RESPOND Project Fault Level Report for Electricity North West Ltd

ENWL Fault Level Report 4 V1, 18/05/2017

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Change record		
Date	**Edited by**	**Reason**
18/05/2017	J.D.Outram	

Contents

Introduction

This report documents the results obtained from PM7000 Fault Level Monitors installed at two ENWL sites in winter 2016-17. These installations and the fault level results obtained are listed below. Detailed results and interpretations are included in the appendices for each site.

In April 2017, 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	Blackbull Primary	23/11/2016	05/04/2017
0888	Nelson Primary	23/11/2016	05/04/2017

Both recordings produced a great deal of raw data, and for each, the recording period was split into two roughly equal halves and the results reported for each half independently.

Connection checks

Connection validation 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

Several Fault Level results were obtained for each site as shown in the table. All results are in kA. The figure in brackets beside them is the Filter value used for the evaluation.

Blackbull Primary, FLM Serial No 0887

Period 23/11/16 to 02/02/17.

Start Time	End Time	10ms Peak Upstream	10ms Peak Downstream	90ms RMS upstream	Combined 10ms Peak[1]
23/11/16 [2]	02/02/17	30.70 (2%)	4.71 (5%)	12.85 (2%)	35.41
10/12/16 19:30	12/12/16 12:00	16.13	(4.71)	6.80	20.84
13/12/16 22:30	15/12/16 14:30	16.09	(4.71)	7.05	20.80

Period 2/2/17 to 5/4/17.

Start Time	End Time	10ms Peak Upstream	10ms Peak Downstream	90ms RMS upstream	Combined 10ms Peak[1]
02/02/17	05/04/17	30.50 (2%)	4.95 (5%)	12.81 (2%)	35.45
09/02/17 08:00	09/02/17 12:30	15.87	(4.95)	6.48 (5%)	20.82
13/03/17 11:30	16/03/17 16:00	15.84 (4%)	(4.95)	6.76 (4%)	20.79

Nelson Primary, FLM Serial No 0888

Period 23/11/16 to 01/02/17.

Start Time	End Time	10ms Peak Upstream	10ms Peak Downstream	90ms RMS upstream	Combined 10ms Peak[1]
23/11/16 15:02	29/11/16 14:00	17.56 (2%)	(3.91)	7.26 (2%)	21.47
29/11/16 14:00	01/02/17 15:02	30.99 (2%)	3.91 (5%)	12.9 (2%)	34.90

Period 01/02/17 to 05/04/17.

Start Time	End Time	10ms Peak Upstream	10ms Peak Downstream	90ms RMS upstream	Combined 10ms Peak[1]
01/02/17 15:03	13/02/17 08:30	30.04 (2%)[3]	(3.96)	12.23 (2%)	34.00
13/02/17 08:30	05/04/17 17:28	22.76 (2%)	3.96 (5%)	9.77 (2%)	26.72

[1] This assumes that 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] This set of results is aggregated for the full beginning to end period, with the relatively short Fault Level deviation intervals reported in the rows below automatically excluded.

[3] This is the aggregated result for the 10 day period, In fact the Peak Fault Level value does change by 14% during this interval, though 10ms RMS and 90ms RMS Fault Level results change little. See appendix 2.

General comment on results

Results at both locations were generally tight, with little scope for manipulation. Light filtering of 2% was used for the main Upstream results and 5% for the Downstream. On several occasions the Upstream contribution to Fault Level distinctly changed value, as listed in the tables above. Downstream results needed rather more filtering. They did show some evidence of systematic variation, particularly at Nelson over the Christmas and New Year periods.

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

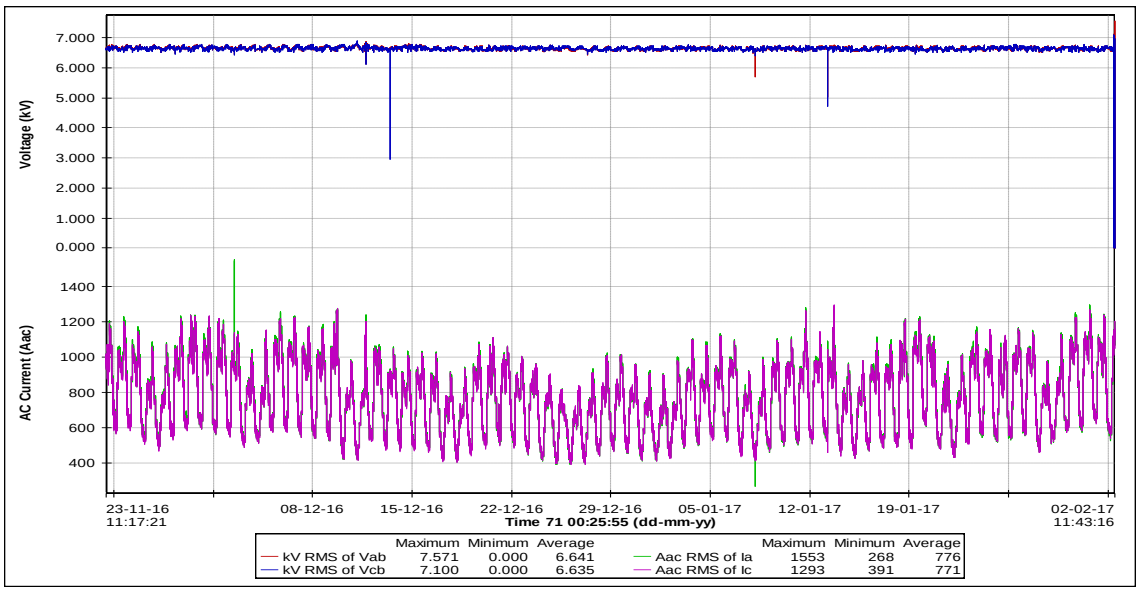
Appendix 1. Blackbull Primary. FLM Serial No 0887

Sources of error

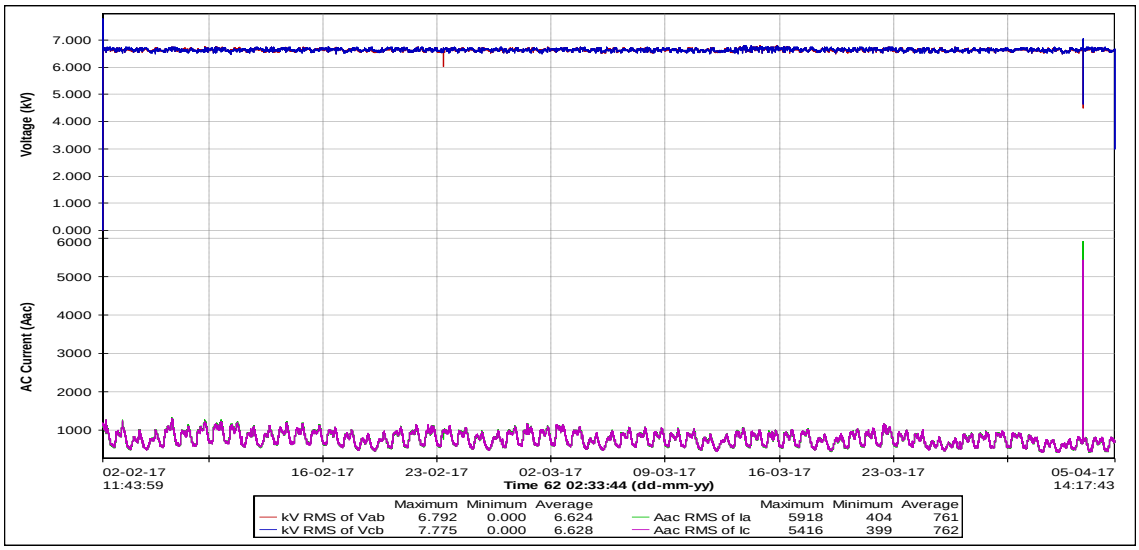
The overall results for Blackbull over the 4 month period are good. There is very little room for manipulation of these results, so sources of error are principally the systematic ones of incorrect assumptions, wrong CT settings, faulty sensors, cables etc. If the current and voltage results recorded by the PM7000 and shown below match the independent measurements reported by the ENWL SCADA or other systems, then it is unlikely that these results are wrong.

Blackbull results, General observations

Graphs 1 and 2 shows the voltage and current for the full recording period.

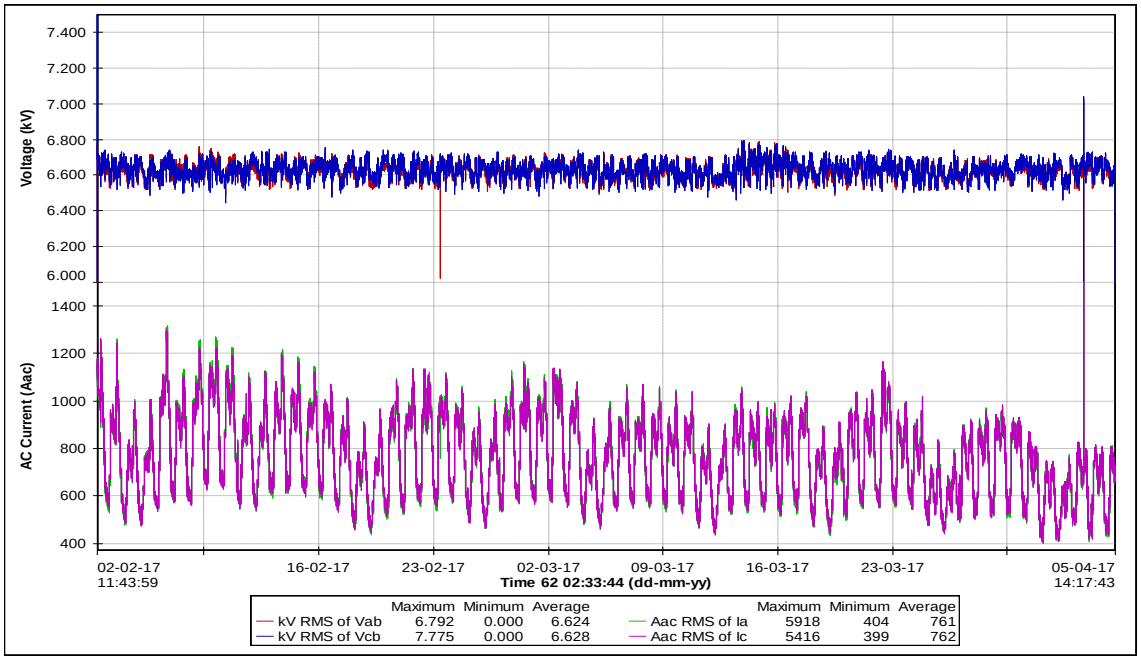


Graph 1. Volts and Current for the recorded period to 02/02/17.



Graph 2. Volts and Current for the recorded period 02/02/17 to 05/04/17.

Graph 3 shows the second half of the recording again zoomed into the Y-axes to see if there is any other major detail



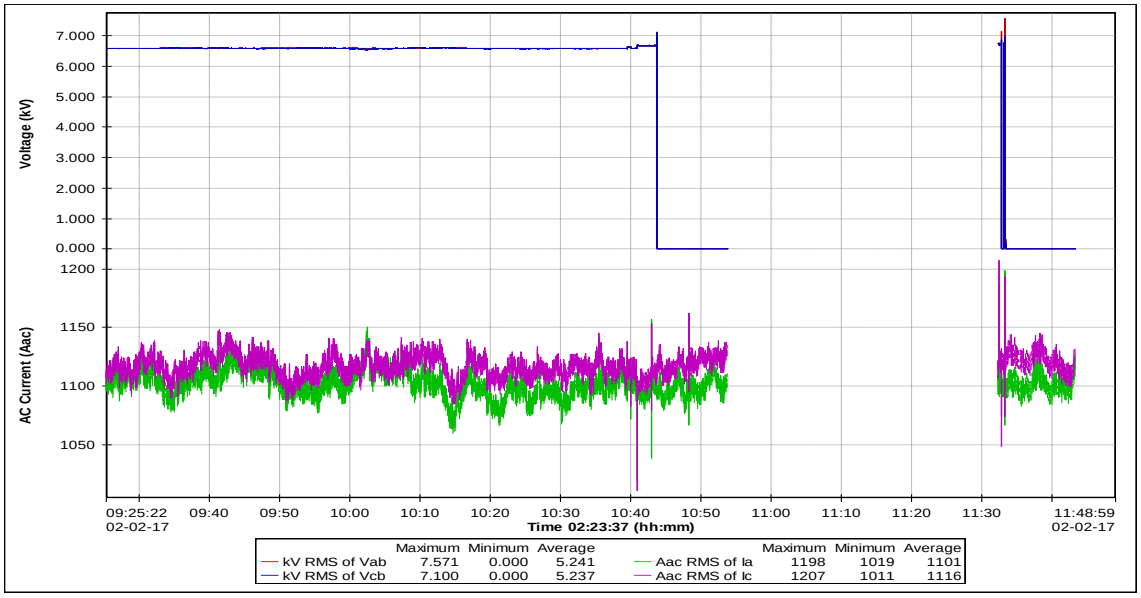
Graph 3. Volts and Current for the recorded period 02/02/17 to 05/04/17. Y-axes magnified.

There was a set of interruptions and restorations over about an hour on 02/02/17. These caused the recording of some short sessions as power came and went. There were a small number of current and voltage events also shown below.

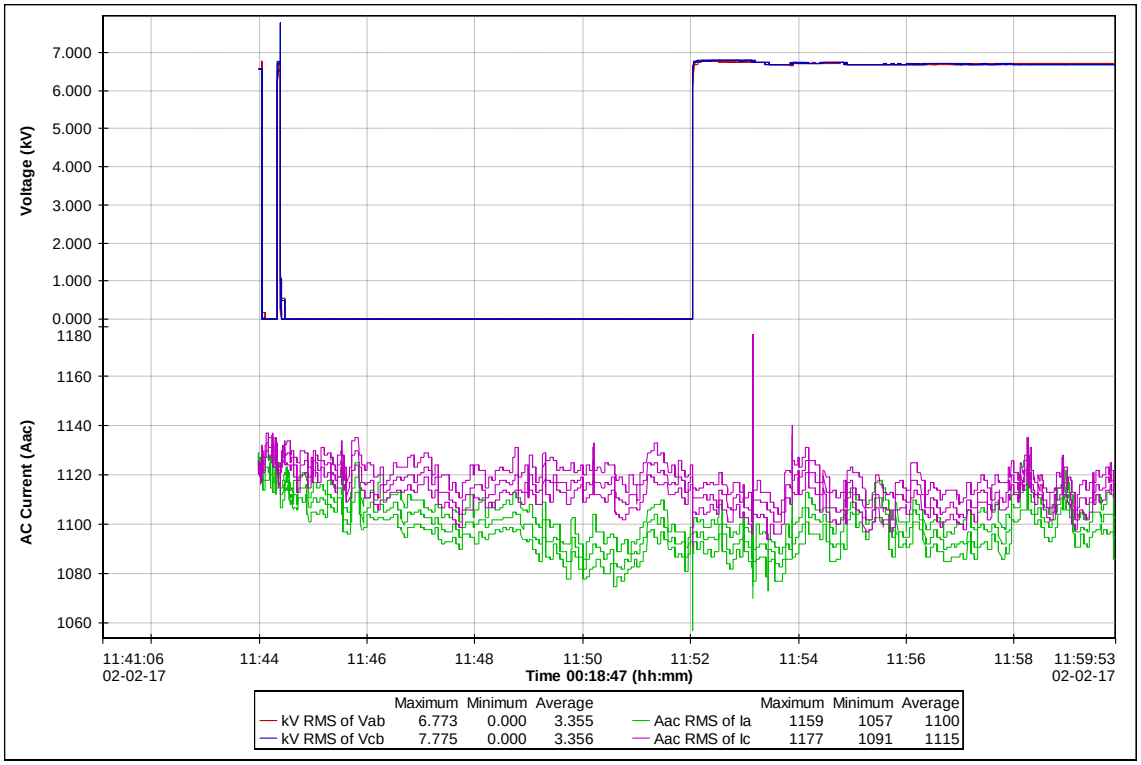
The interruptions #1 and #2 are shown in Graphs 4 and 5.

Graph 6 shows two major current events on 02/12/16 which are expanded in Graphs 7 and 8. Graphs 9 and 10 show further current events on 03/04/17.

