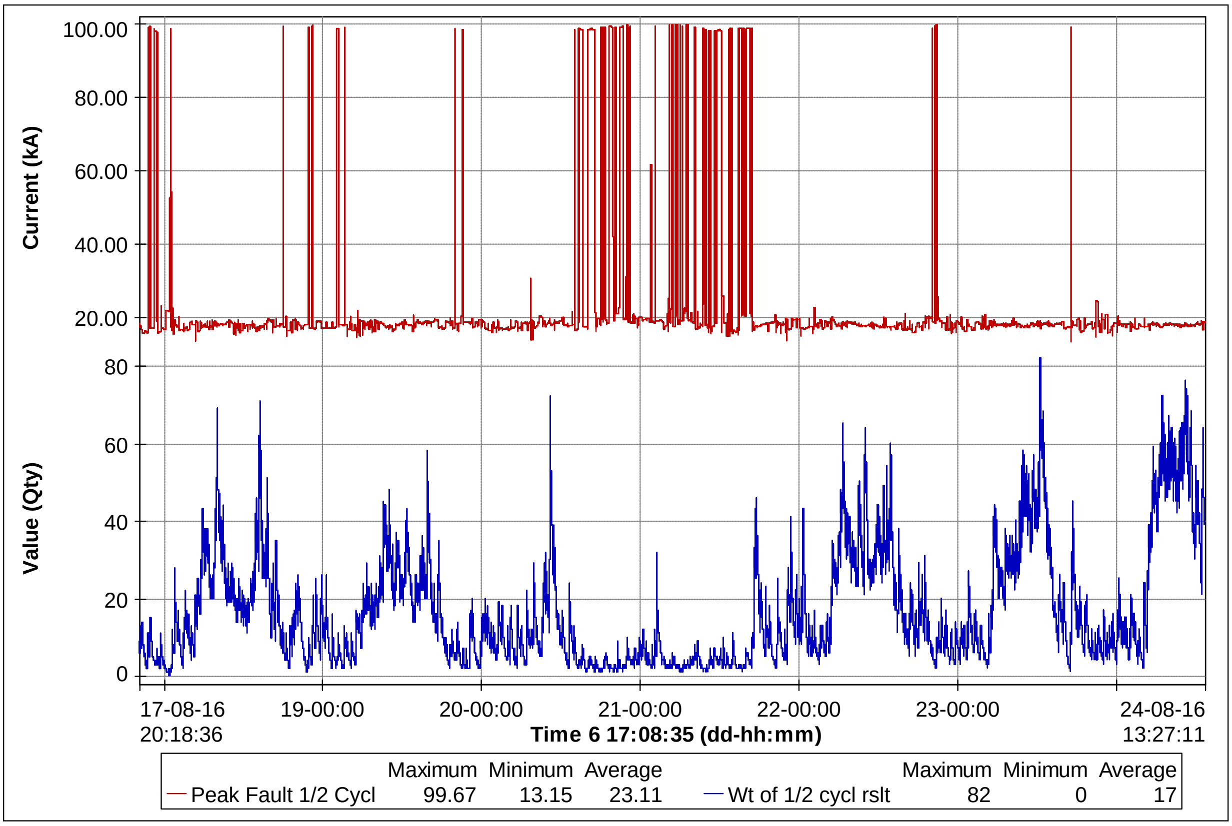
The following graphs 20 and 21 show the detail results and weighting applied at ½ cycle and 90 ms respectively. Both cases show the low weightings available. They are both good examples of why the weighted population method of evaluation is preferred, because these *unweighted* graphs show large numbers of bad results arising from extremely small disturbance events (with correspondingly small weightings). Graph 22 shows an expanded section of the ½ cycle weighting and Fault Level current results illustrating the association.



Graph 20. Peak upstream results and weighting present at ½ cycle.



Graph 21. RMS upstream results and weighting present at 90ms.



Graph 22. Peak upstream results and weighting present at ½ cycle expanded to show association between poor current results and low disturbance weighting.

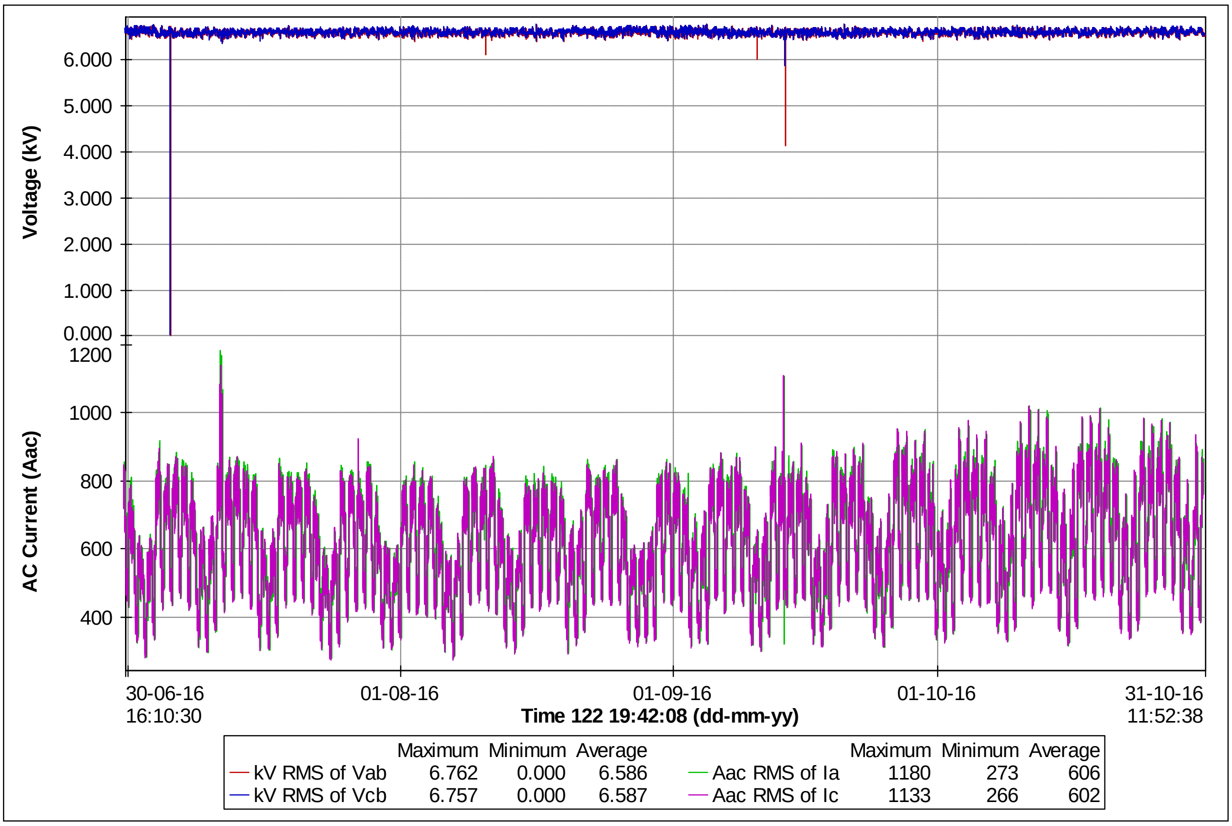
Appendix 2. Littleborough Primary. FLM Serial No 0888

Sources of error

The overall results for Littleborough Primary over the 4 month period are not as uniformly good as at Bamber Bridge. The ½ cycle results are strong, but the Upstream 90ms RMS population distribution is weak and relatively broad. As discussed below, there were large numbers of regular small and very short disturbances. These yielded good ½ cycle results but little at 90ms. As with Bamber Bridge, there is little room for manipulation of the ½ cycle 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. In the event the 90ms Upstream RMS result is still quite well defined. As discussed below there are two distinct Fault Level regions over the course of the 4 month recording, and the two populations are visible in all the Upstream results, including the 90ms RMS.

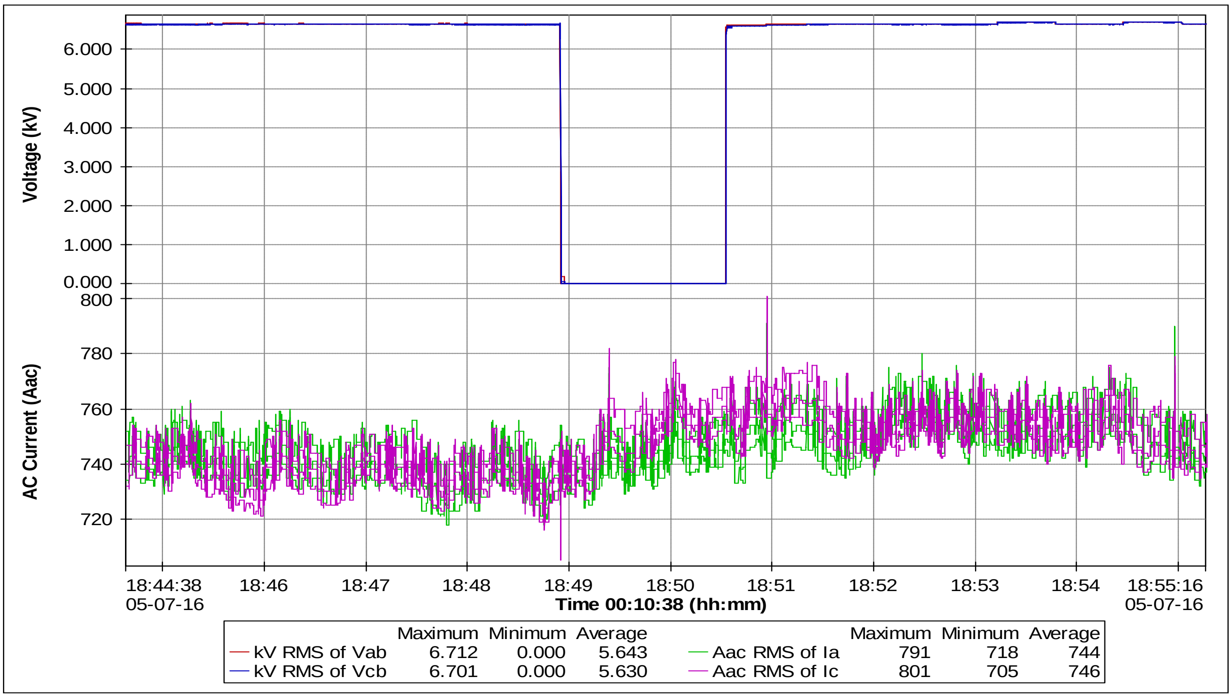
Littleborough Primary results, General observations.