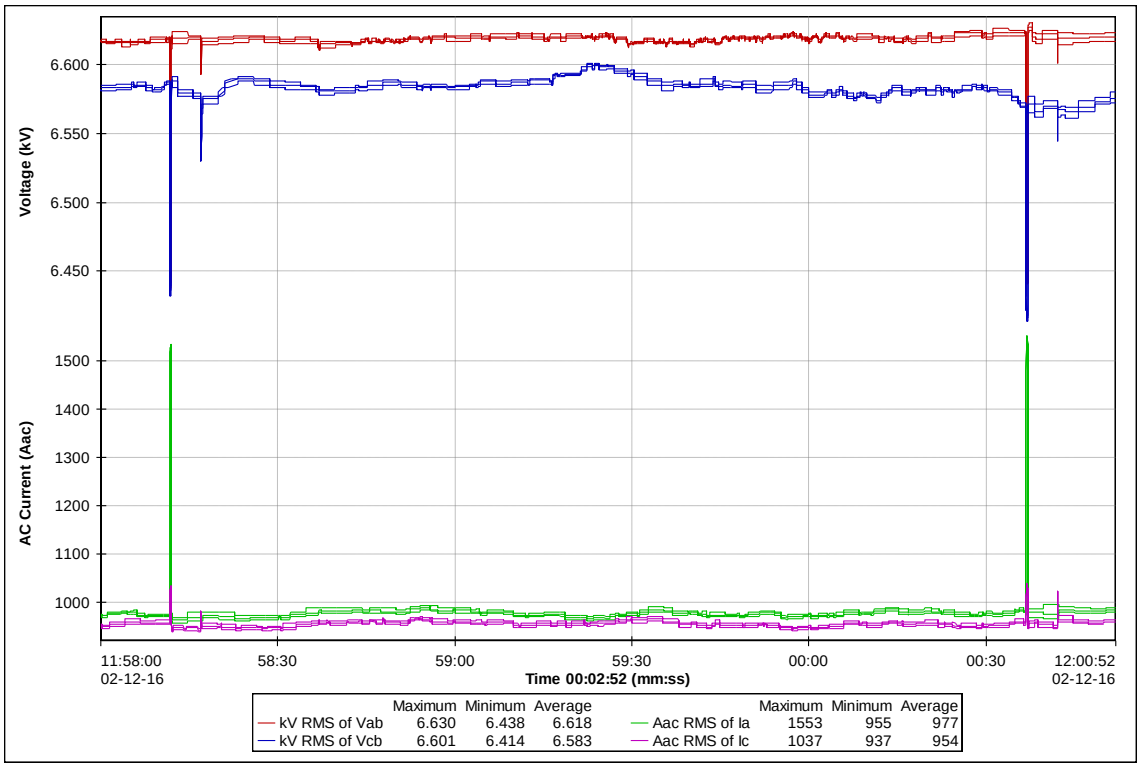
Voltage events are shown in Graphs 11, 12, 13 and 14.



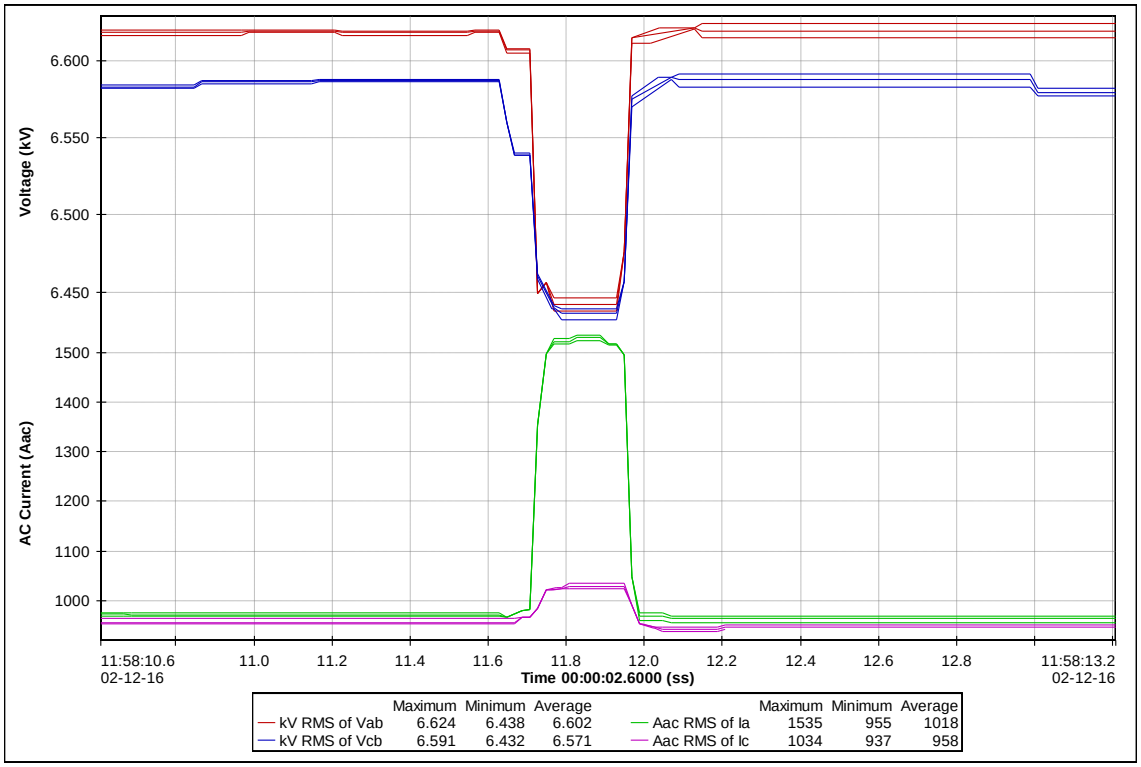
Graph 4. Interruption set #1



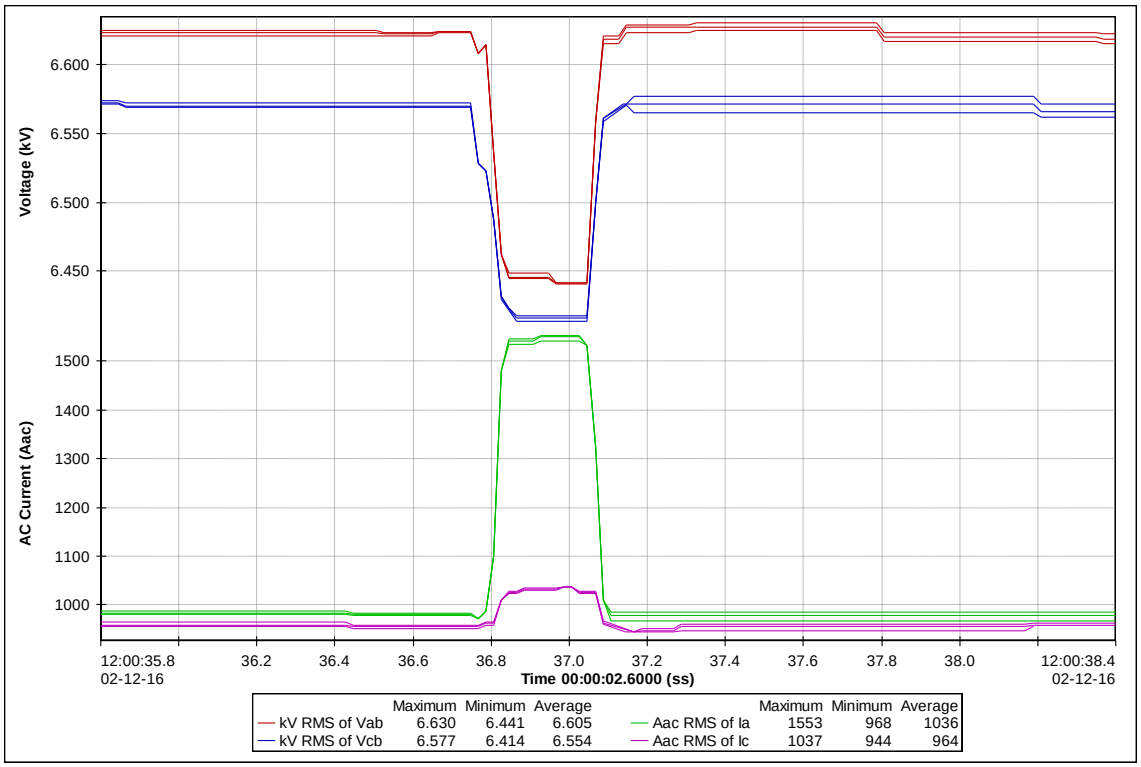
Graph 5. Interruption set #2 (Note time axis scale change)



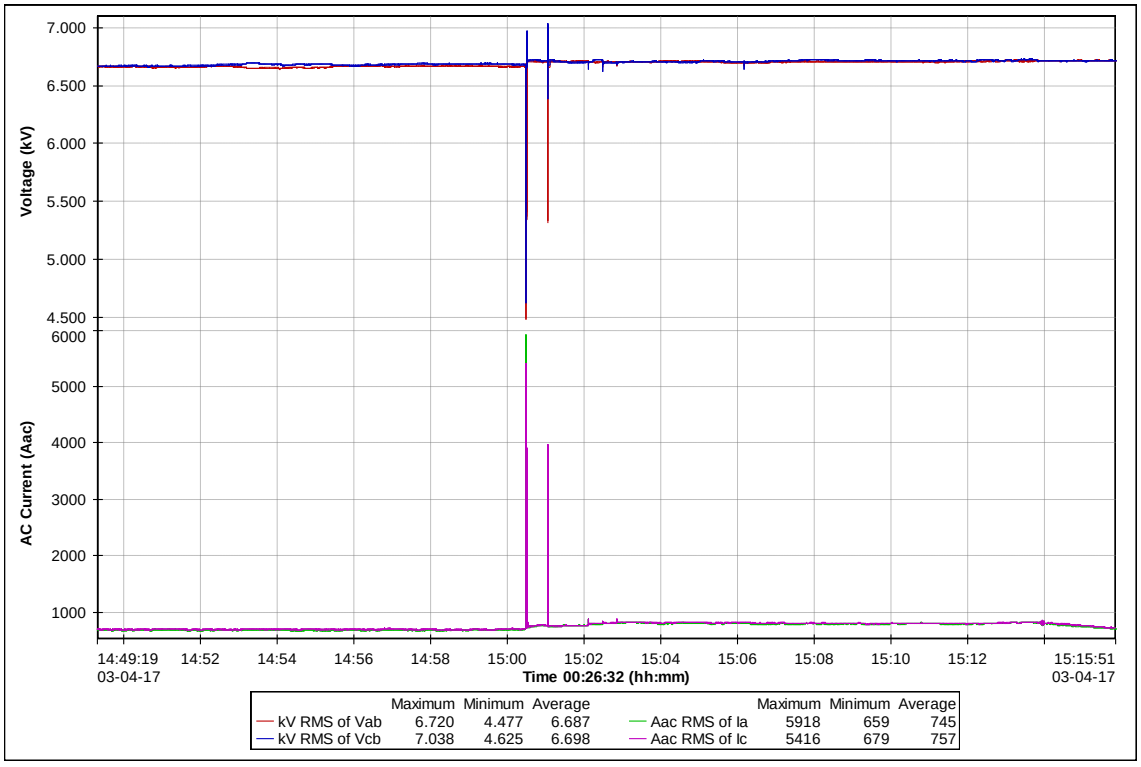
Graph 6. Two major current events on 2nd December.



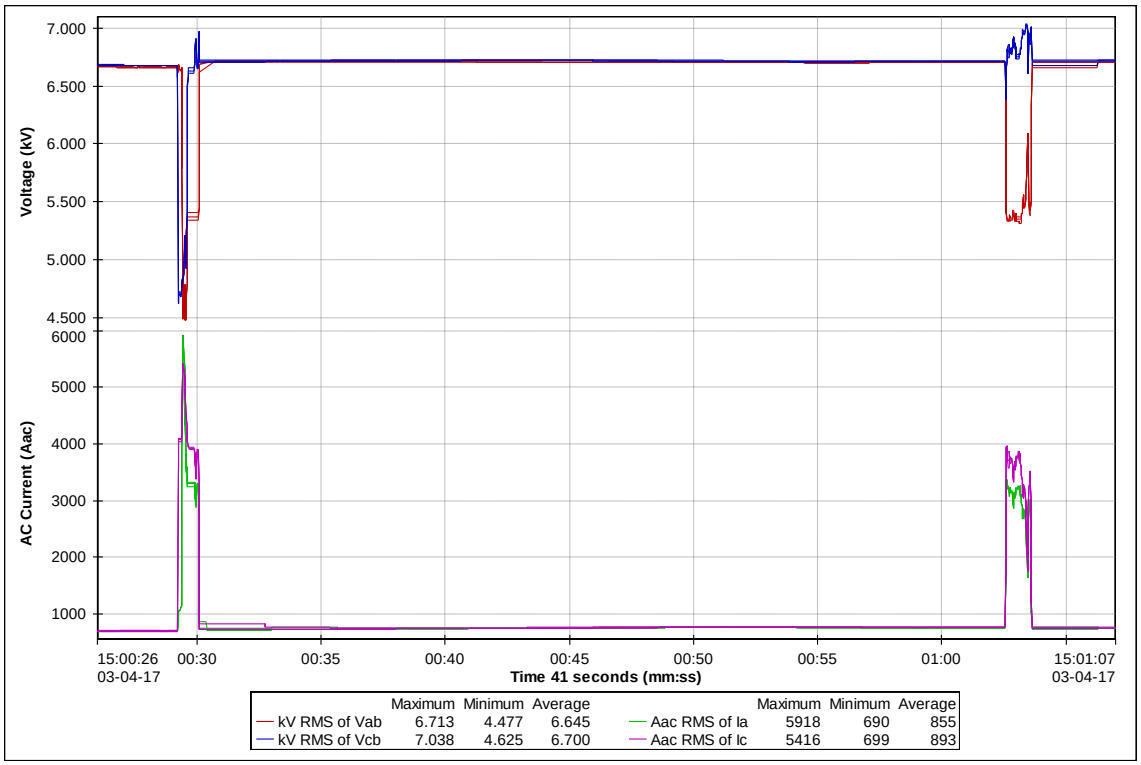
Graph 7. Major current events #1, expanded.



Graph 8. Major current events #2, expanded.

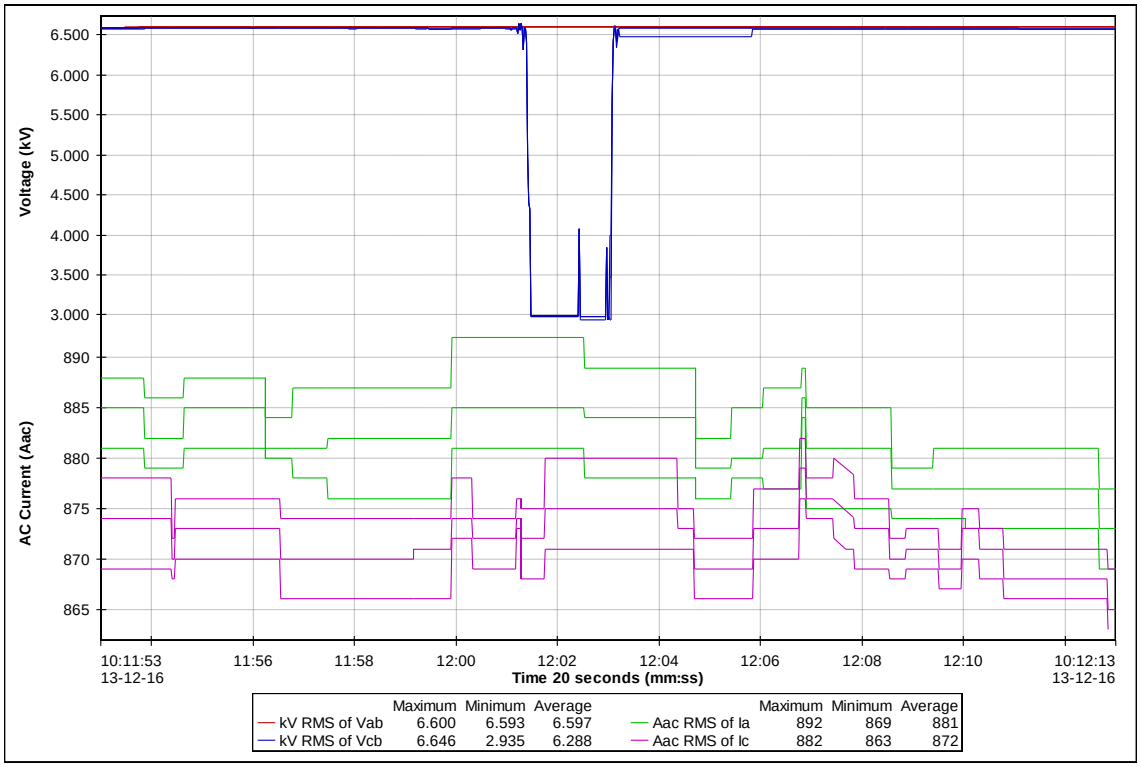


Graph 9. Further Major current events #3 & #4 on 3rd April.