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

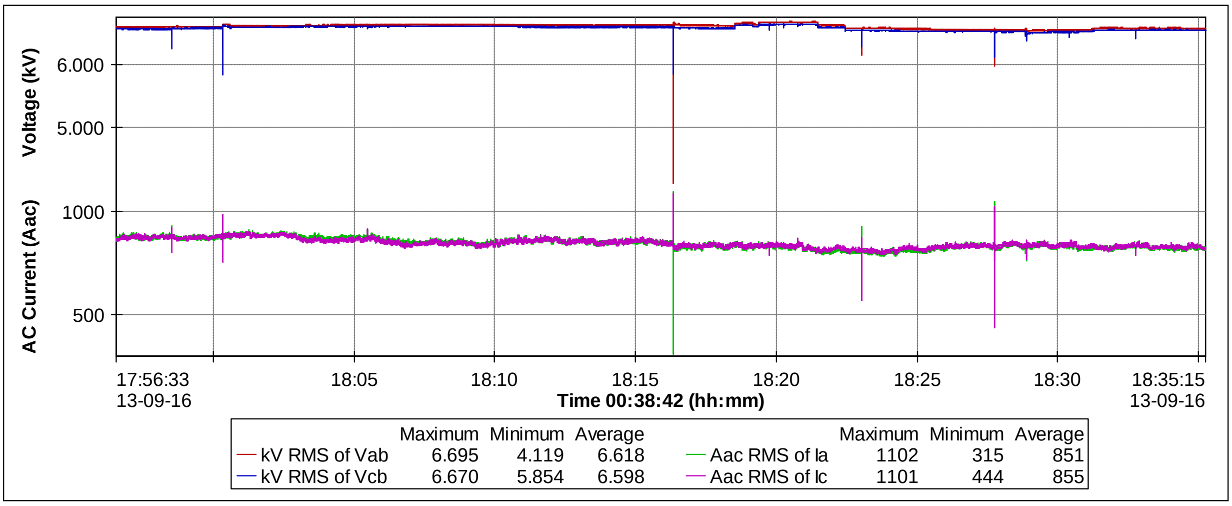


Graph 1. Volts and Current for the full recorded period.

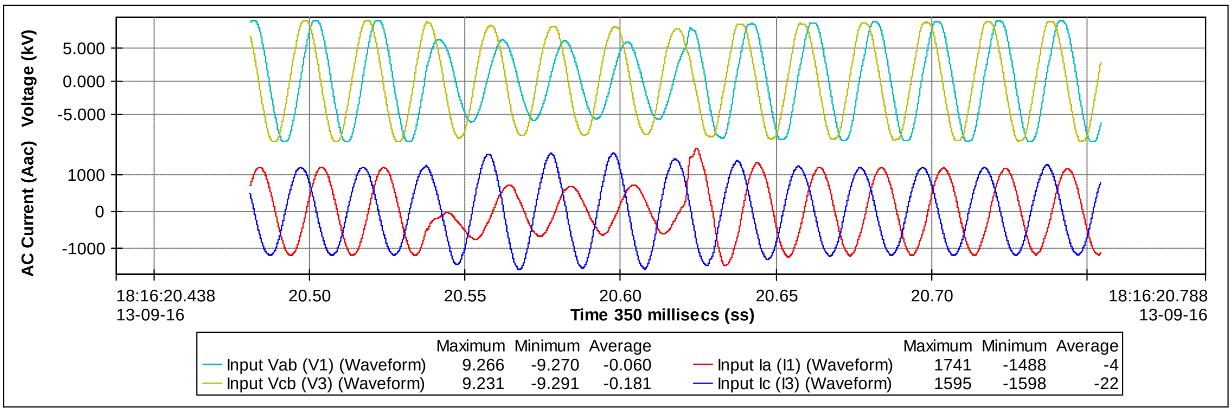
During the recording period there was one interruption for ~1 ½ minutes on 5th July, and a cluster of disturbances on 13th September. Graphs 2 and 3 show the effects on the voltage RMS, and graph 4 shows the waveforms associated with the largest of the Sept 13th disturbances.



Graph 2. Voltage interruption on 5th July.



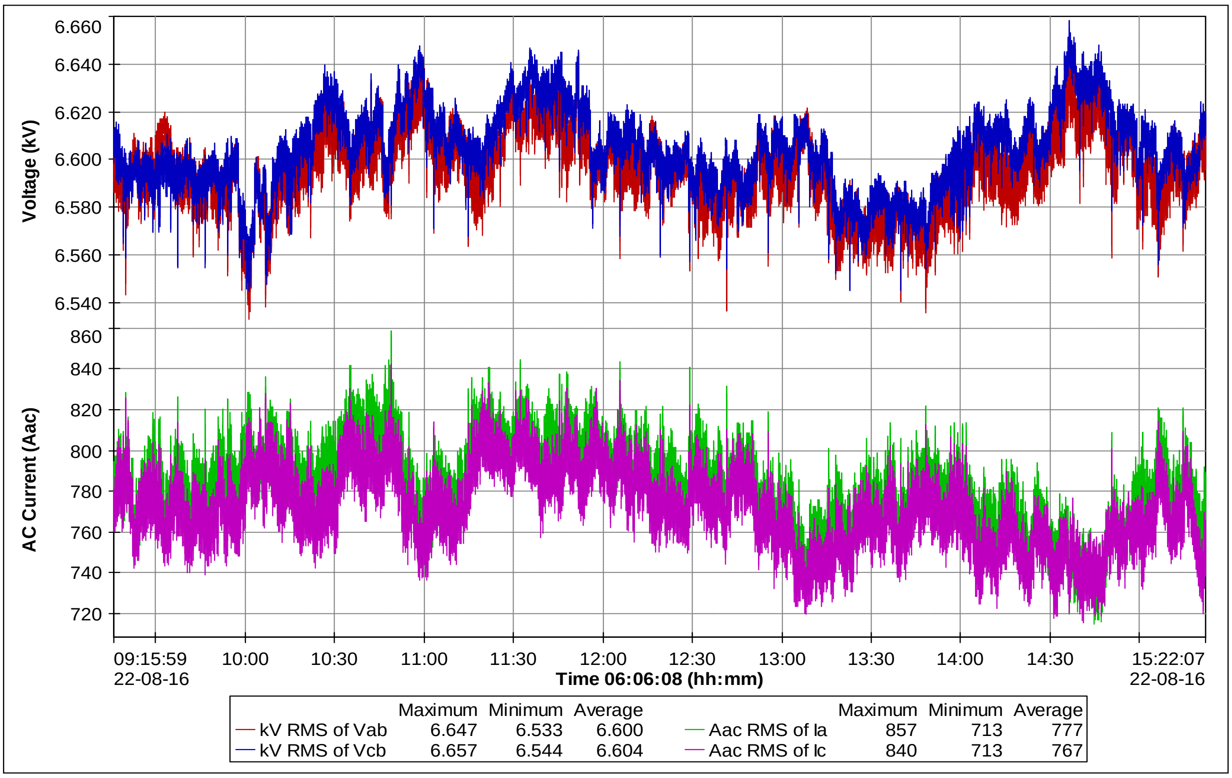
Graph 3. Cluster of disturbances on 13th September.



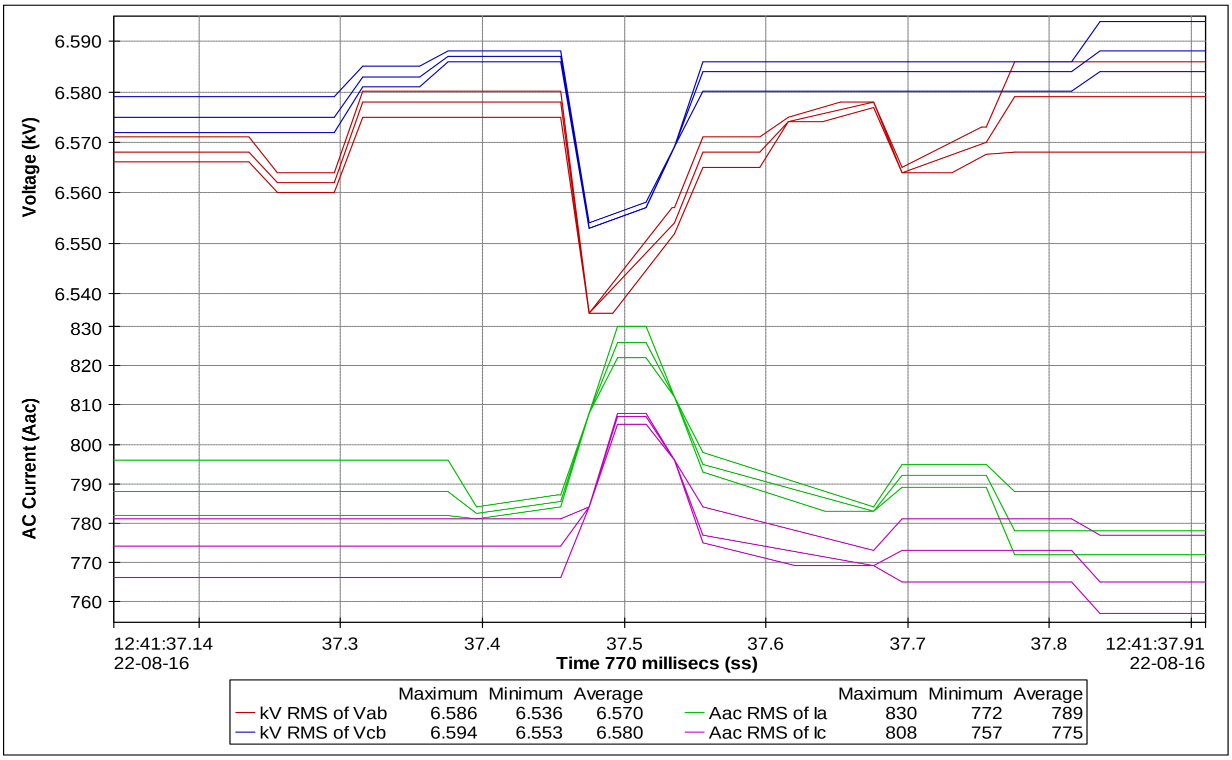
Graph 4. Waveforms for the worst case RMS disturbance shown in Graph 3.