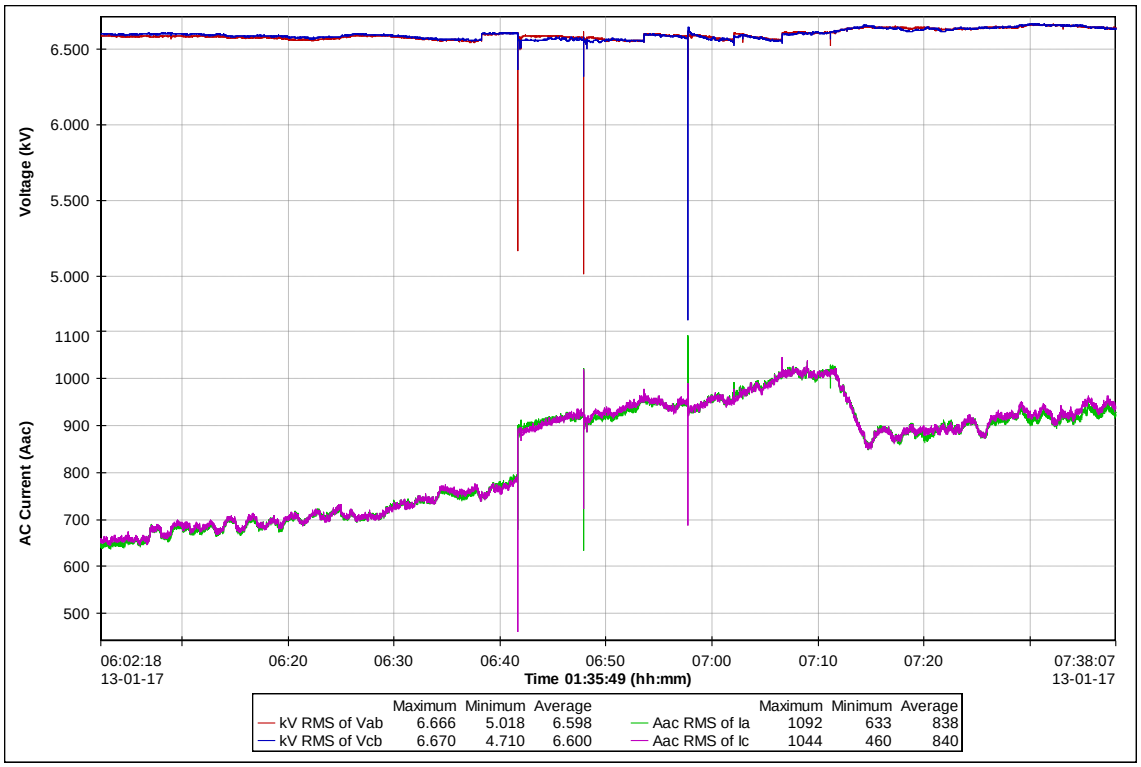


Graph 10. Major current events #3 & #4, expanded.

The above current spikes are actually not useful for Fault Level evaluation as they may have come close to saturating the CTs.

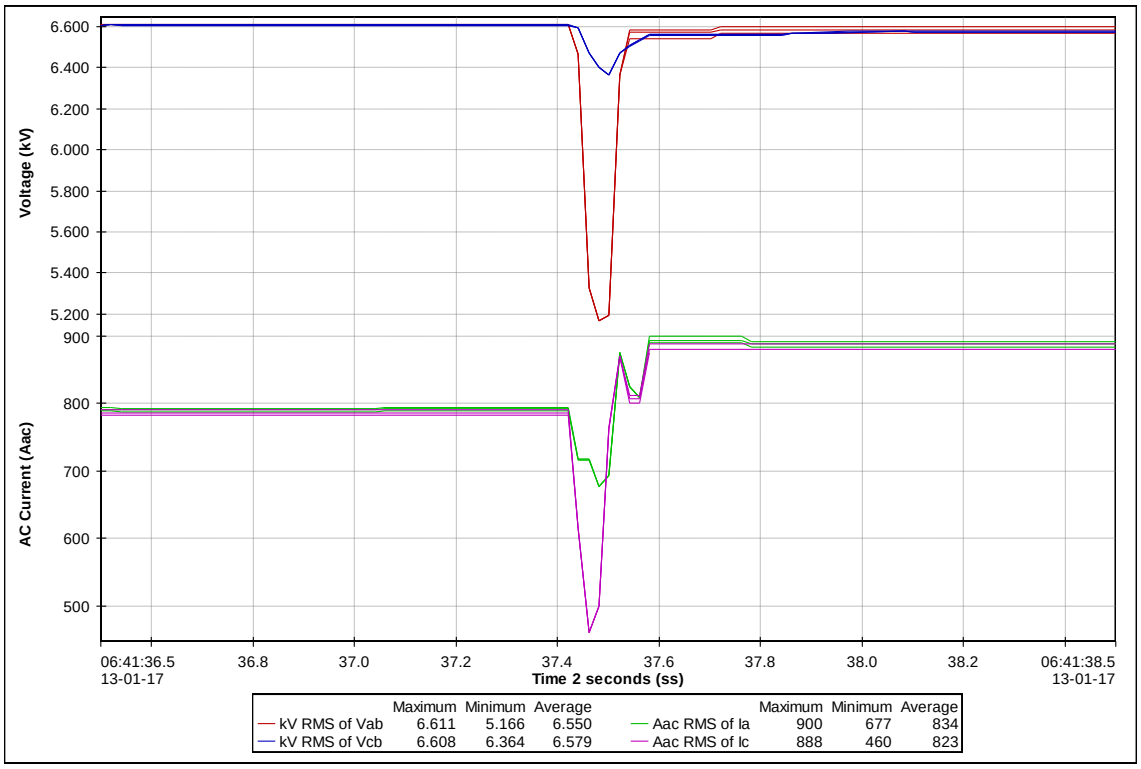


Graph 11. Single phase voltage event, 13/12/16

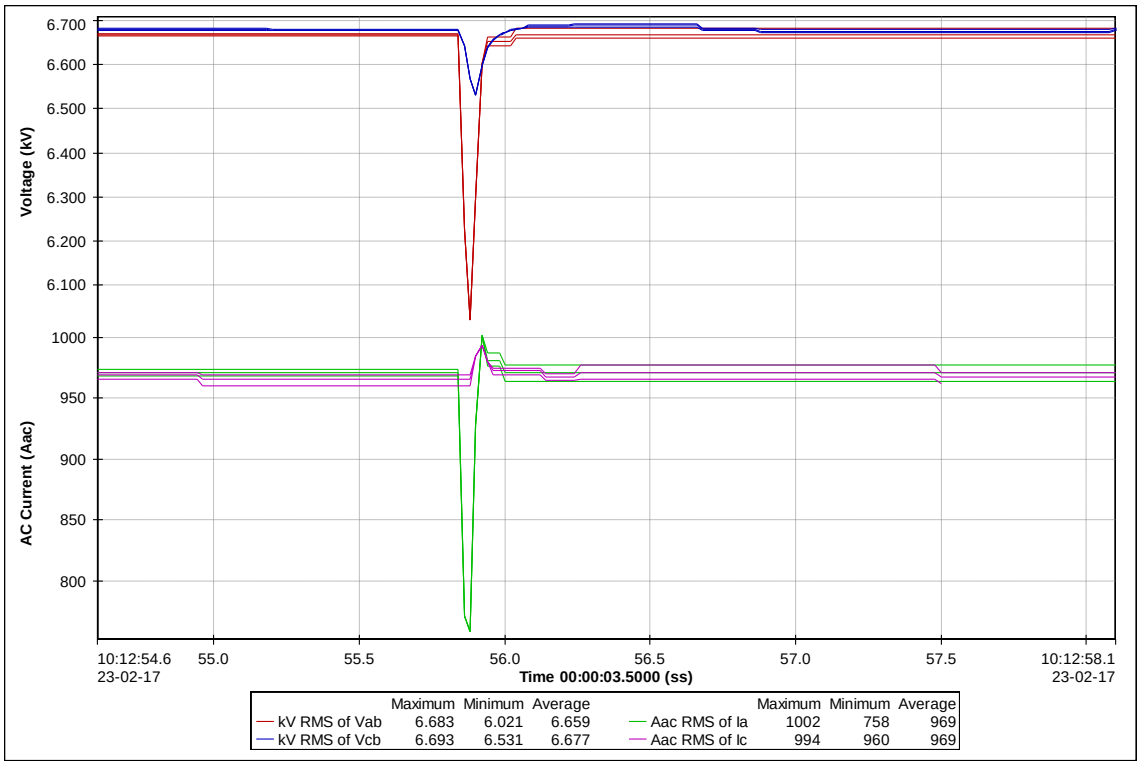


Graph 12. Isolated voltage events, 13/01/17. All three are short, <200ms. The first is expanded below.

The First appears the most interesting. All are short, < 200ms.



Graph 13. First of the isolated voltage events, 13/01/17, expanded.

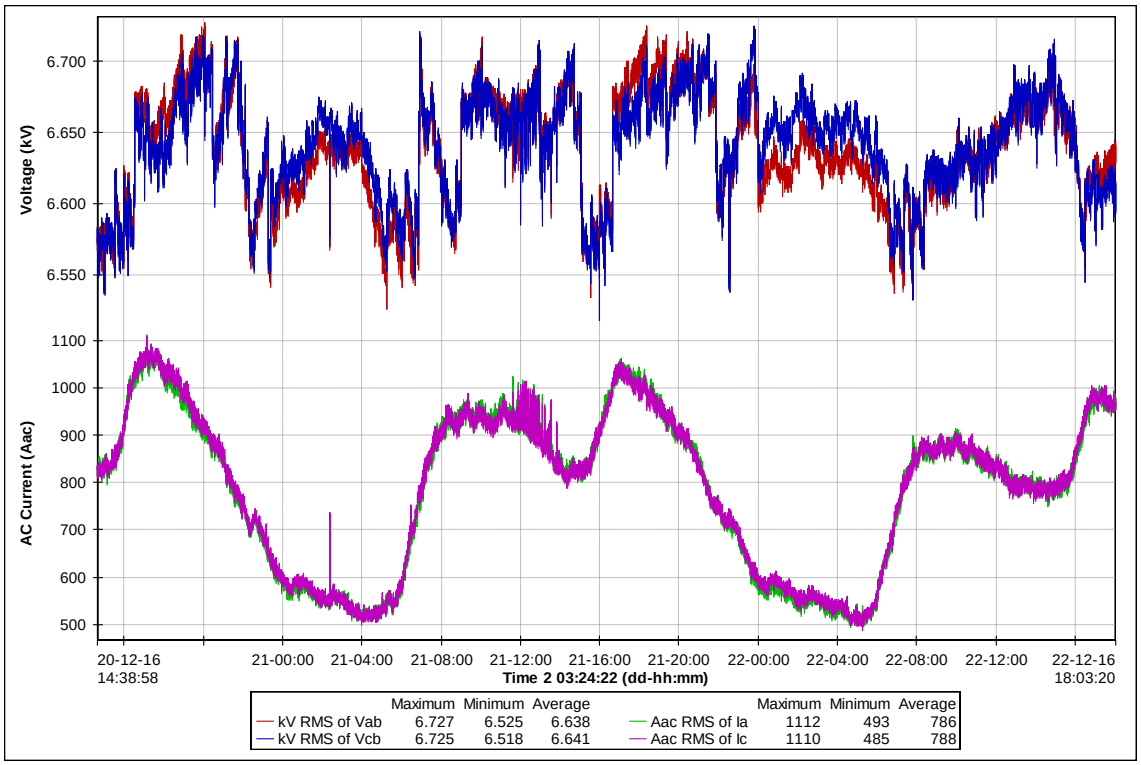


Graph 14. Isolated voltage events, 23/02/17.

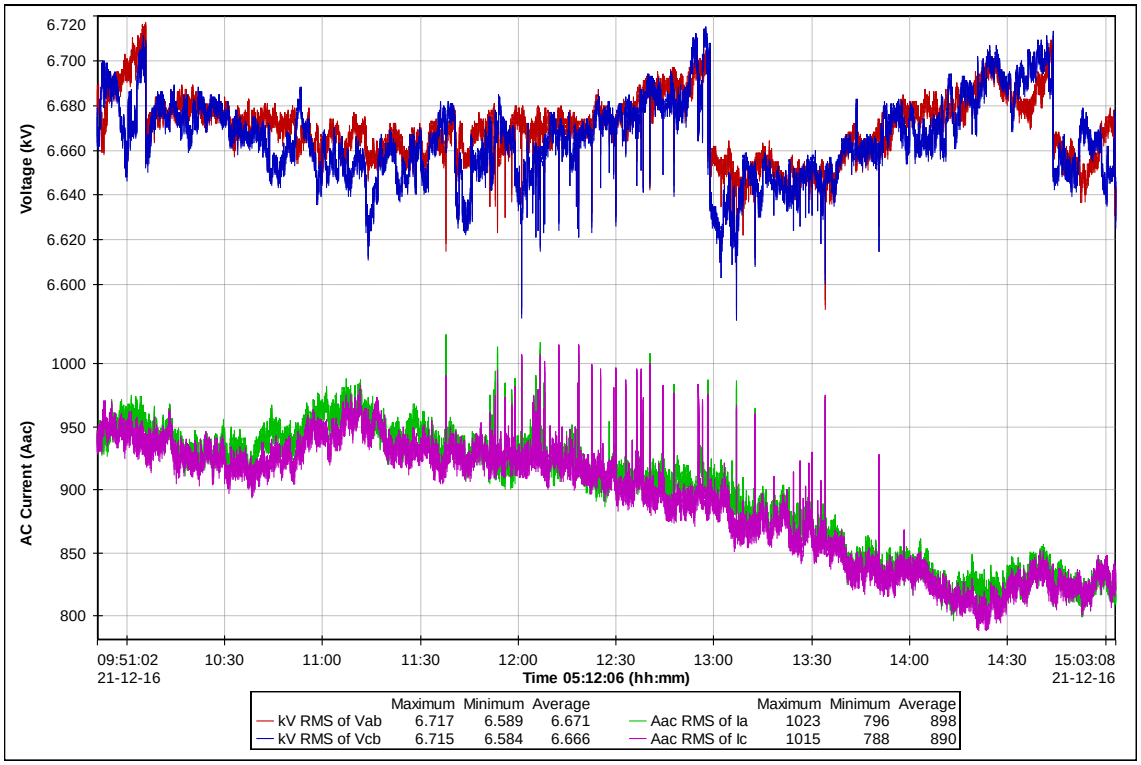
Blackbull Primary results, disturbances useful for Fault Level.

In addition to the major events noted above, there was a period of abnormal load behaviour on 21/12/16 lasting around 90 minutes which was useful for Fault Level extraction. All of the pulses in this period were quite similar. Some were shorter than others, but none longer than ~300ms., until the last one of any substance, which was ~350ms. Graphs 15 to 20 show these in detail.

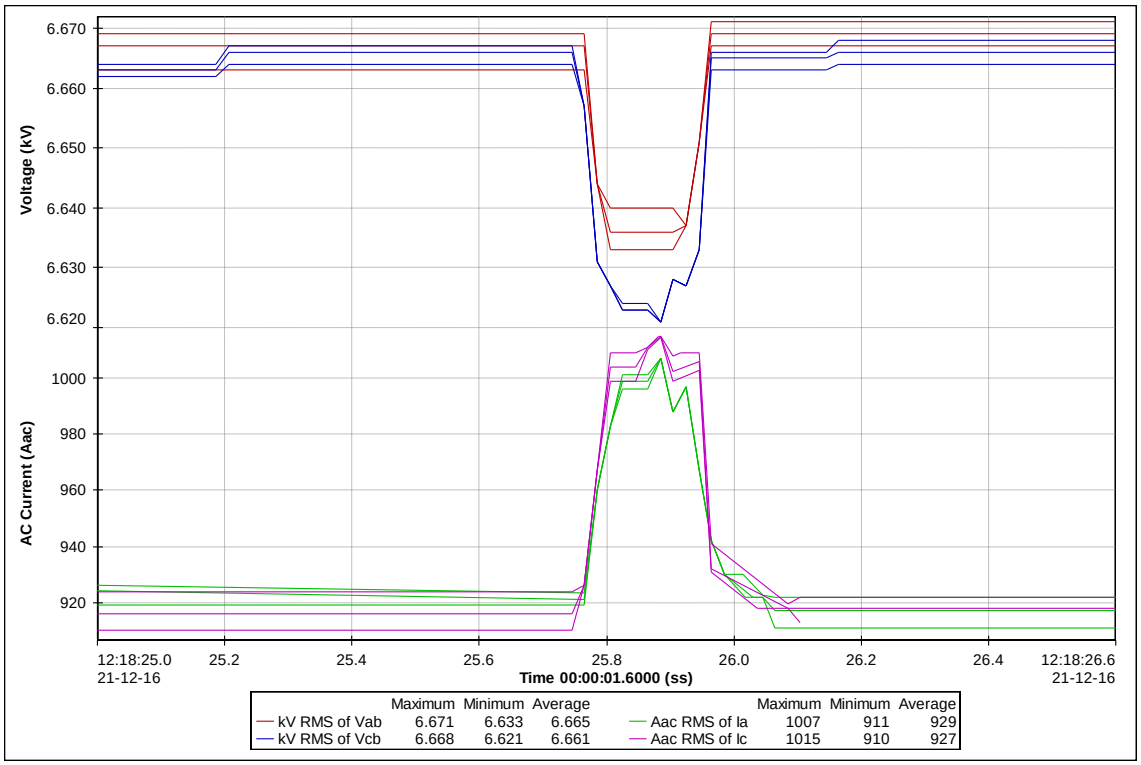
From 13/3 to 17/3/17 there appear to be a lot of what might be tapping operations which produce significant negative voltage spikes. The spikes are small and again very short, but they do add to the downstream 10ms peak Fault Level evaluation energy. These are shown in Graphs 21 to 24.



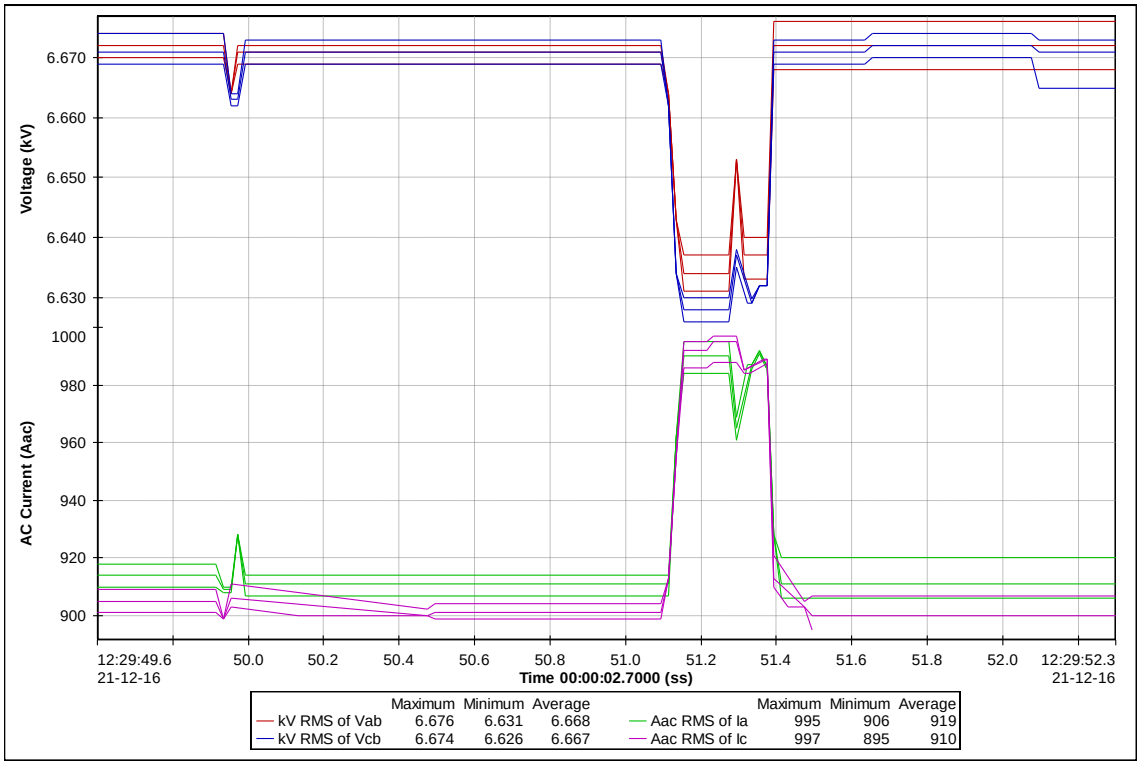
Graph 15. Useful current disturbances on 21/12/16, in context.



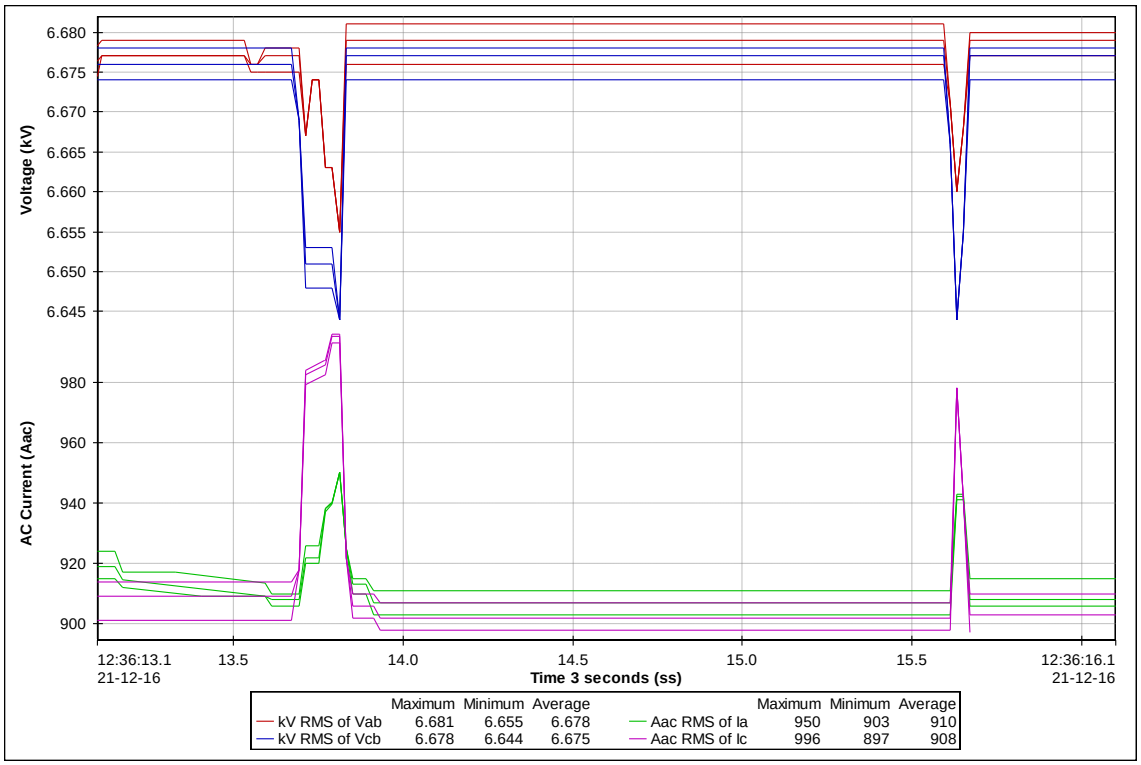
Graph 16. Useful current disturbances on 21/12/16. (Block expanded)



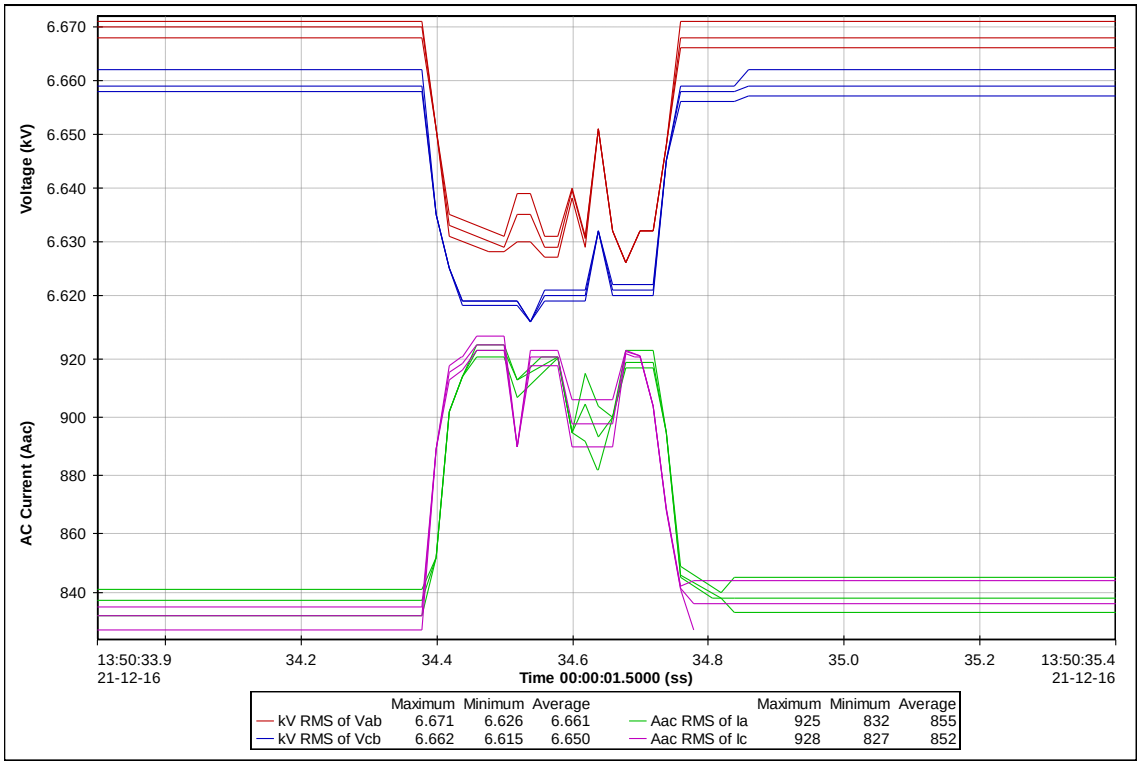
Graph 17. Expansion of example pulse (a) 21/12/16.



Graph 18. Expansion of example pulse (b) 21/12/16.



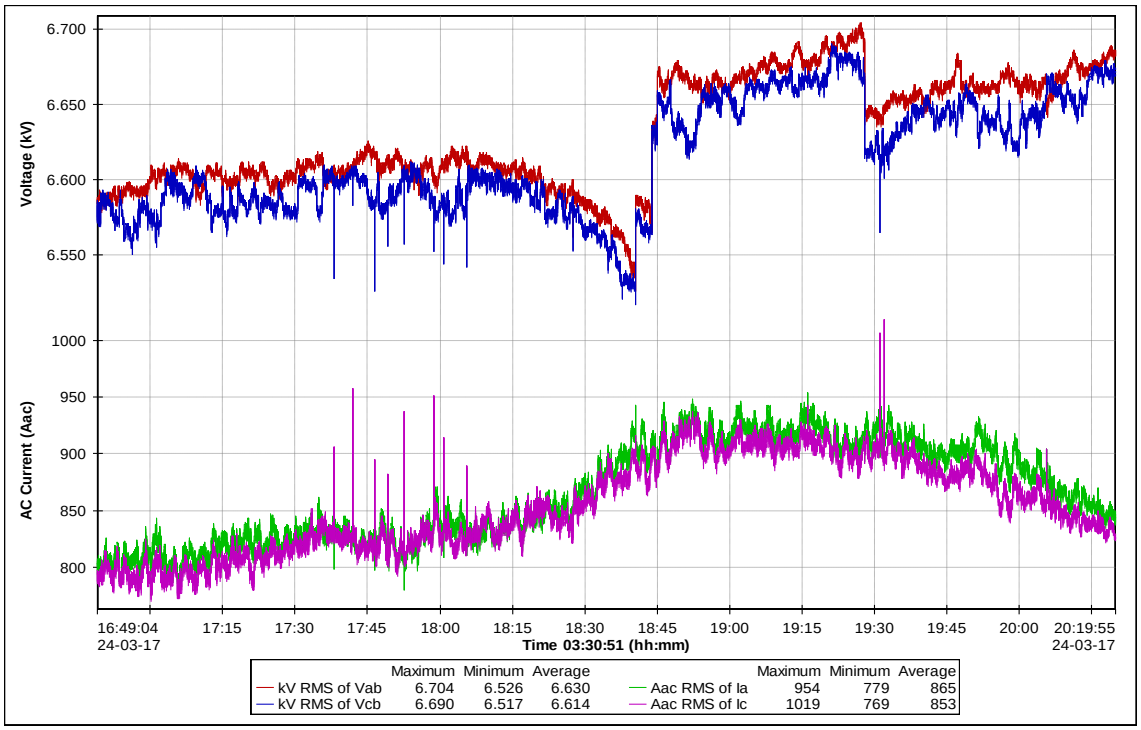
Graph 19. Expansion of example pulses (c) 21/12/16.



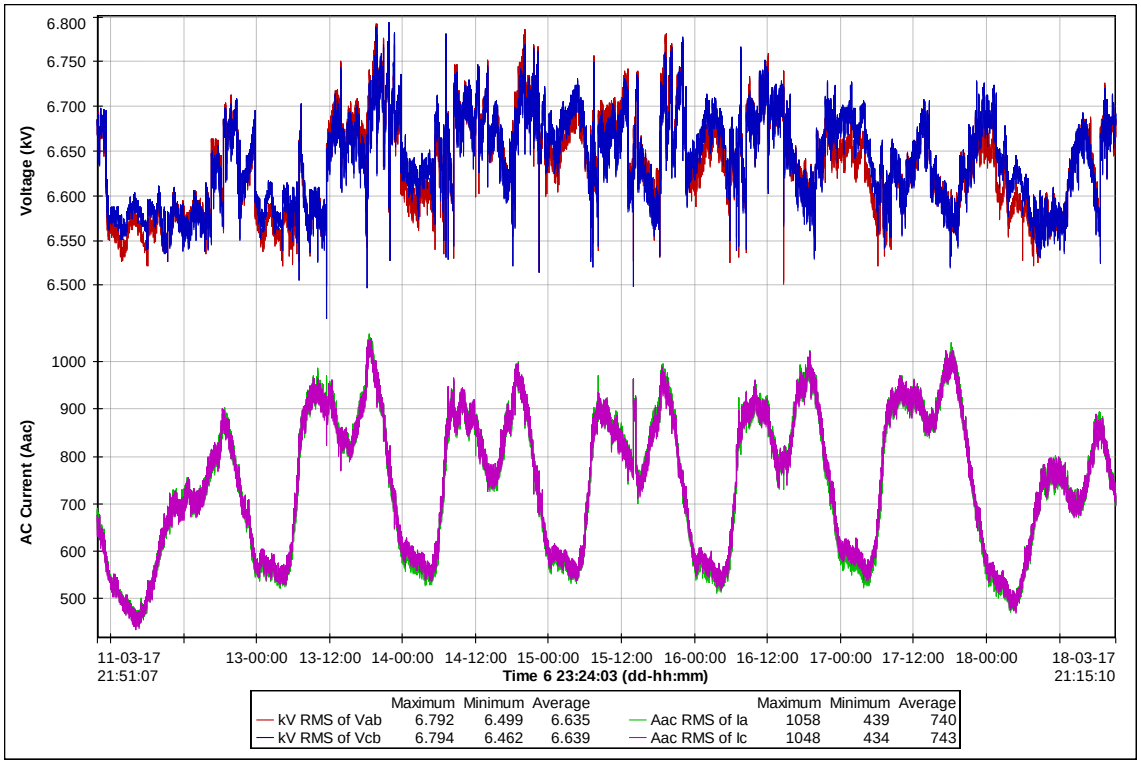
Graph 20. Expansion of final substantial pulses (d) 21/12/16.

There were few apparently useful spikes from the second half of the recording, though there were some on 24/03/17 around 18:00.