Useful Fault Level type disturbances.

There were large numbers of very short and fairly regular disturbances. Graph 5 shows a 6 hour example. Graph 6 expands a typical one of these, and shows that although there is ~0.5% voltage variation for 40A current change, it is not really long enough to give a 90ms evaluation.



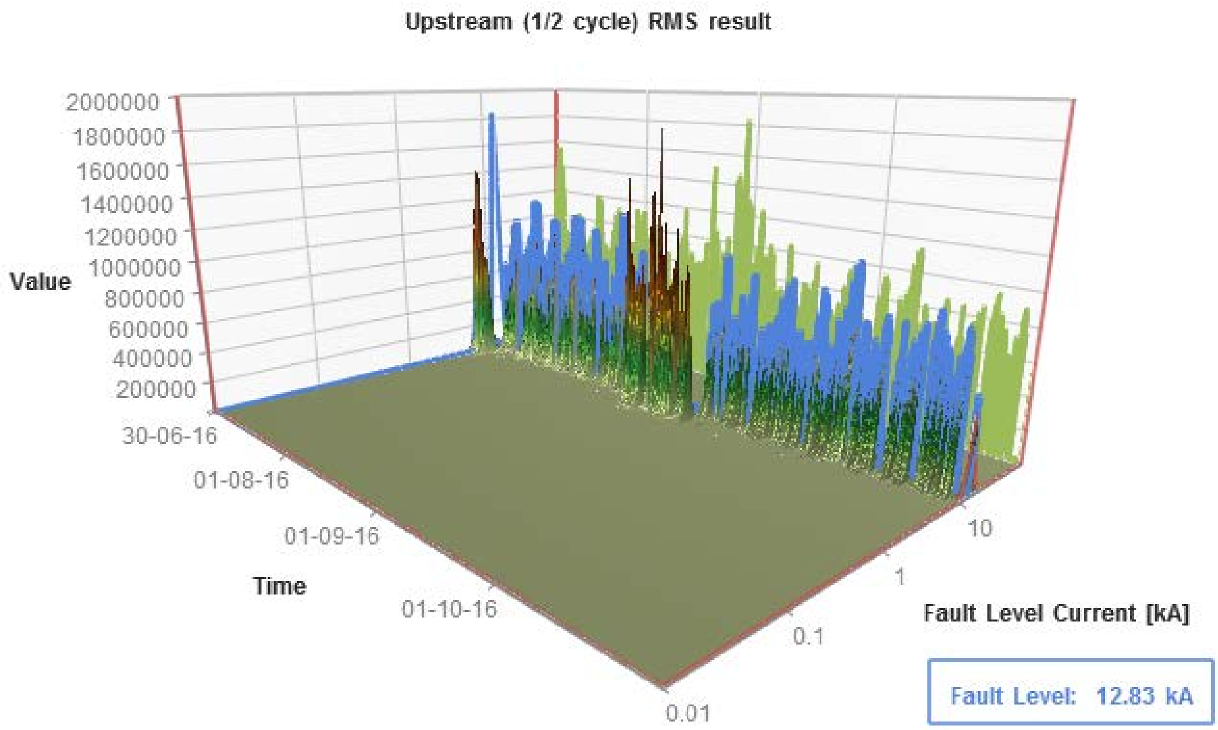
Graph 5. Section of recording showing reasonably regular current spikes leading to useable voltage disturbances.



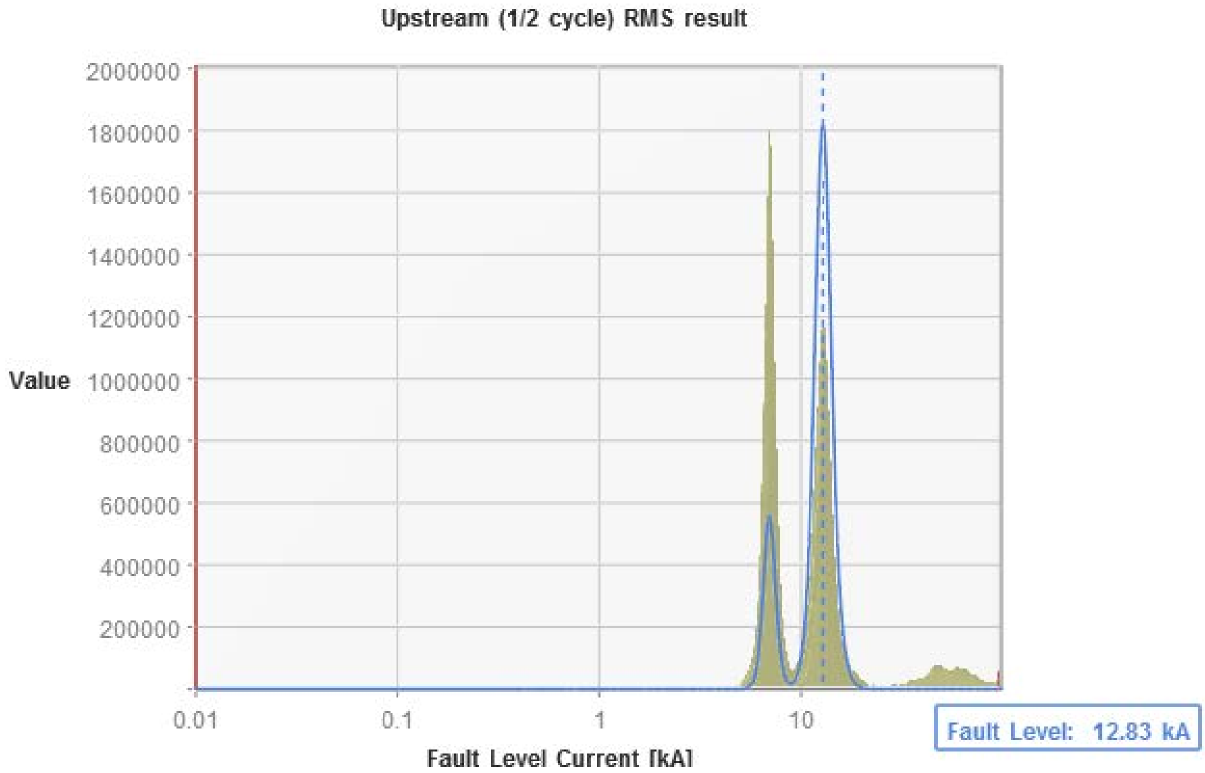
Graph 6. Expansion of typical spike at 12:41 illustrating duration.

Fault Level Results

As discussed above, the Upstream 90ms RMS result is weak. When compared with the ½ cycle RMS result, the peaks of the 90ms populations are sensible, but in isolation, they are not definitive. This analysis begins with the ½ cycle results which are at least an order of magnitude stronger.



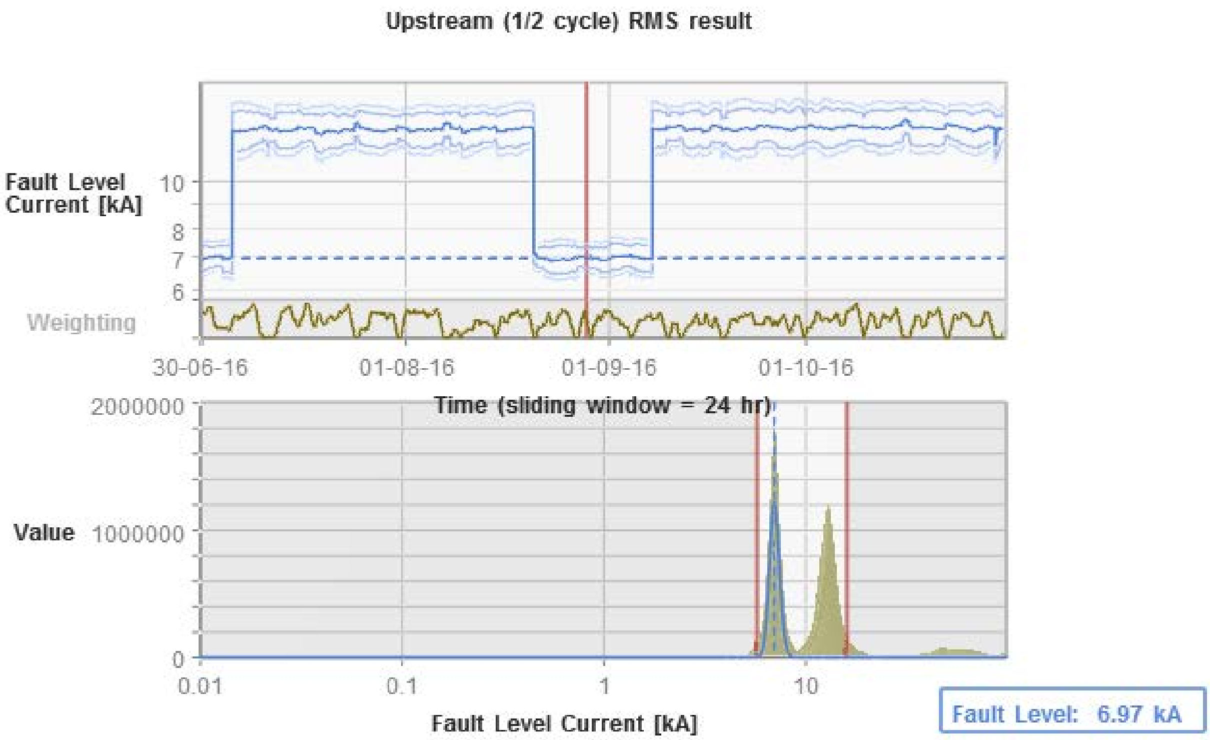
Graph 7. Upstream RMS Fault level at ½ cycle. 3D Distribution shown with 2% filtering.



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

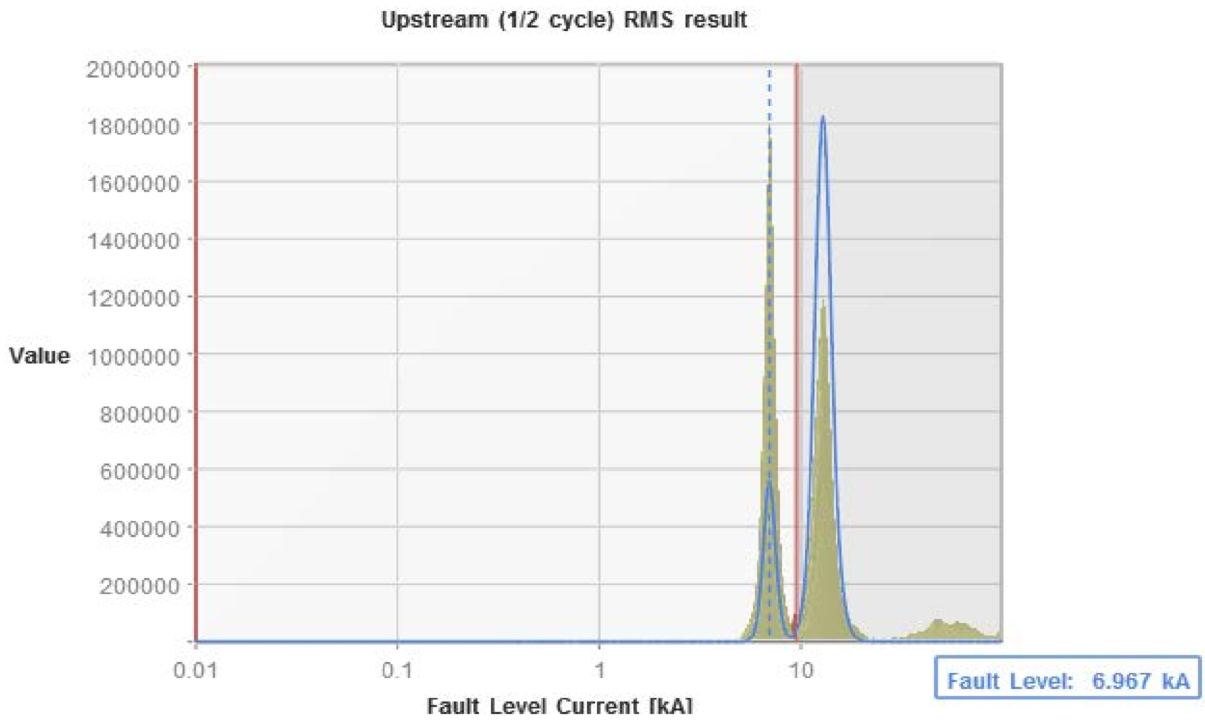
The main population is very tight, and eliminating filtering altogether yields an almost identical result of 12.80kA.

Clearly there are in fact two populations, and from graph 7 we can see a few days at the start and a 2½ week period starting late August for which the Fault Level was lower than the 12.83kA listed above. Graph 9 shows the Fault Level against time for the accrual period reduced to 1 day.



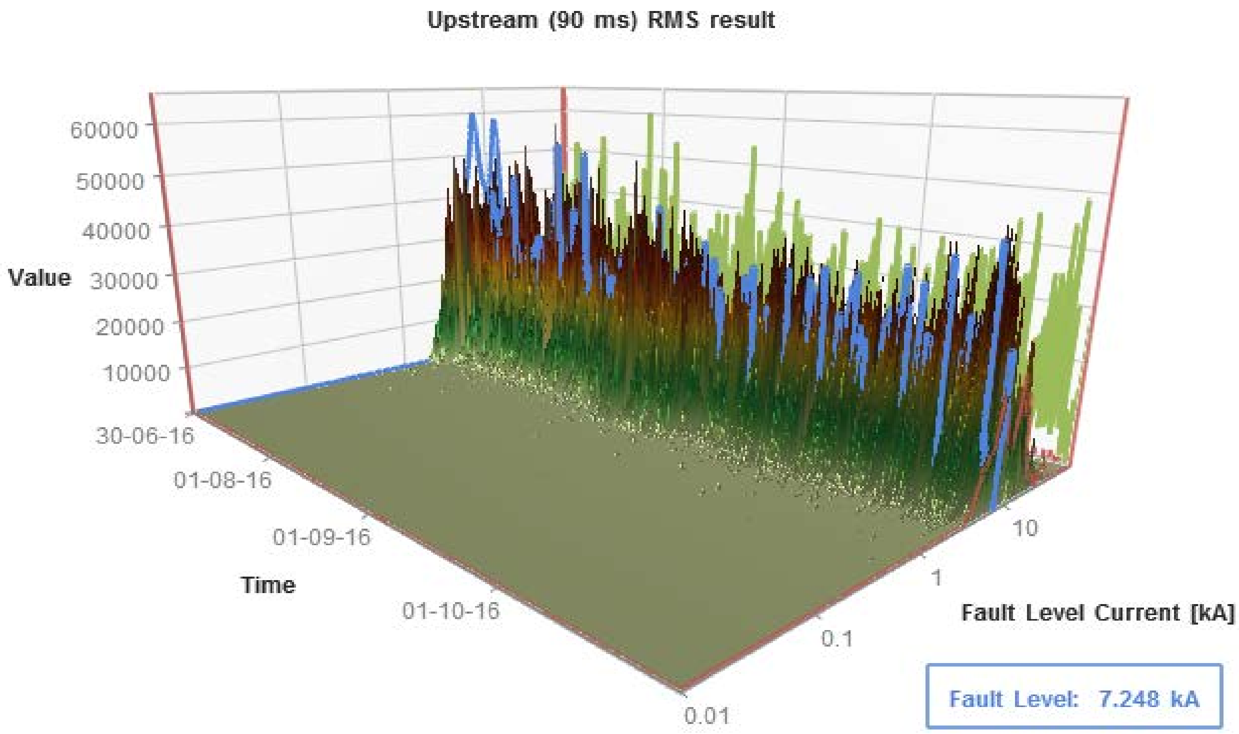
Graph 9. Fault Level against time for a 1 day sliding accrual period window, with 2% filtering.

By accruing results over the full four months, and using the 2D presentation, we can exclude the upper result and obtain a composite result for the two lower periods, as shown in Graph 10



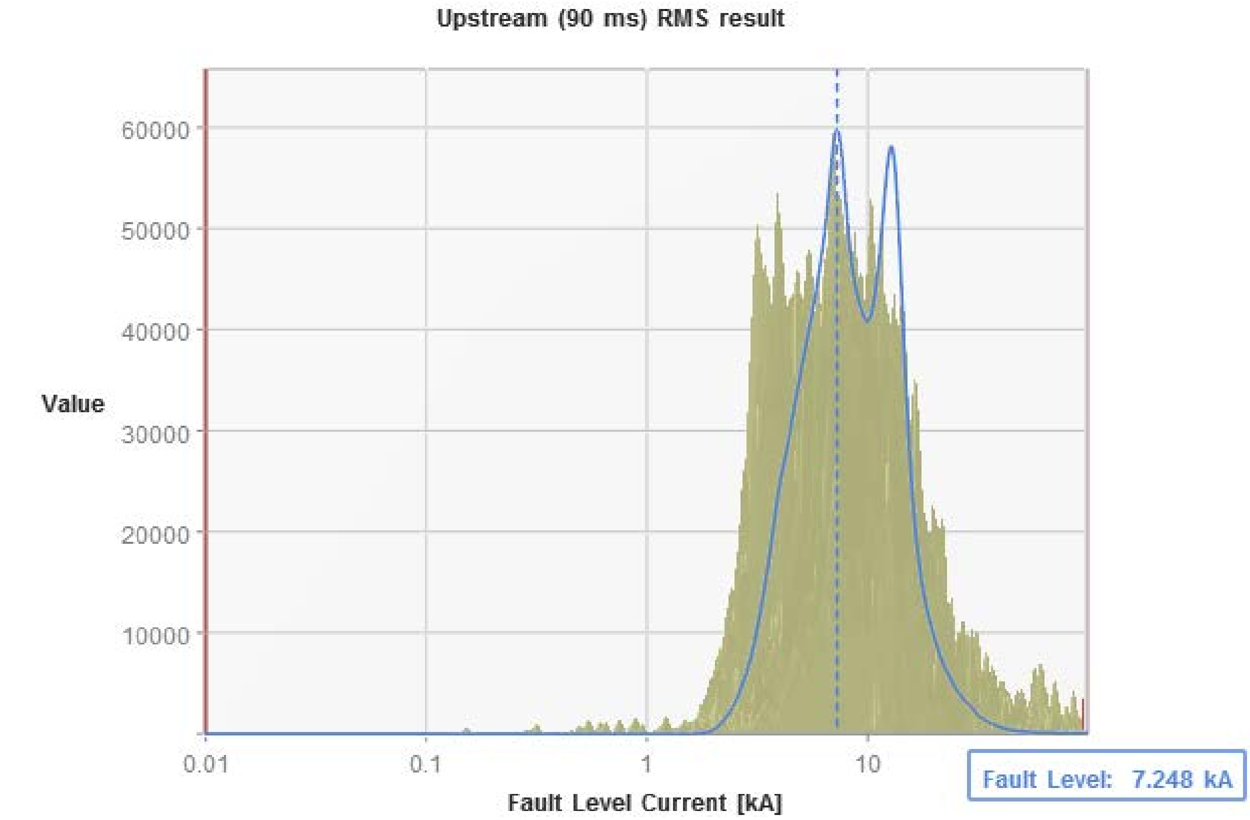
Graph 10. Upstream ½ cycle RMS result for the Low Fault Level regime, 2% filtering.