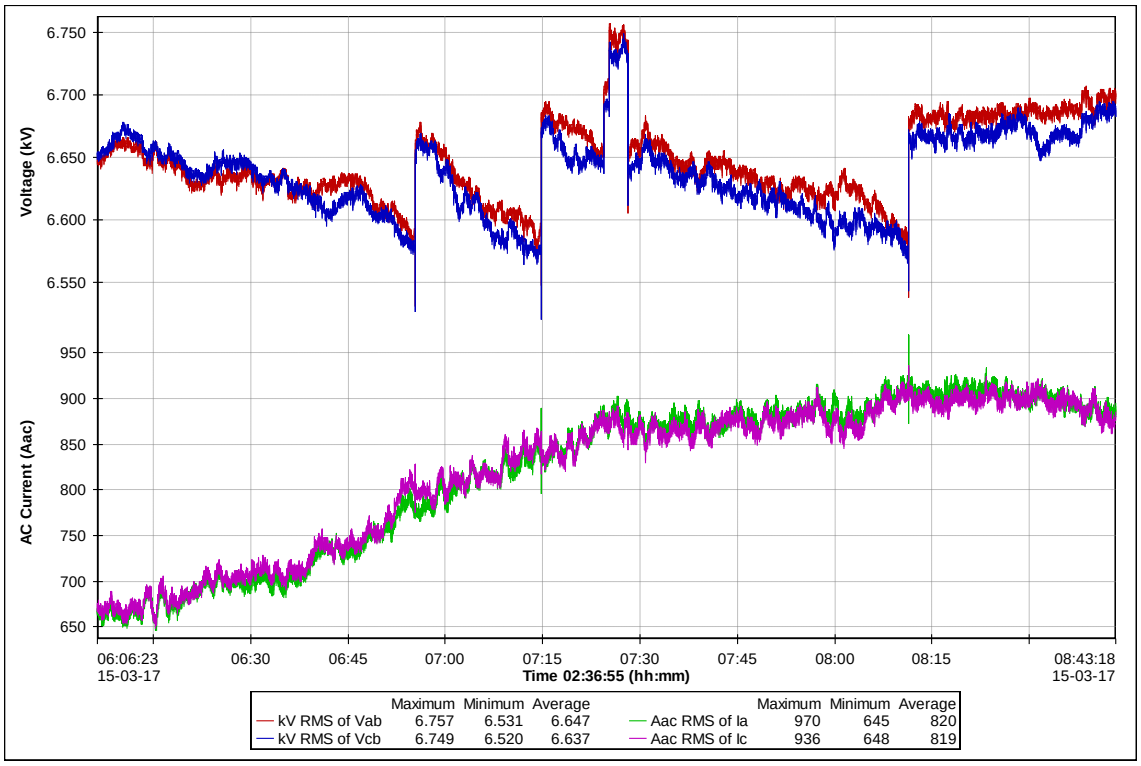
All of the latter are 1 or 2 cycles wide. They will be useful for 10ms Fault Level evaluation, but no use at 90ms for the RMS Break.



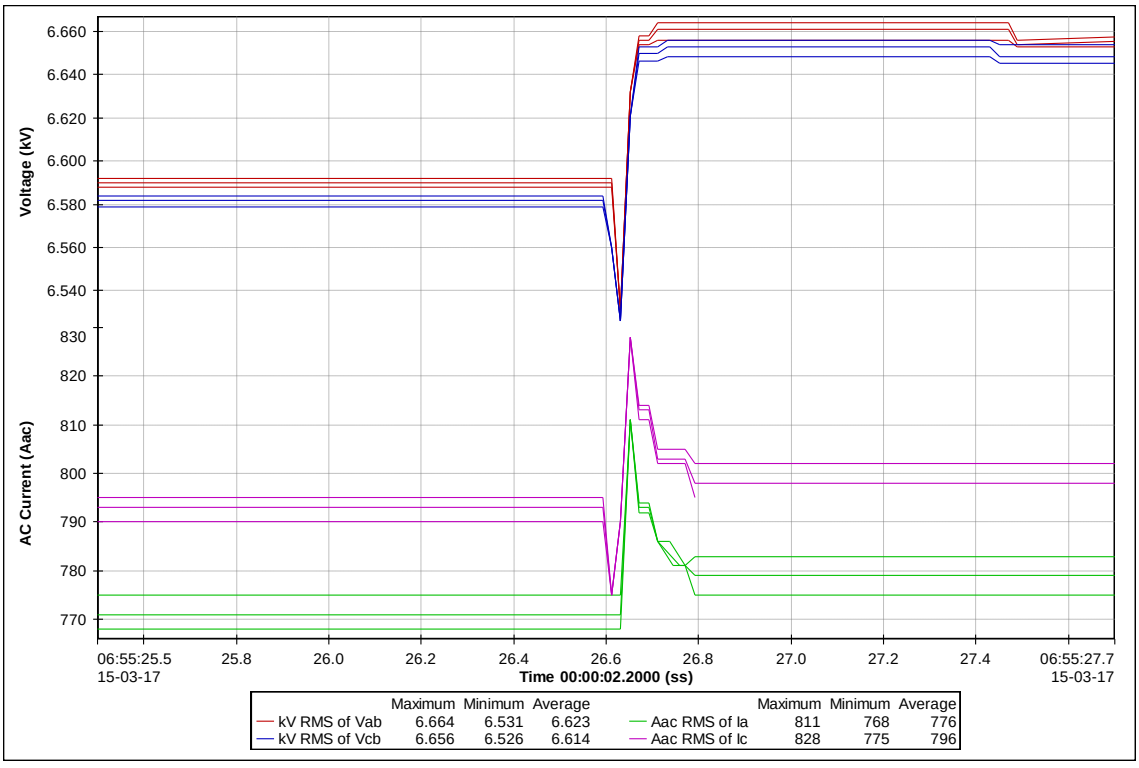
Graph 21. Some useful current spikes on 24/3/17



Graph 22. Very short voltage spikes between 13/03/17 and 17/03/17.



Graph 23. Examples of short negative voltage spikes.



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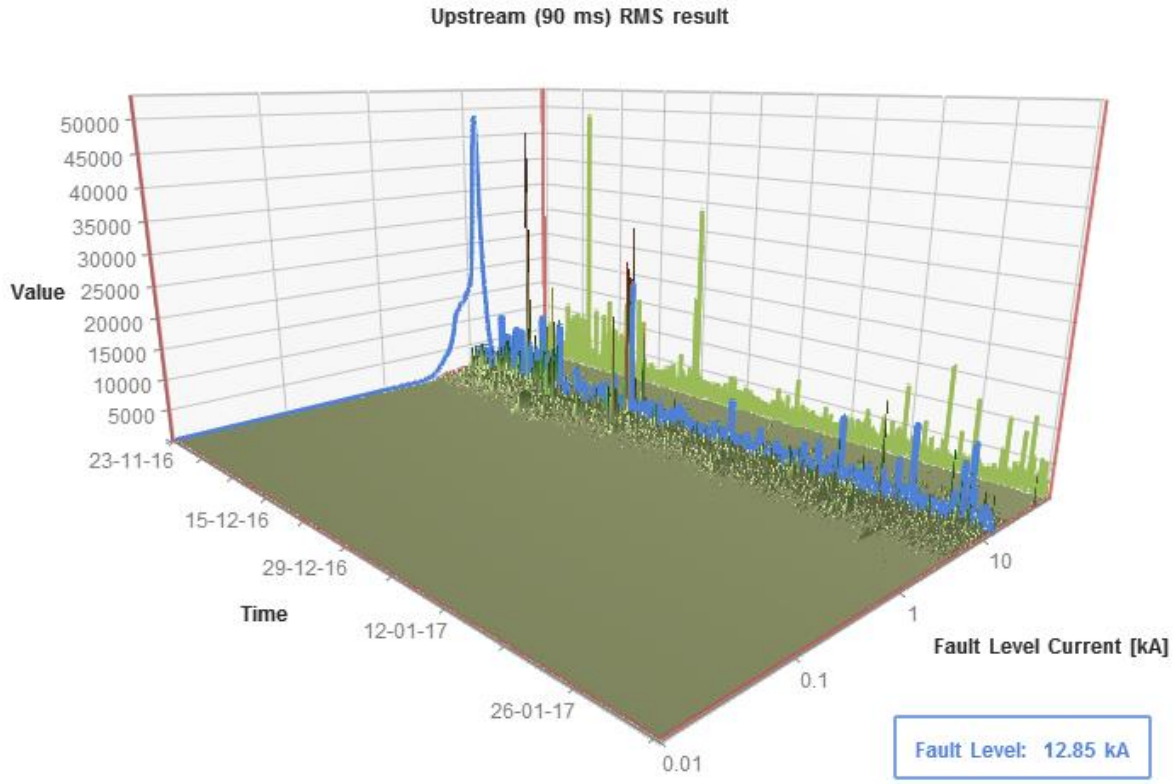
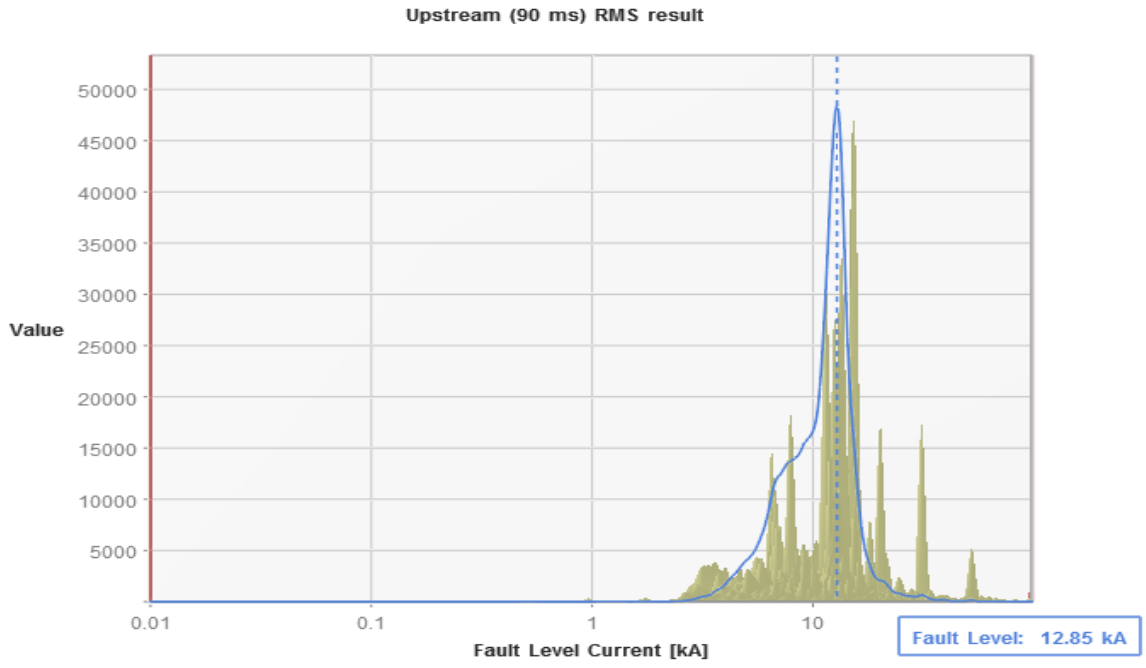
Graph 24. Example of short negative voltage spike expanded.

Blackbull Primary Fault Level Results



Graph 25. First half recording. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.

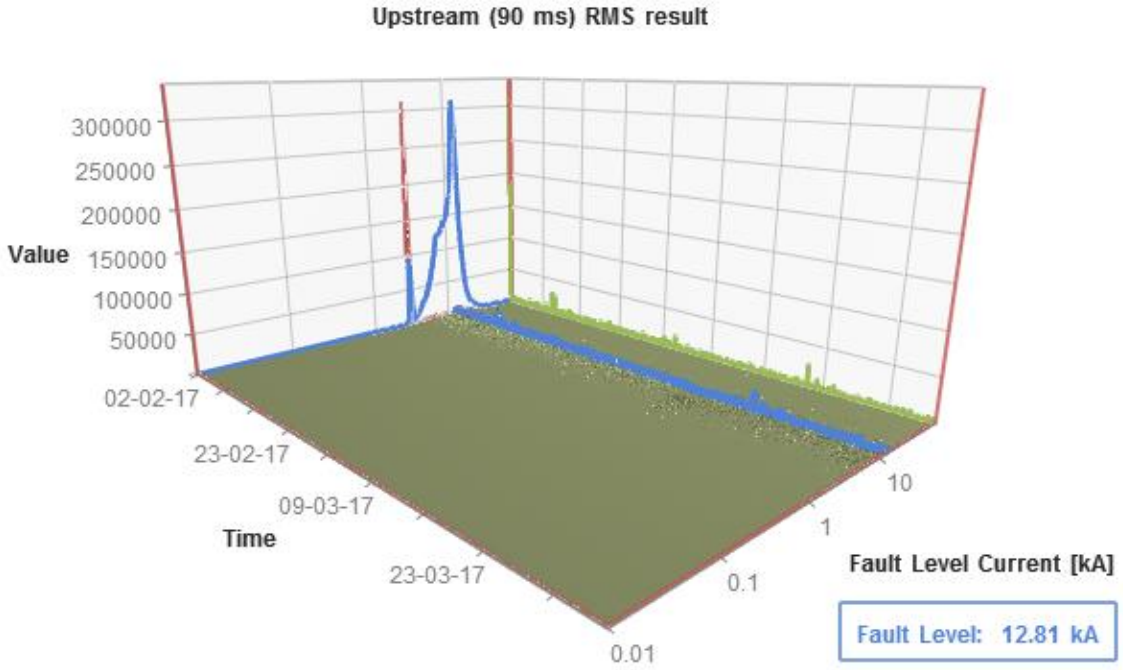
Graph 25 shows that the mean Upstream 90ms RMS Fault Level for the period 23/11/16 to 02/02/17 was 12.85 kA. Graph 26 shows the same thing in 2 dimensions.



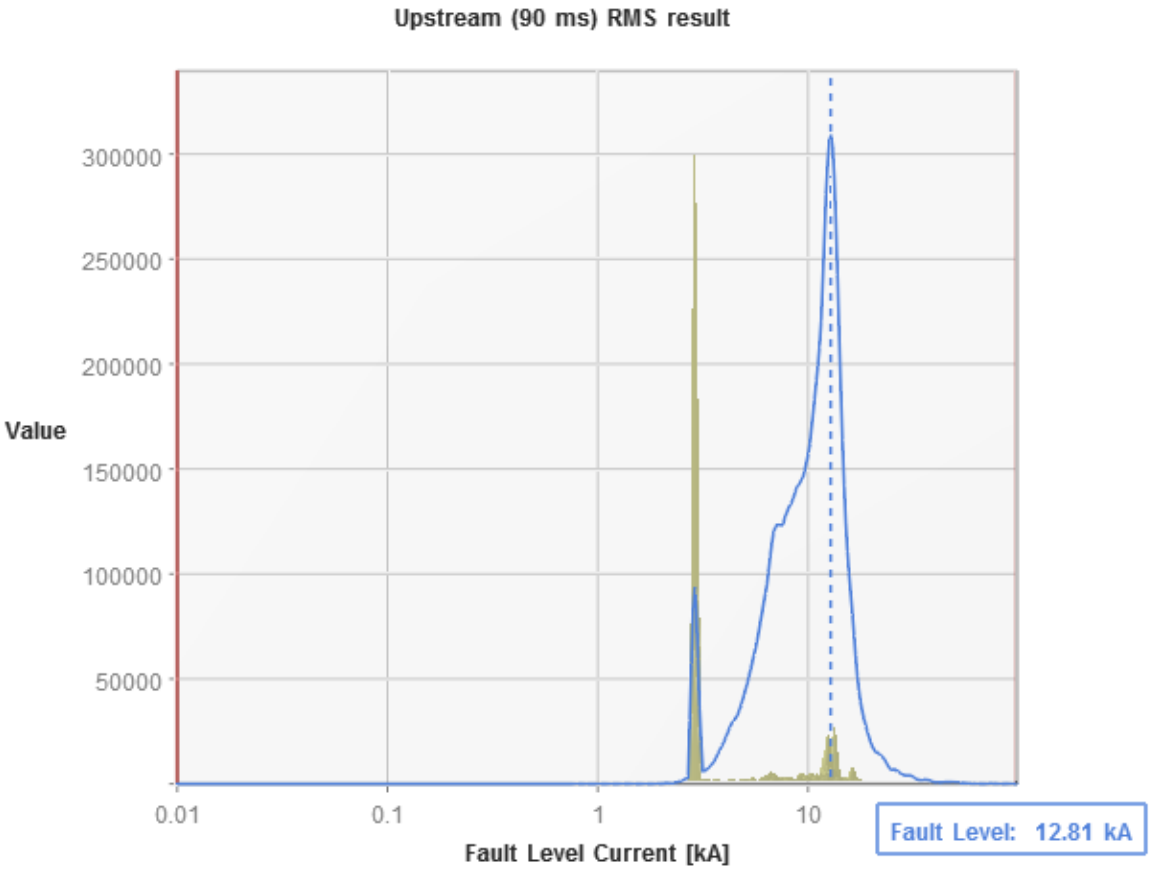
Graph 26. First half recording. Upstream RMS Fault level at 90ms. 2D Distribution shown with 2% filtering.

From the above it can be seen that there is some disturbance energy suggesting a population at a level lower than the aggregate 12.85kA. This is examined later.

Graphs 27 and 28 show the Upstream RMS Fault Level at 90ms for the second half period.