Using the ½ cycle Upstream RMS result as a reference, we can look at the 90ms RMS result. See graphs 11 and 12.



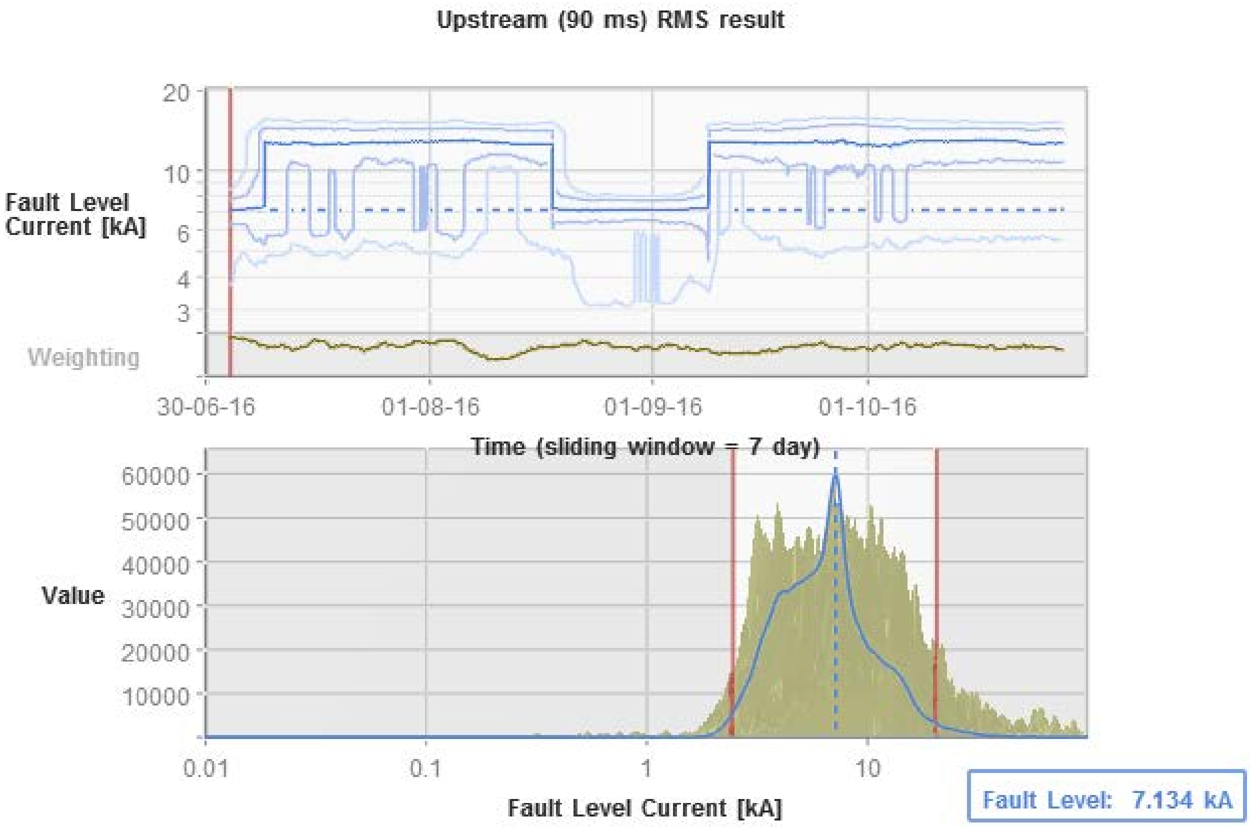
Graph 11. Upstream 90ms RMS result, 2% filtering, 3D presentation.

With the accrual time set to the full recording period, it is much less easy to see what is happening.



Graph 12. Upstream 90ms RMS result, 2% filtering, 2D presentation.

However with the accrual period reduced to seven days, and results shown against time, we can again see that there are four distinct periods. Graph 13 refers.



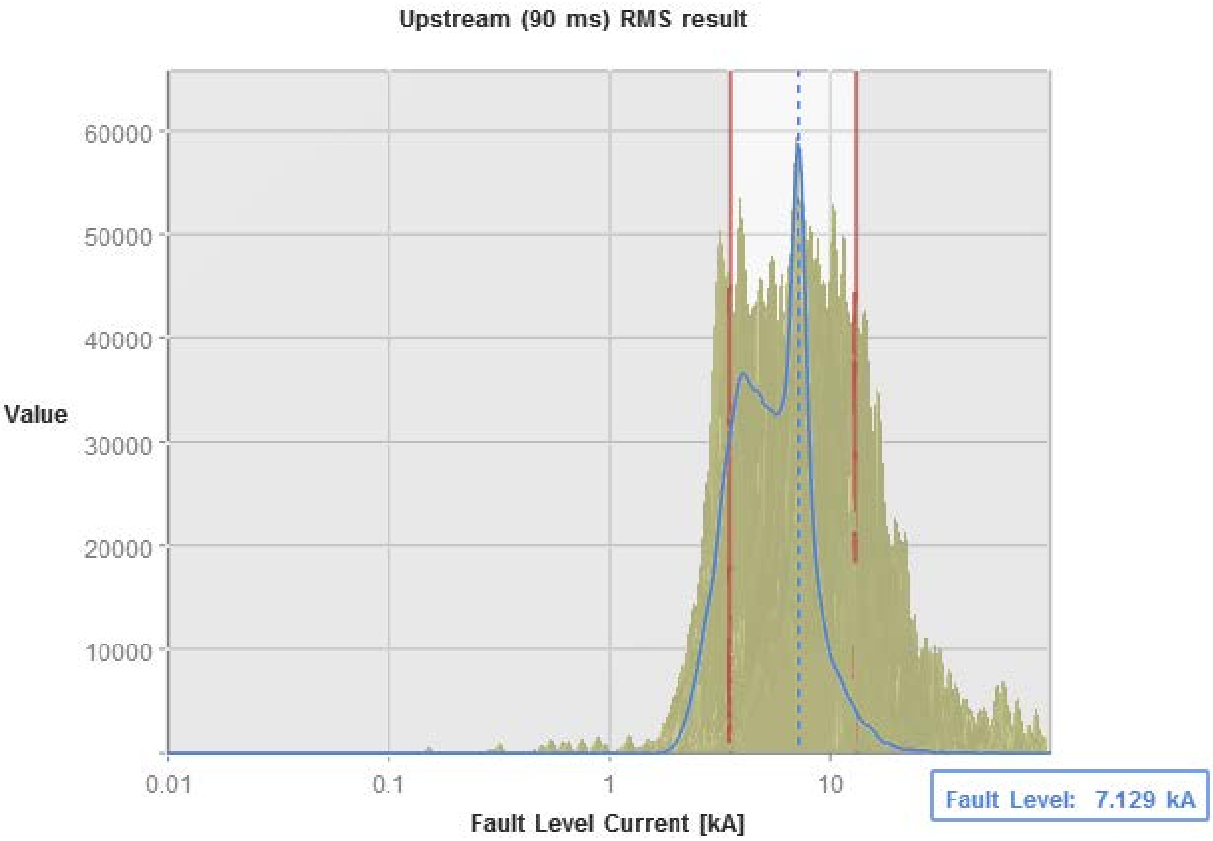
Graph 13. Upstream 90ms RMS result, 2% filtering, Fault Level against time, 7 day accrual boxcar.

Unfortunately as can be seen from the lower faded blue lines in the upper time graph, the result for the Lower Fault Level cannot be distinguished from the Upper on the basis of Fault Level value alone, because even during the High Fault Level periods, there are clearly many results producing low Fault Level values, so it is necessary to use "time" as a discriminator as well. Bear in mind that the *total* disturbance energy for 90ms is very low so these results do not merit the confidence we can apply to the ½ cycle RMS result.

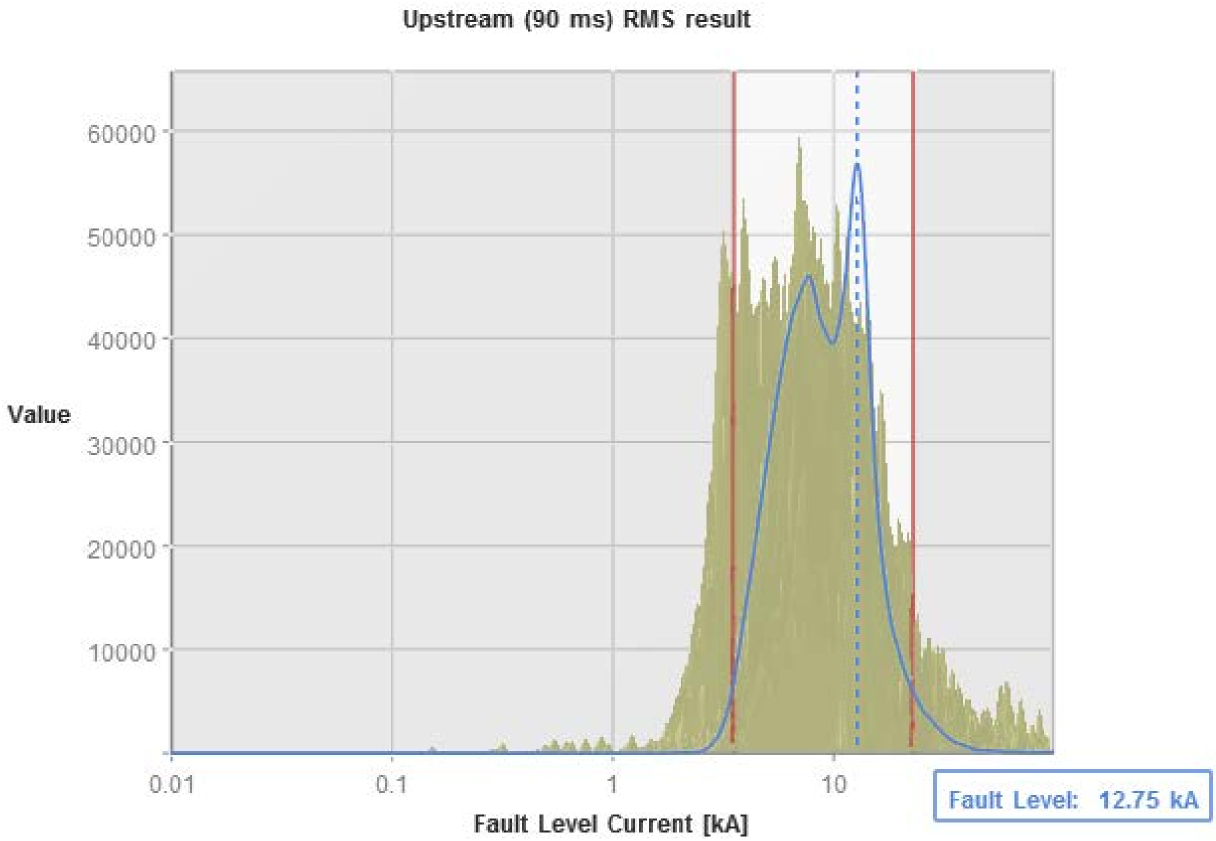
If we use the time information obtained from the ½ cycle data, viz. from start to ~17:30 on 5/7/16, and from ~13:30 on 20/8/16 to ~11:30 on 7/9/16 for the Low Fault Level periods, and allow a little margin (1-2 hours), we get four fault level results as shown below.

Period	Fault Level result (kA)
Start to 15:00 on 5/7/16	7.129
19:00 on 5/7/16 to 12:00 on 20/8/16	12.75
15:00 on 20/8/16 to 10:00 on 7/9/16	7.149
13:00 on 7/9/16 to end	12.82

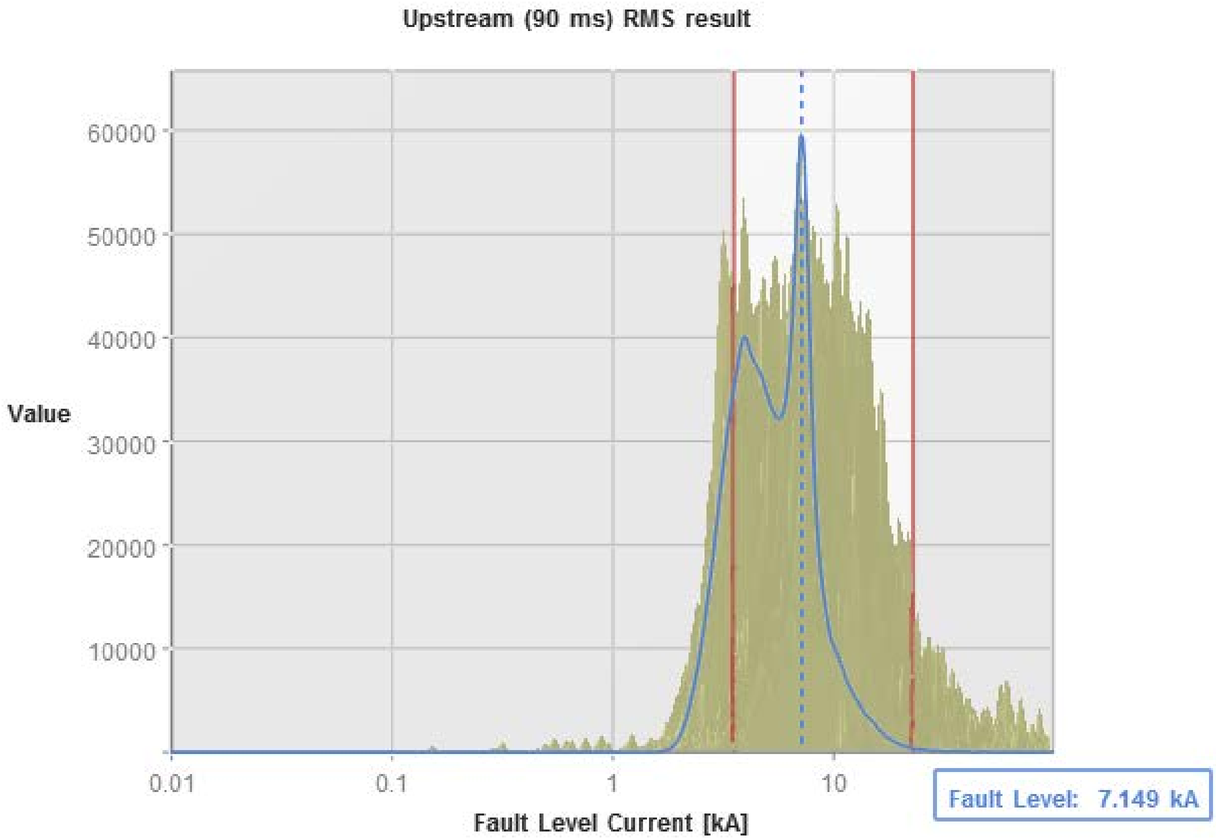
The distributions from which these Fault Level values were obtained are shown in graphs 14 to 17. Filtering of 2% was applied to all of them.



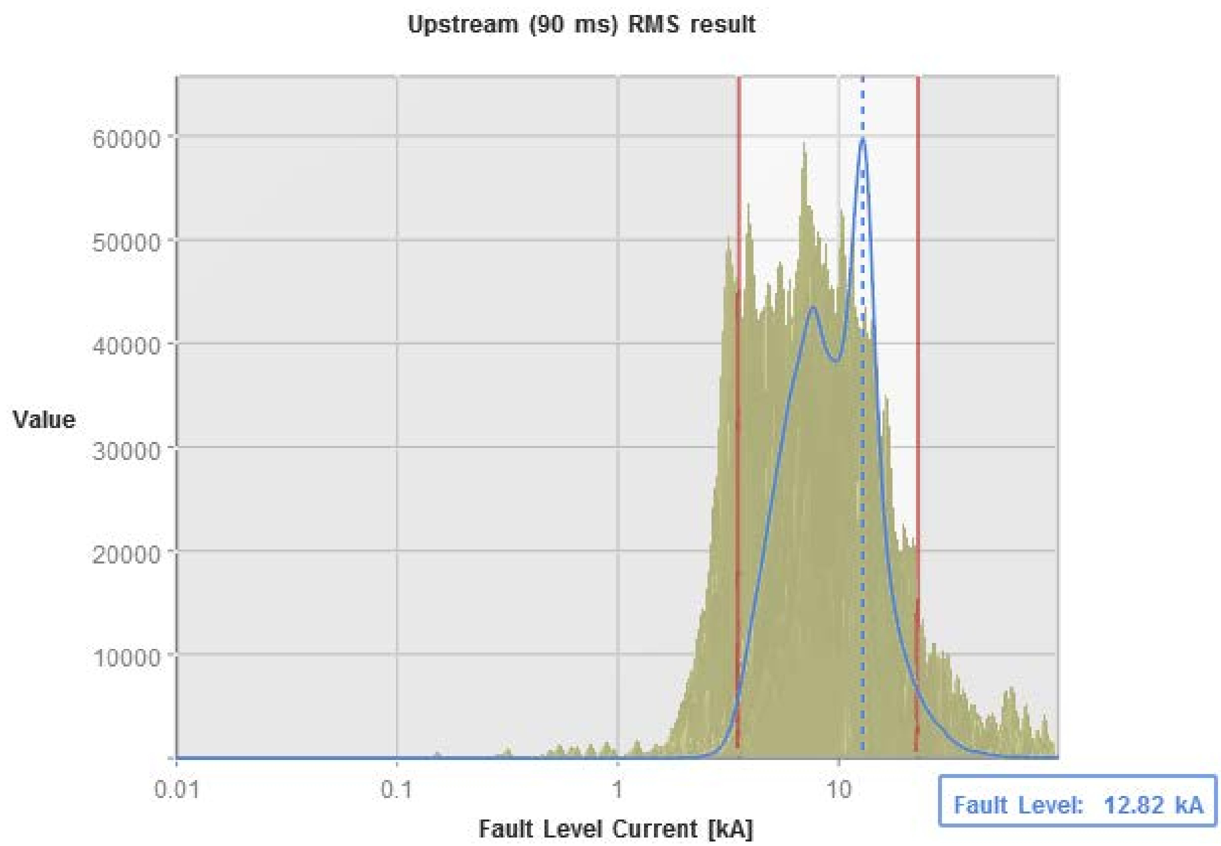
Graph 14. Upstream 90ms RMS result. Accrual period Start to 15:00 on 5/7/16 (Low value)



Graph 15. Upstream 90ms RMS result. Accrual period 19:00 on 5/7/16 to 12:00 on 20/8/16 (High value).



Graph 16. Upstream 90ms RMS result. Accrual period 15:00 on 20/8/16 to 10:00 on 7/9/16 (Low value).