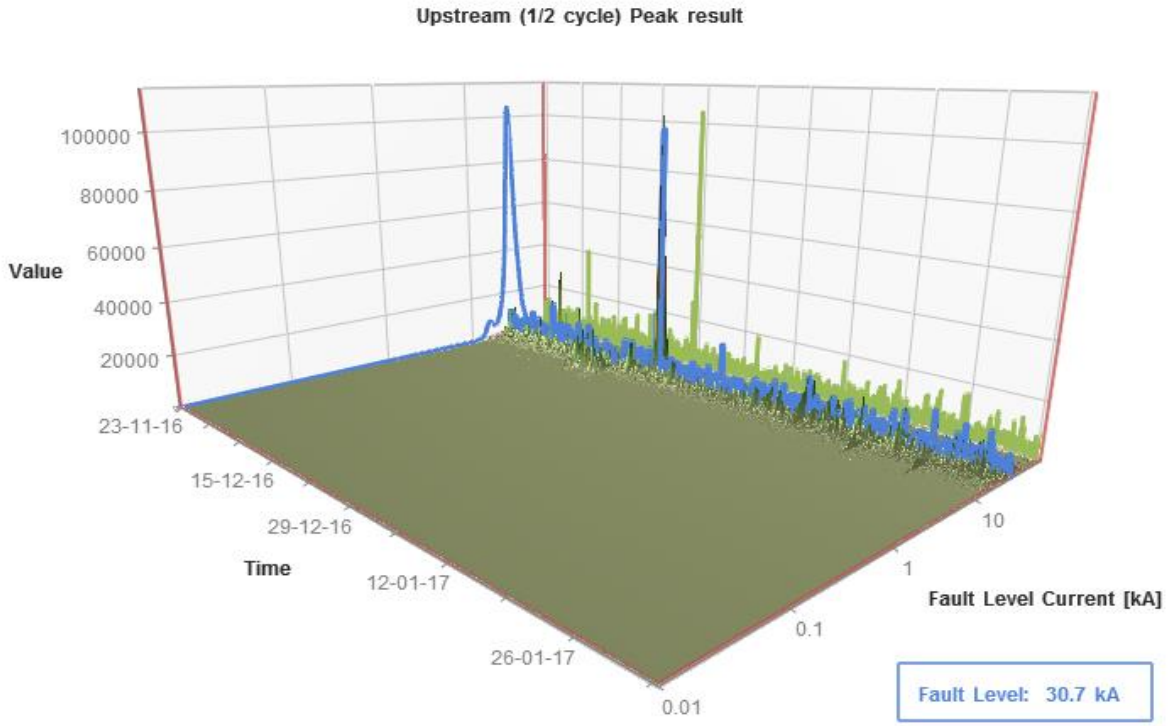
Graph 27. Second half recording. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.



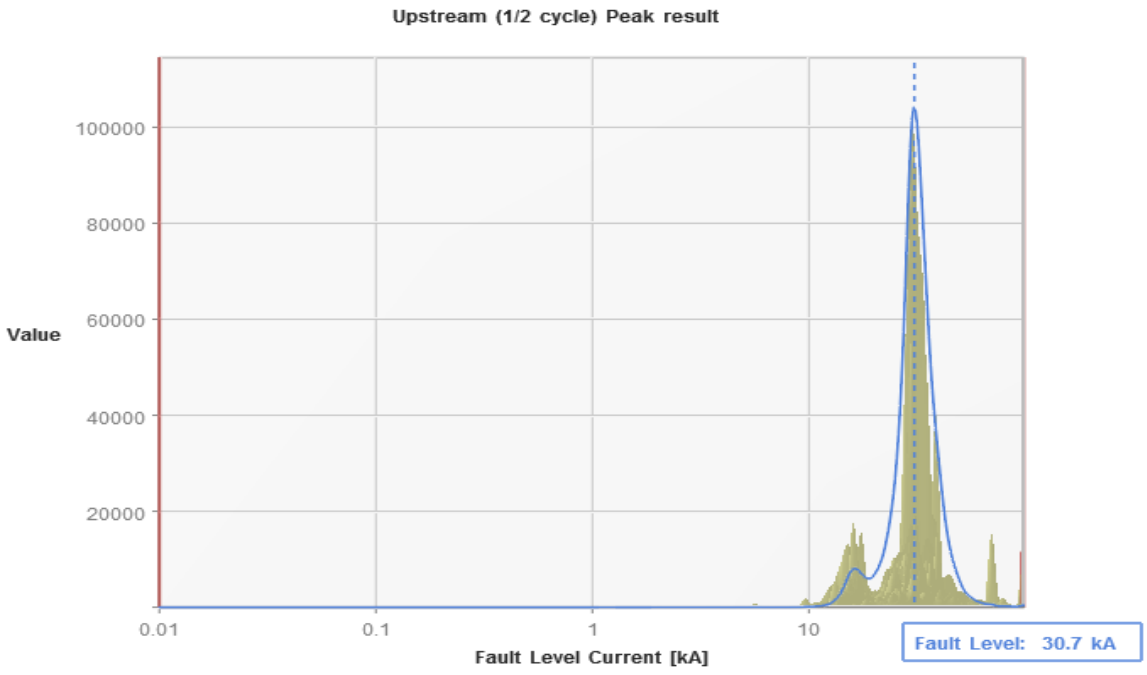
Graph 28. Second half recording. Upstream RMS Fault level at 90ms. 2D Distribution shown with 2% filtering.

From the above it can again be seen that there is some disturbance energy suggesting a population at a level lower than the aggregate 12.81kA. This is also examined later.

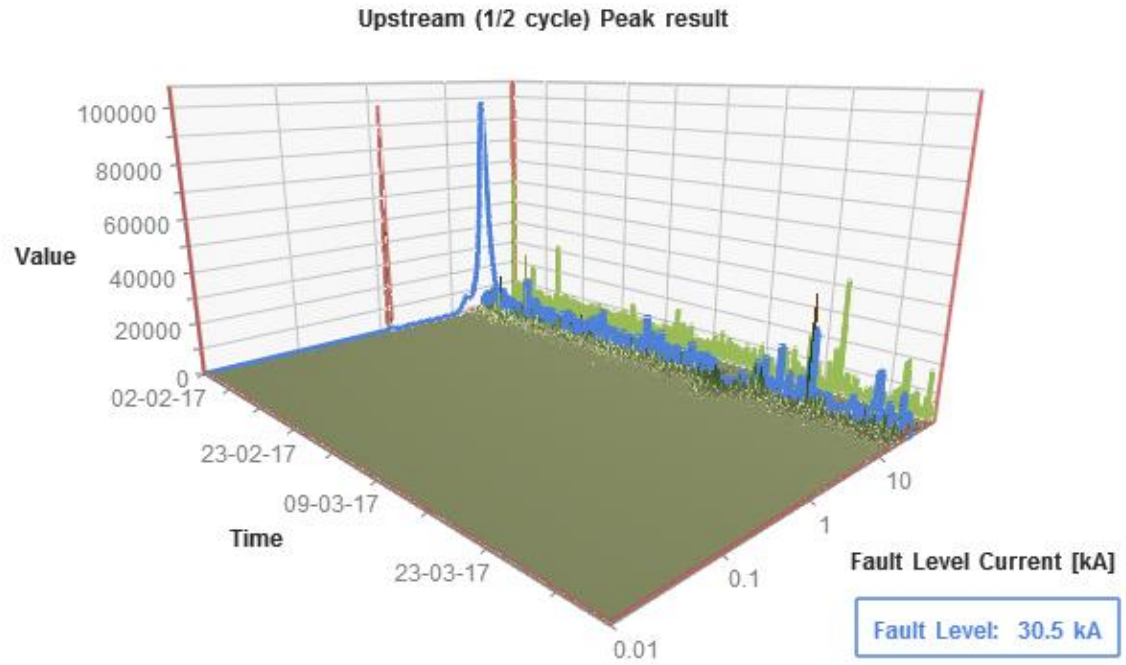
Graphs 29 to 32 show the Peak Upstream Fault Level for the first and second half periods. For the second half of Blackbull recording the Fault Level results are taken to 03/04/17 14:00 to exclude the current spikes on 03/04/17 at 15:01.



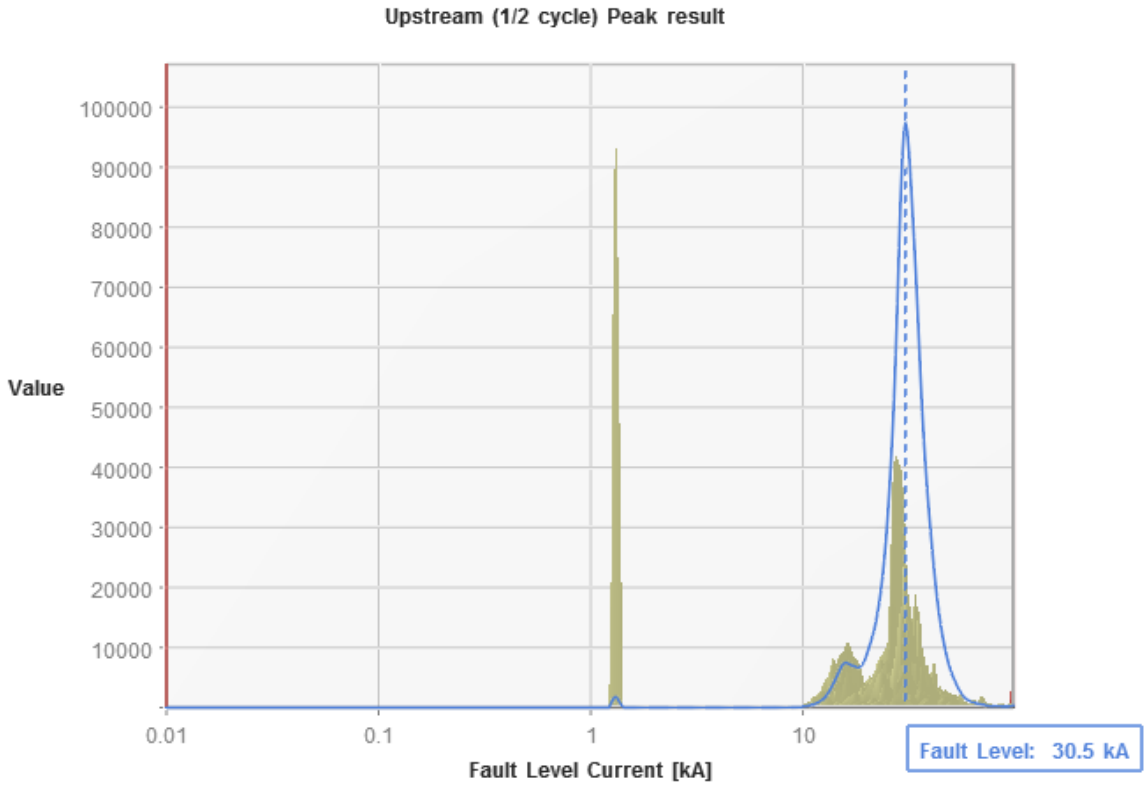
Graph 29. First half recording. Upstream Peak Fault level at 10ms. 3D Distribution shown with 2% filtering.



Graph 30. First half recording. Upstream Peak Fault level at 10ms. 2D Distribution shown with 2% filtering.

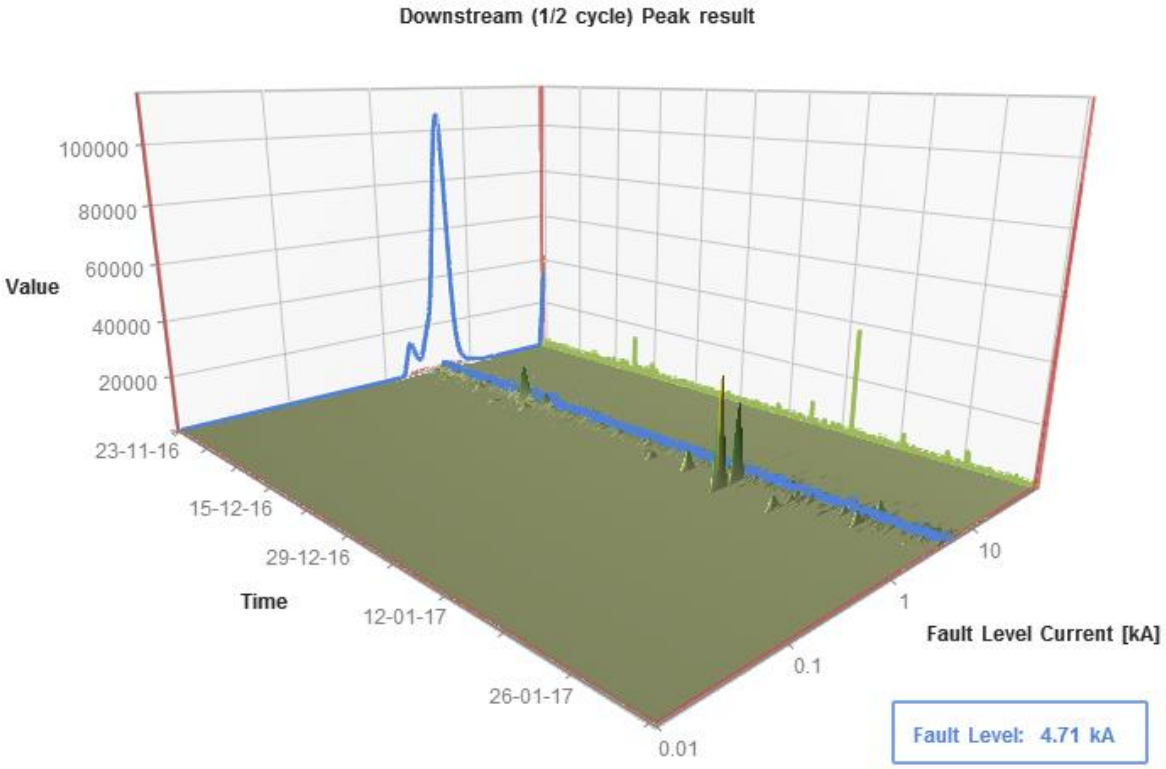


Graph 31. Second half recording. Upstream Peak Fault level at 10ms. 3D Distribution shown with 2% filtering.

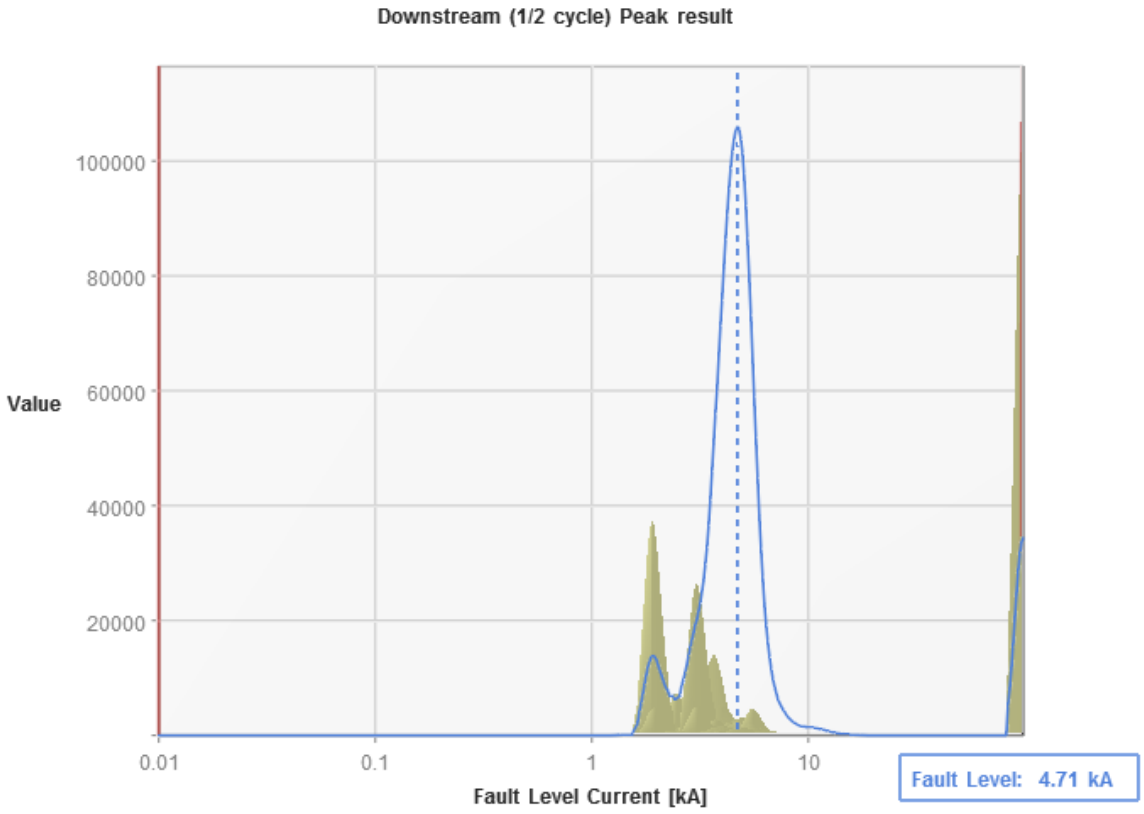


Graph 32. Second half recording. Upstream Peak Fault level at 10ms. 2D Distribution shown with 2% filtering.

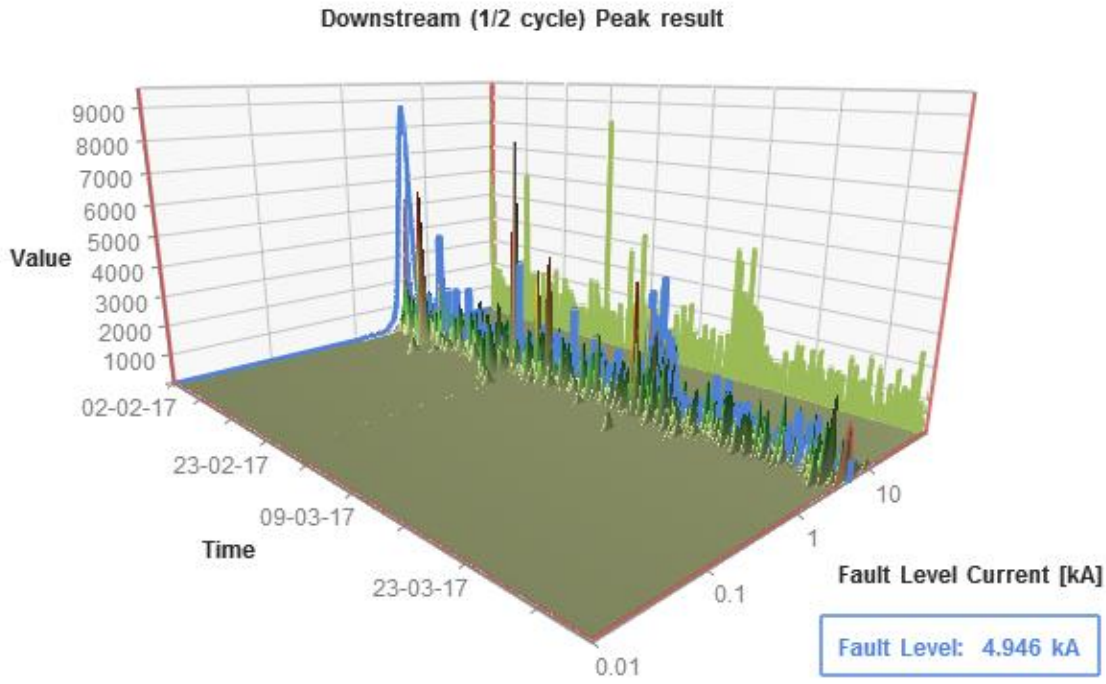
Graphs 33 to 36 show downstream contribution for first and second halves of the recording.



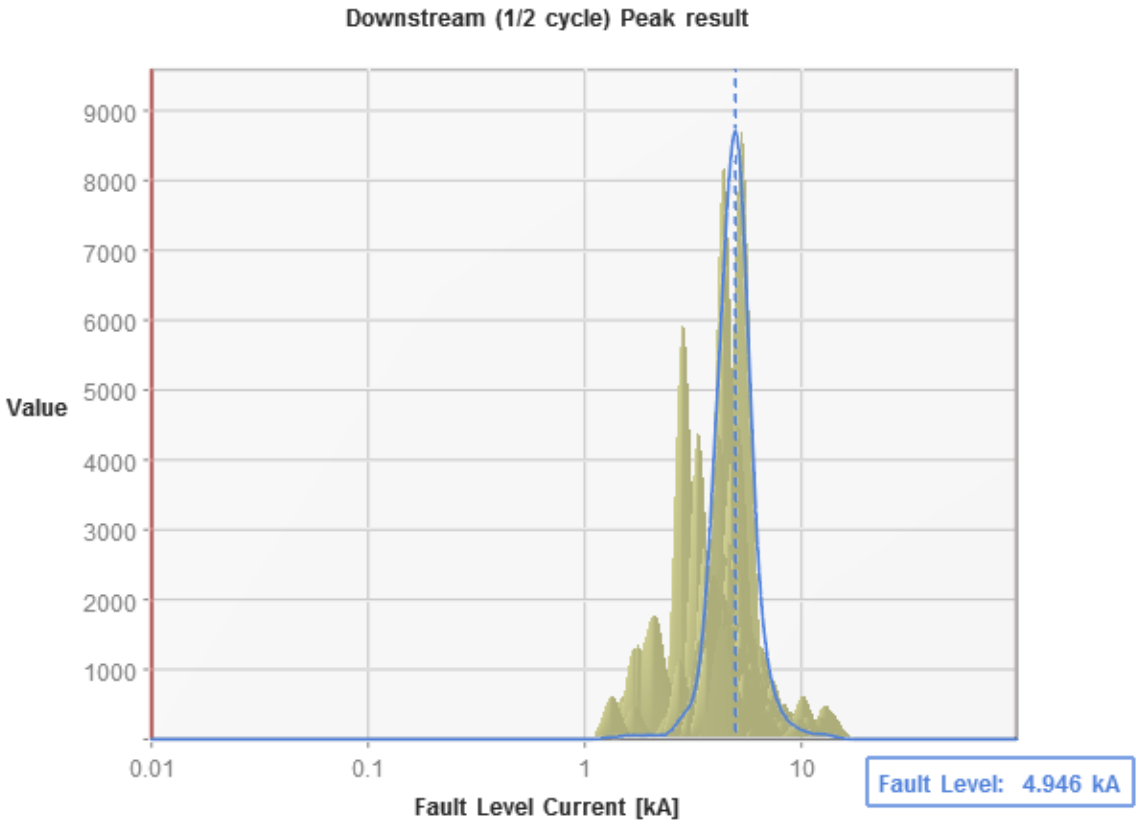
Graph 33. First half recording. Downstream Peak Fault level at 10ms. 3D Distribution shown with 5% filtering.



Graph 34. First half recording. Downstream Peak Fault level at 10ms. 2D Distribution shown with 5% filtering.



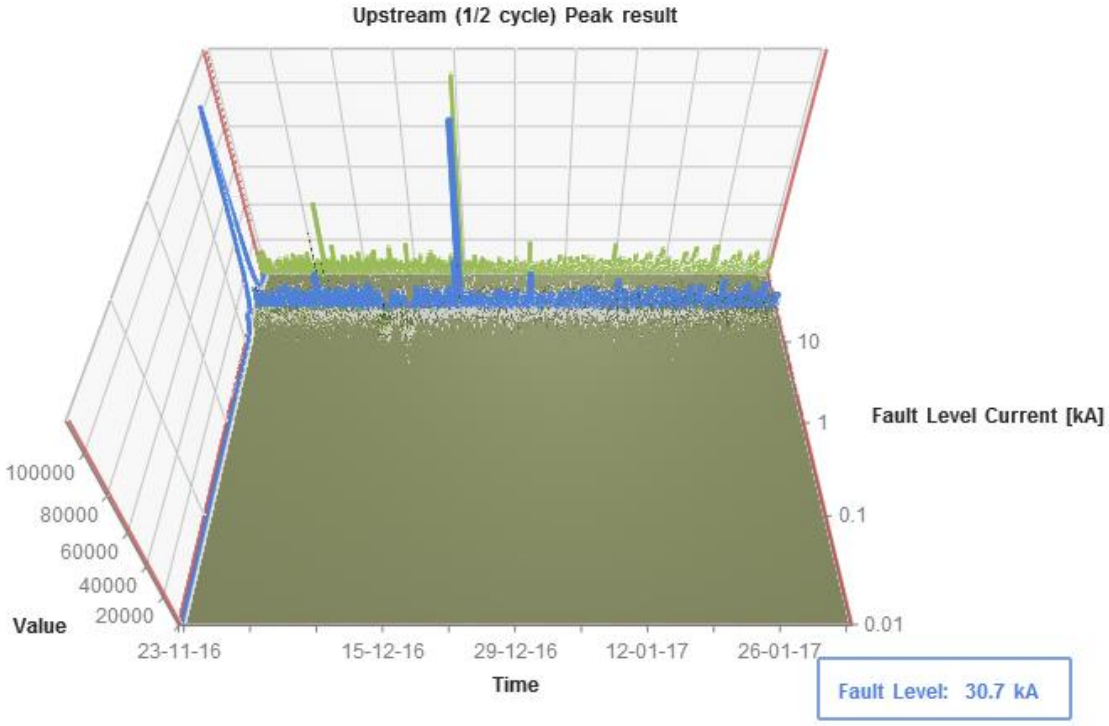
Graph 35. Second half recording. Downstream Peak Fault level at 10ms. 3D Distribution shown with 5% filtering.



Graph 36. Second half recording. Downstream Peak Fault level at 10ms. 2D Distribution shown with 5% filtering.

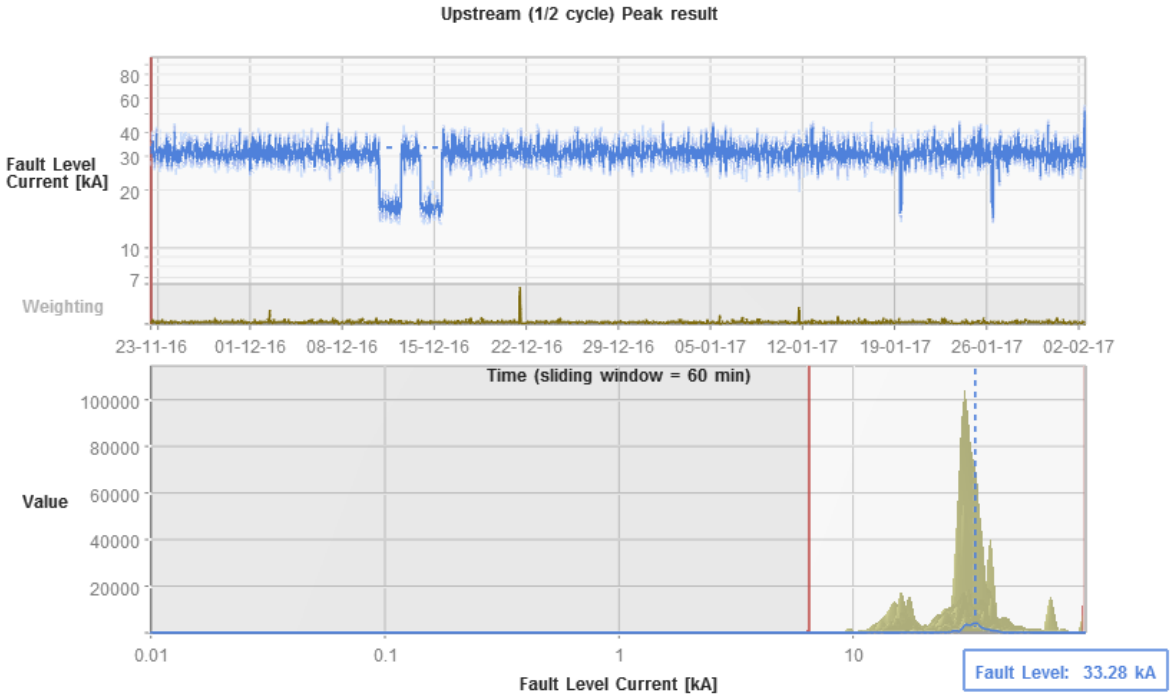
Fault Level changes occurring during the four months.

During the first half of the Blackbull Peak Make 10ms recording, the 3D presentation suggests there were at least two periods when Fault Level was significantly lower than the normal value for the period. Graph 37 shows the 3D graph re-positioned.



Graph 37. First half recording. Upstream Peak Fault level at 10ms, 2% filtering.

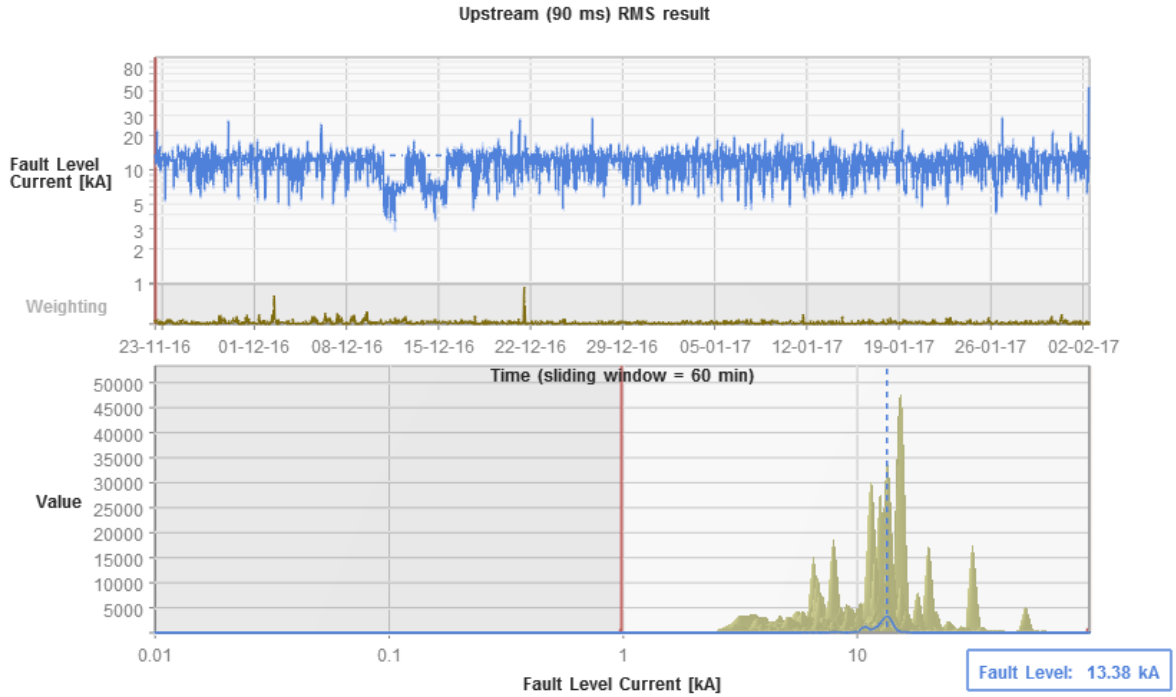
Presenting the same information against time with a very short (60 minute) aggregation interval we can see four regions of reduced Fault Level. Graph 38 refers.



Graph 38. First half recording. Upstream Peak Fault level at 10ms, 2% filtering. 60 min aggregation interval.

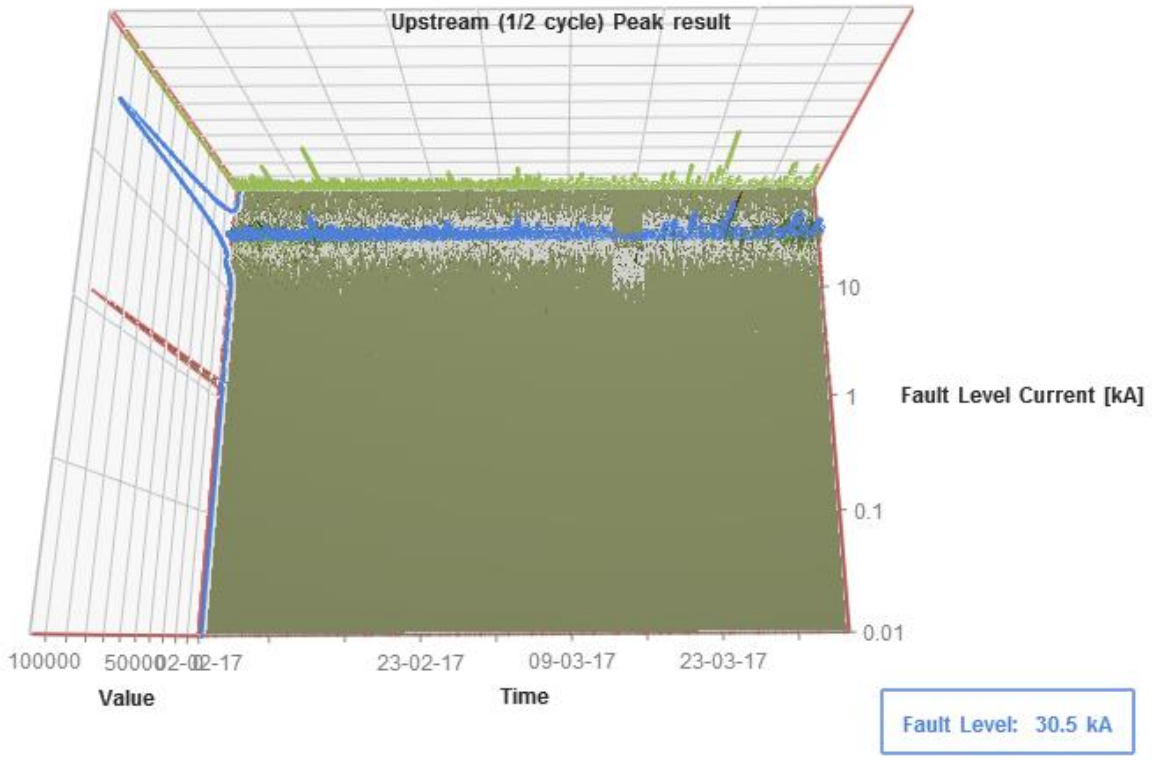
Aggregating results just from within each of these two main deviating periods yielded 16.13 and 16.09kA for the first and second respectively. The two later periods on the 19/01/17 and 26/01/17 (both Thursday mornings, both starting around 9am) each lasted 3-4 hours, and produced similar Fault Levels.