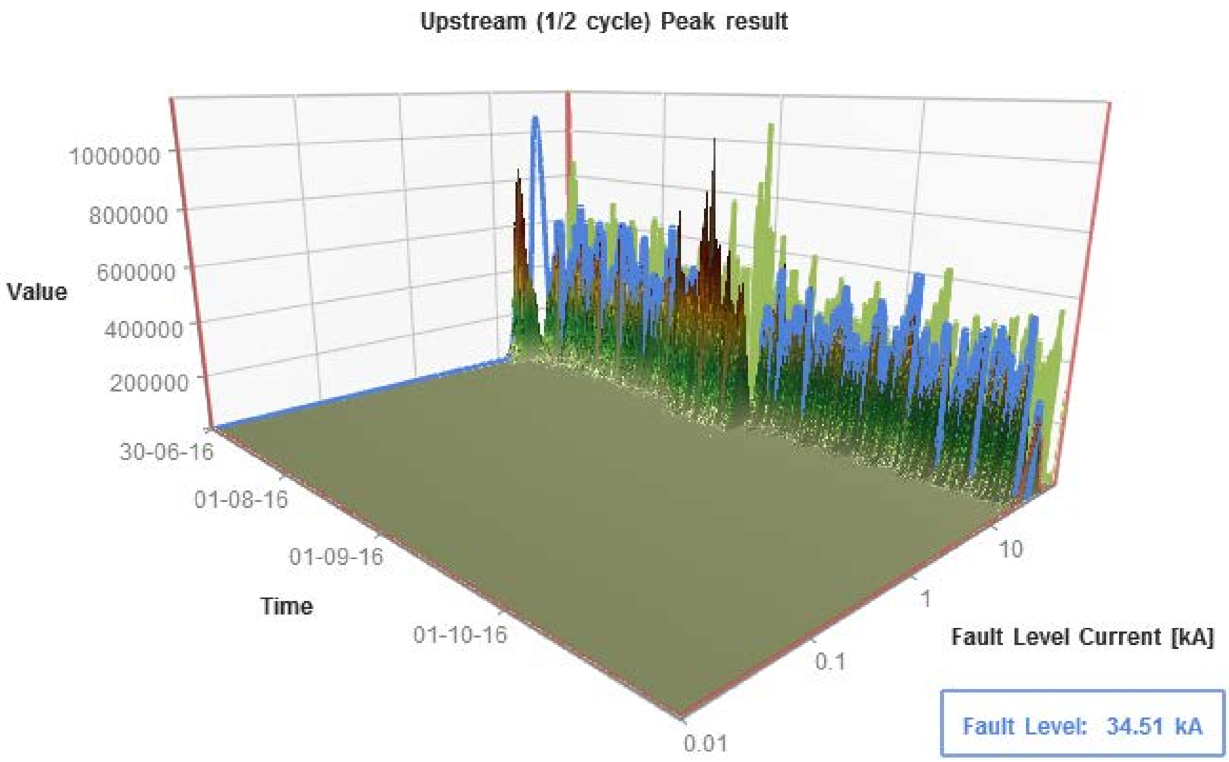


Graph 17. Upstream 90ms RMS result. Accrual period 13:00 on 7/9/16 to end (High value).

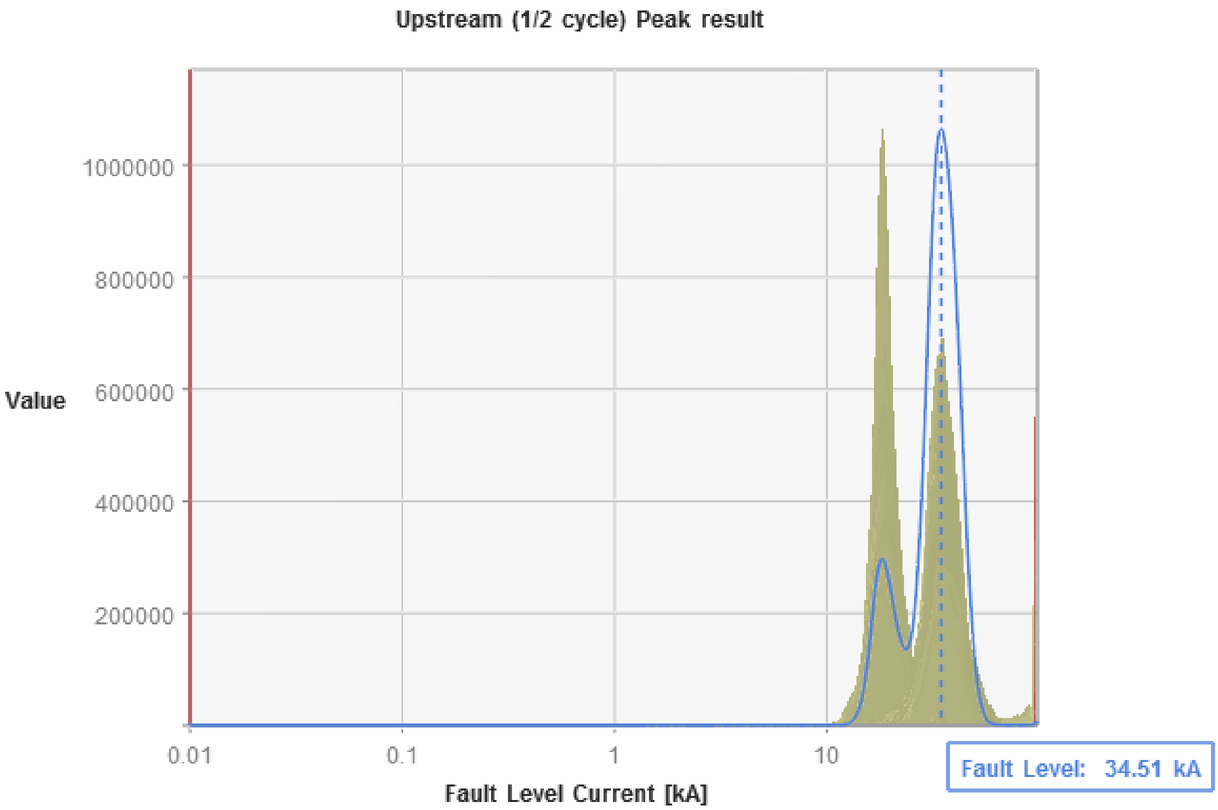
Referring back to Graph 12, which shows the result accruing over the full recording period, the lower peak is at 7.248kA and the upper at 12.76kA, both exhibiting a slight pulling influence from the other compared with the averages of the regions in isolation, (7.14kA and 12.79kA).

These compare with the ½ cycle results of 6.97kA and 12.83kA for the Lower and Upper Fault Level regimes. [My view is that in reality, the 90ms RMS Fault Level is unlikely to be above the ½ cycle RMS Fault Level, so since the lower region ½ cycle result from the FLM (6.97kA) is so much stronger and tighter than the 90ms result (7.14kA), the 90ms result is the one more likely to be in error.]

The ½ cycle peak result is straightforward. Graphs 18 and 19 show the 3D and 2D views for the full period with 2% filtering.



Graph 18. Upstream ½ cycle Peal Fault Level result 3D presentation, 2% filtering.

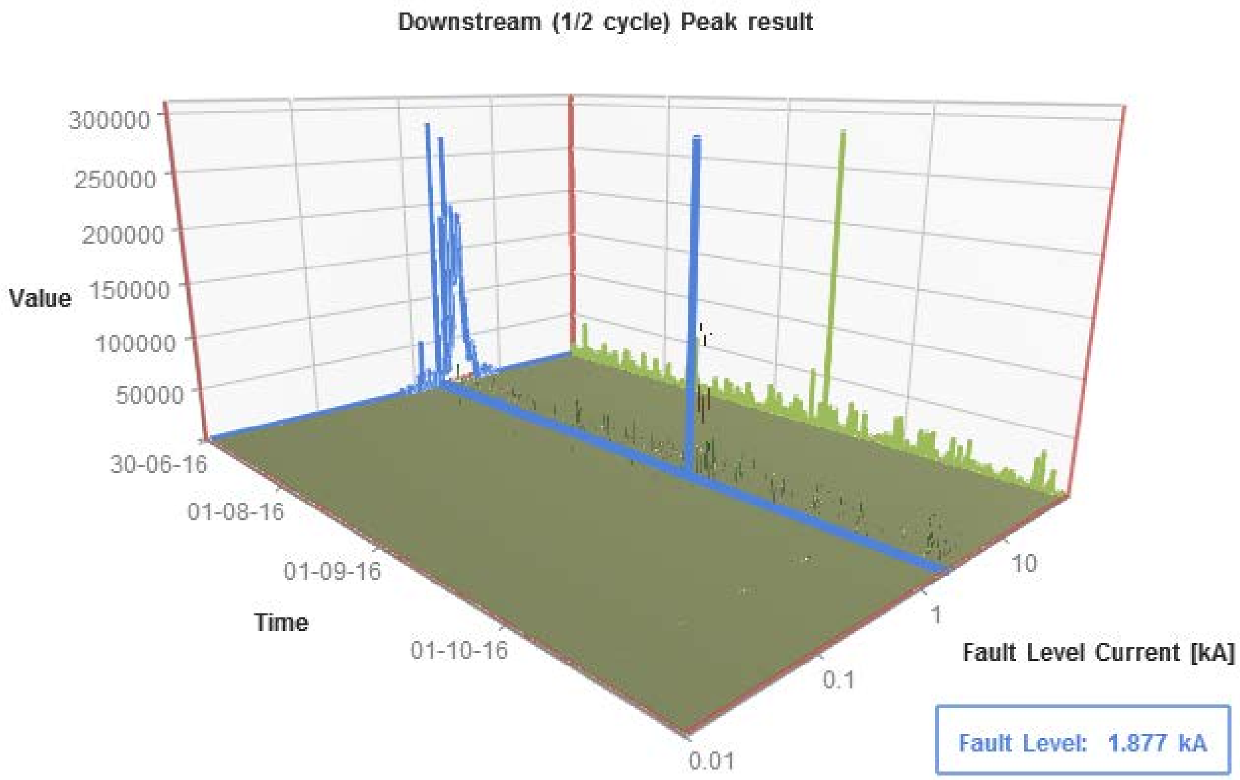


Graph 19. Upstream ½ cycle Peal Fault Level result 2D presentation, 2% filtering.

Without filtering, the result drops to 34.2kA. The lower peak with 2% filtering is at 18.2kA, without, at 18.05kA

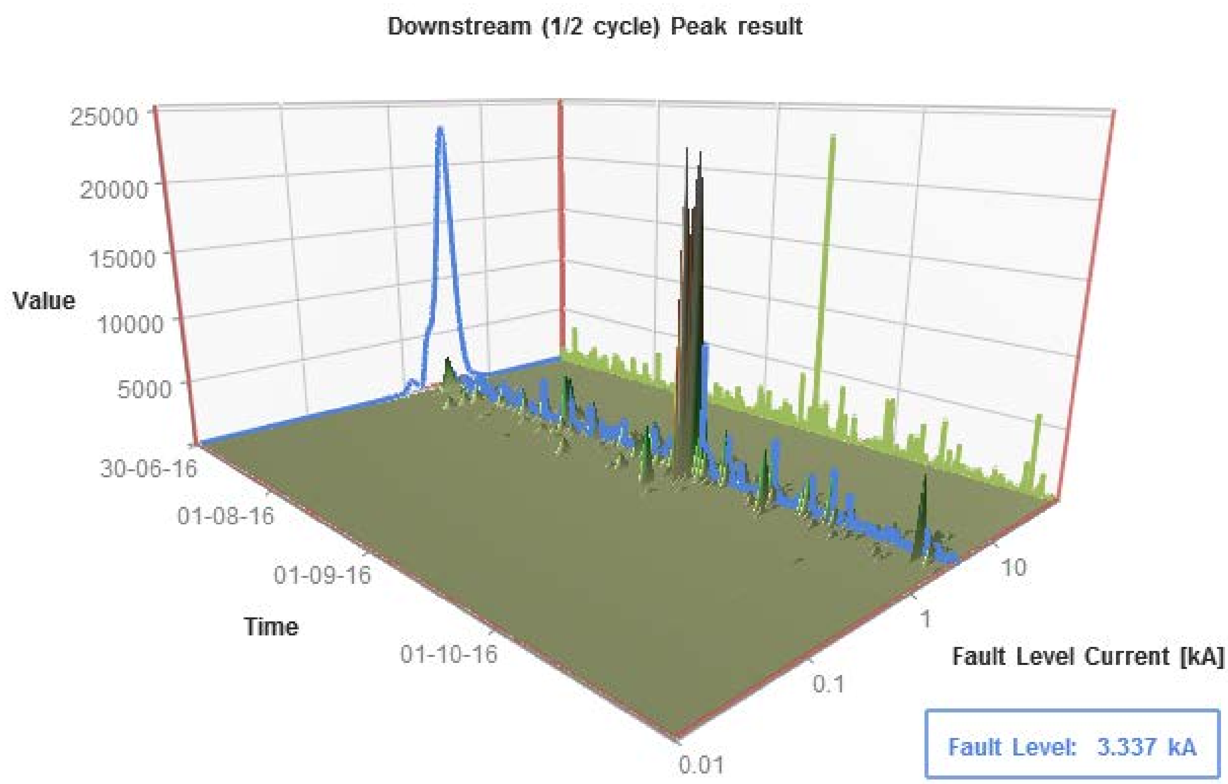
Downstream Fault Level contribution

Graphs 20 and 21 show the Peak half cycle Fault Level detected for downstream contribution. Graph 20 is with no filtering, and Graph 21 with 5%.



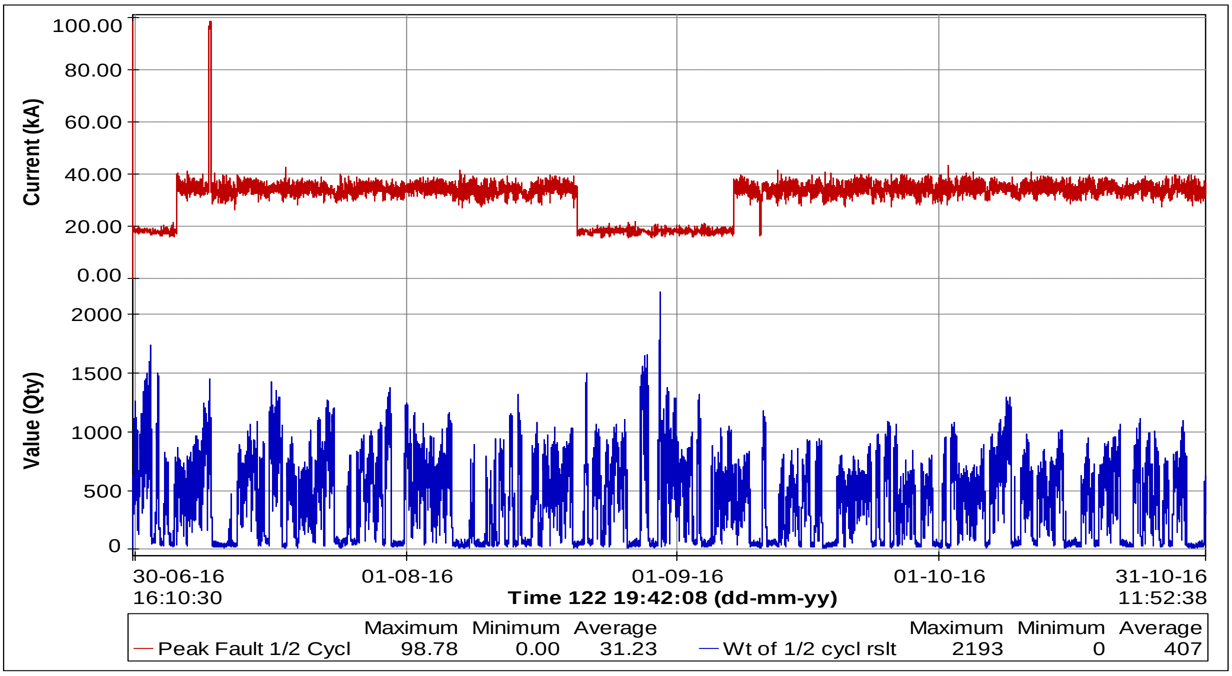
Graph 20. Downstream ½ cycle Peal Fault Level result 3D presentation, no filtering.

Without filtering, the result is dominated by a single spike from the cluster of events on 13th Sept. The other events during that interval give a higher contribution, so while any one of these results may be correct at the time, the worst case may be better represented by the filtered result below. Graph 21 shows 5% filtering.

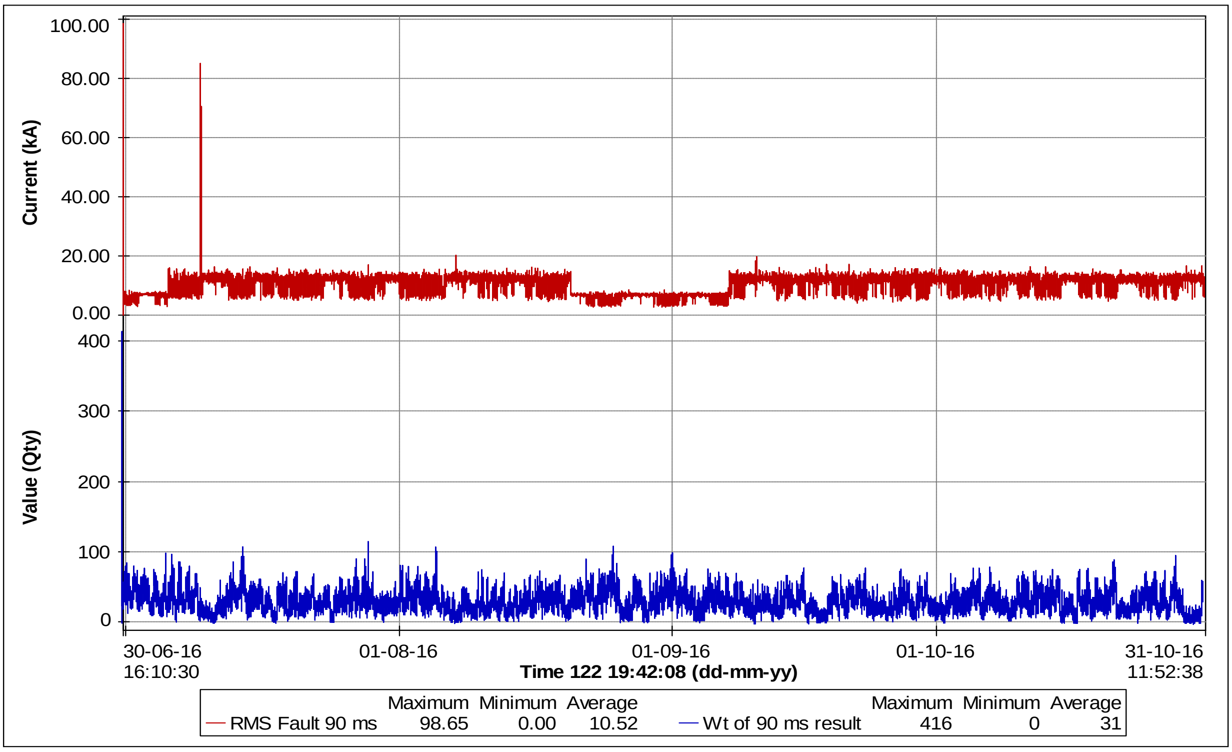


Graph 21. Downstream ½ cycle Peal Fault Level result 3D presentation, 5% filtering.

The following graphs 22 and 23 show the detail results and weighting applied at ½ cycle and 90 ms respectively.



Graph 22. Peak upstream results and weighting present at ½ cycle.



Graph 23. RMS upstream results and weighting present at 90ms.