Results for the 90ms Break Fault Level for the same main deviation intervals were 6.8 and 7.05kA. Results for the short later periods were somewhat noisy as shown in Graph 39.



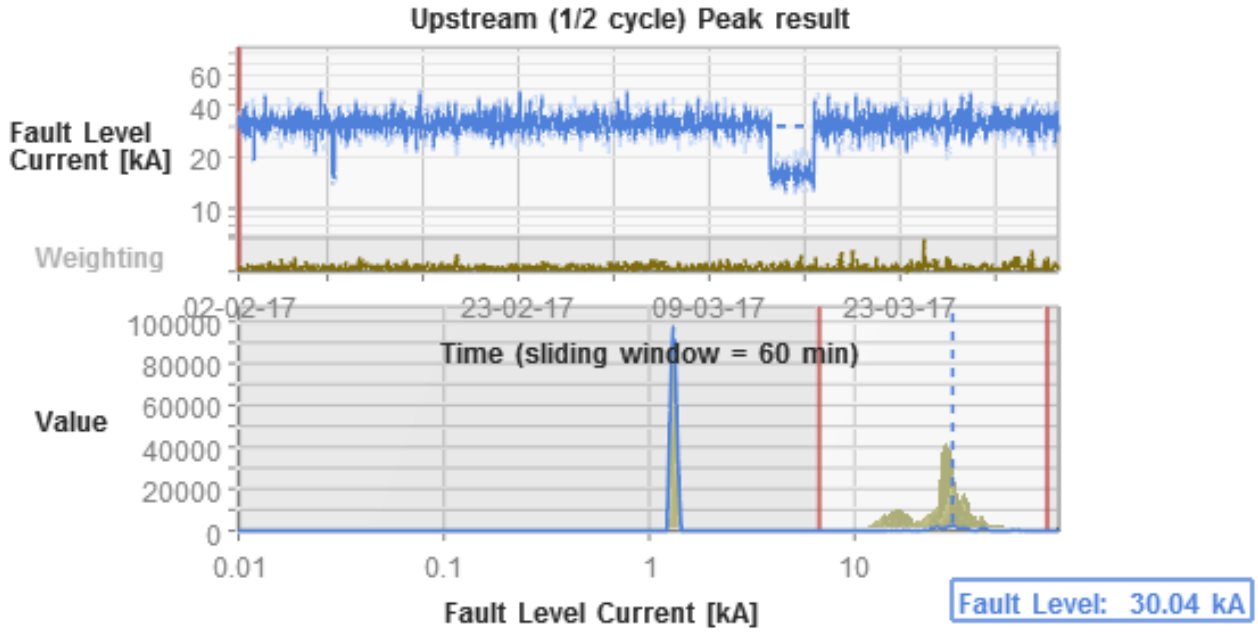
Graph 39. First half recording. Upstream RMS Fault level at 90ms, 2% filtering. 60 min aggregation interval.

During the second half of the Blackbull Peak Make 10ms recording, the 3D presentation suggests there was at least one period when Fault Level was significantly lower than the normal value for the period. Graph 40 shows the 3D graph re-positioned.



Graph 40. Second half recording. Upstream Peak Fault level at 10ms, 2% filtering.

Presenting the same information against time with a very short (60 minute) aggregation interval we can see two regions of reduced Fault Level. Graph 41 refers.



Graph 41. Second half recording. Upstream Peak Fault level at 10ms, 2% filtering.

The short deviation period (about 4 hours) on 09/02/17 gave a Peak Fault Level value of 15.87kA, and the longer one, for which 4% filtering was used, gave 16.84kA.

Graph 42 shows the same periods for the 90ms RMS Break result. Results were 6.48k and 6.76kA for the early and late periods respectively.

Graph 42. Second half recording. RMS Break Fault level at 90ms, 2% filtering.

Appendix 2. Nelson Primary. FLM Serial No 0888

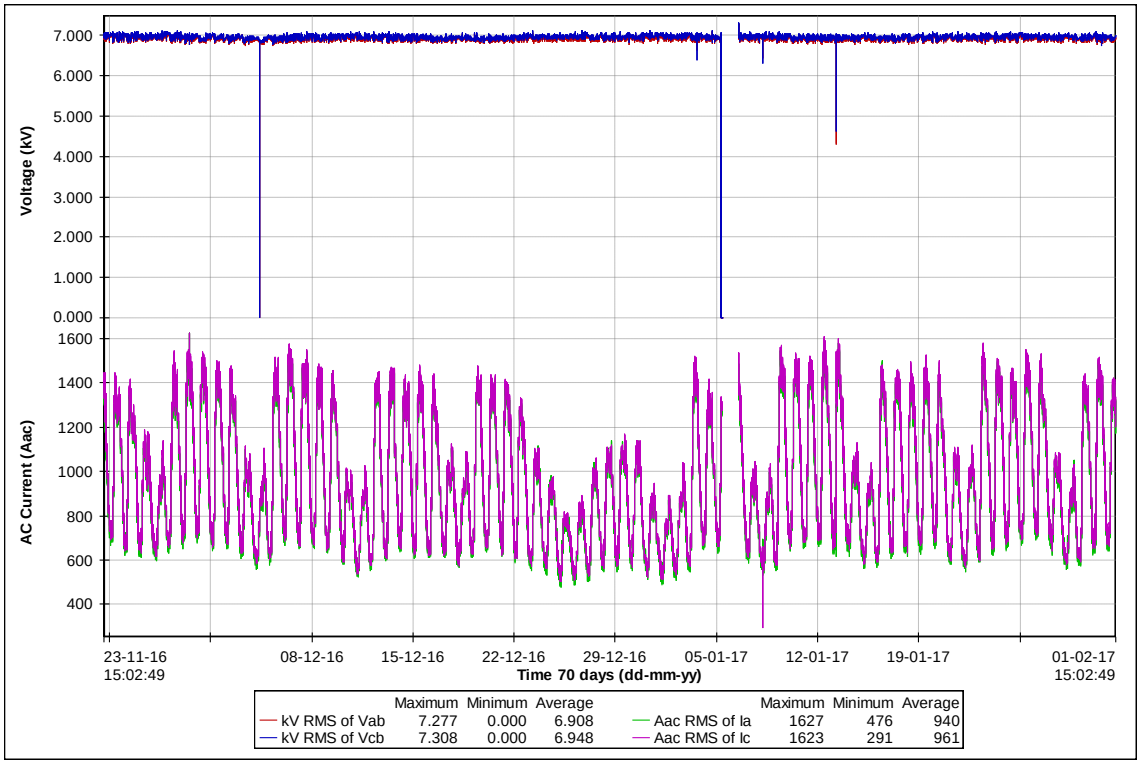
Sources of error

The overall results for Nelson over the 4 month period are of similar quality to those of Blackbull. There is little room for manipulation of the upstream results, so sources of error are principally the systematic ones of incorrect assumptions, wrong CT settings, faulty sensors, cables etc. There is some variation in the downstream results for the February-Mach period, though there is a fairly uniform spread in time of results, and an indication that the variation is somewhat systematic on a weekly basis.

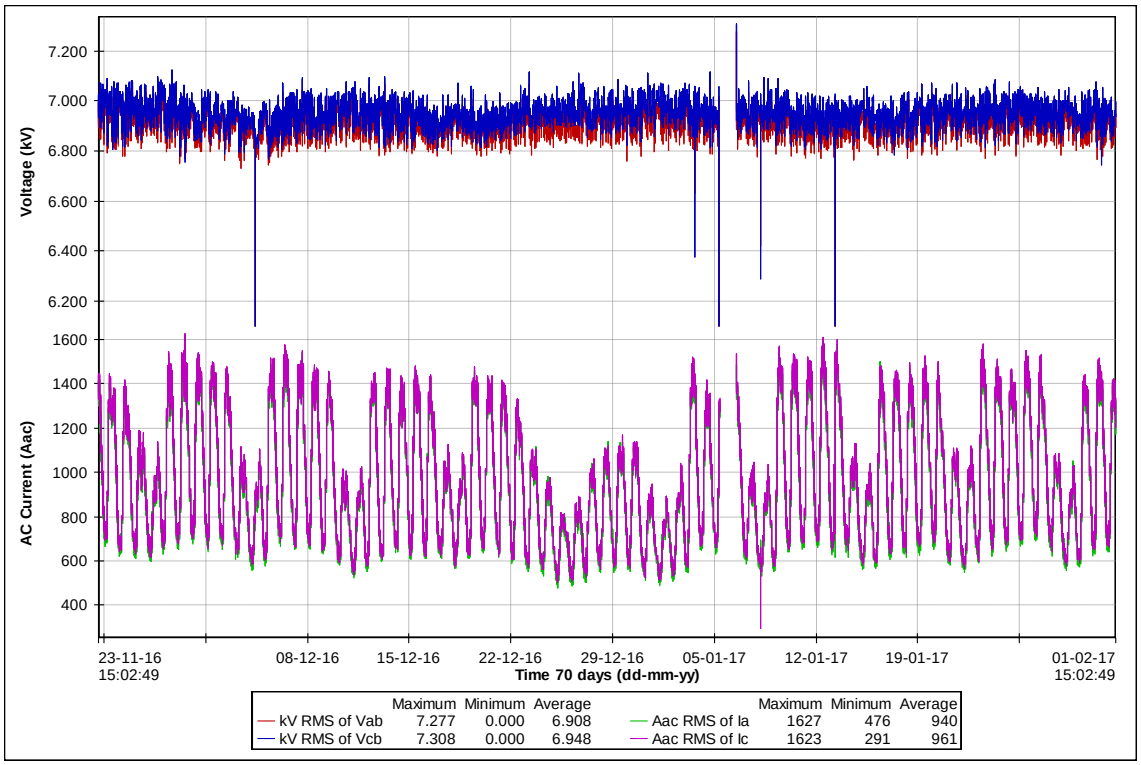
If the current and voltage results recorded by the PM7000 and shown below match the independent measurements reported by the ENWL SCADA or other systems, then it is unlikely that these results are wrong.

Nelson Primary results, General observations.

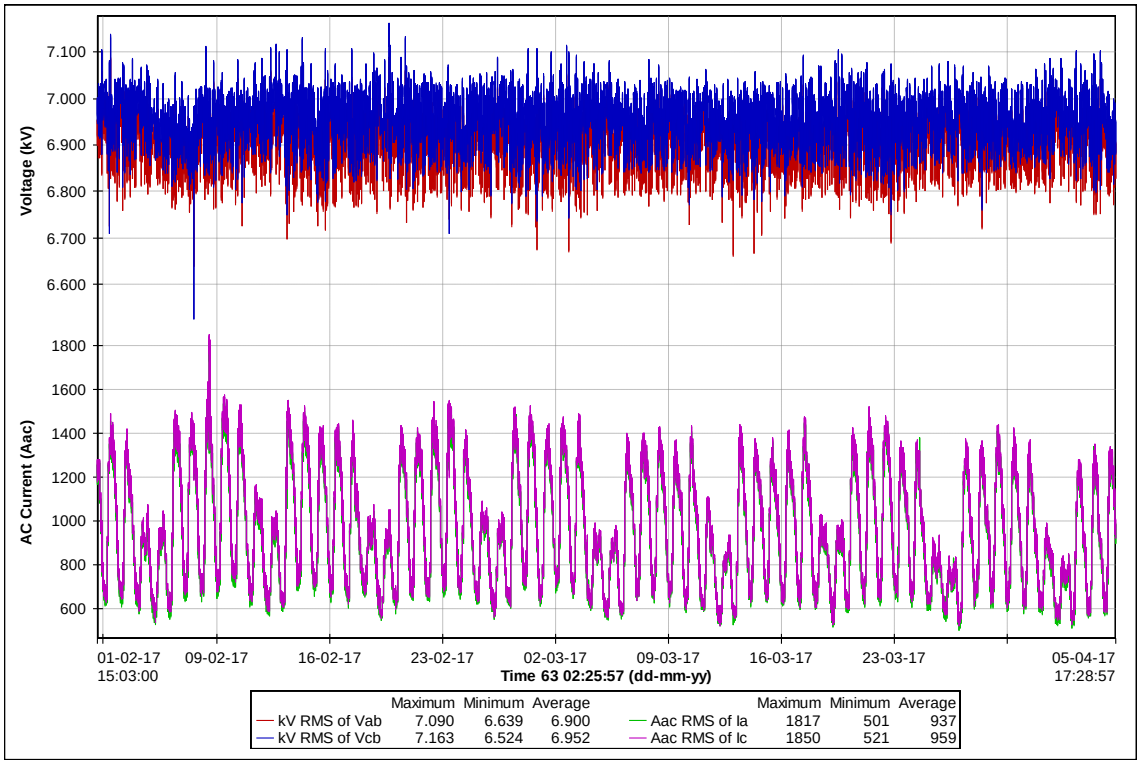
Graphs 1, 2 and 3 shows the voltage and current for the full recording period. The first half of the recorded data as shown in Graph 1 has its Voltage Y-axis detail suppressed by the interruption spikes present, so Graph 2 presents the same material with the Y-axis voltage forced to a narrower span (6.1 to 7.3kV)



Graph 1. Volts and Current for the recorded period to 01/02/17.

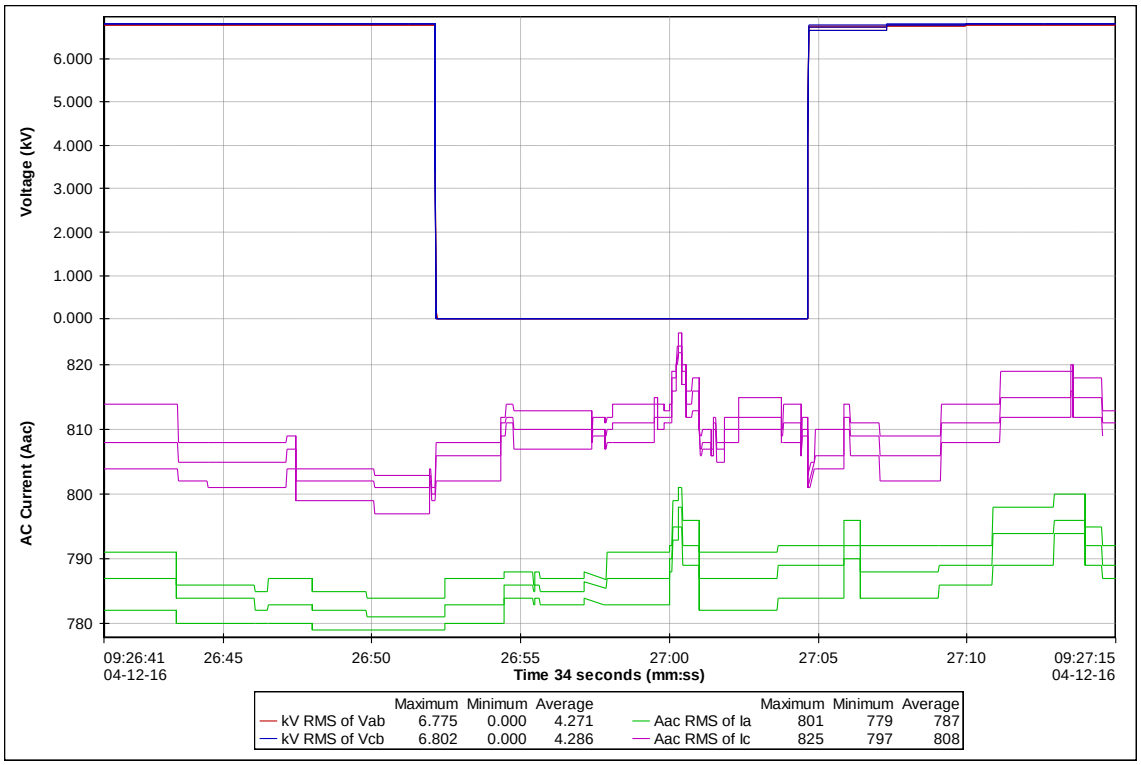


Graph 2. Volts and Current for the recorded period to 01/02/17. Y-axis voltage restricted to 6.1 to 7.3kV.

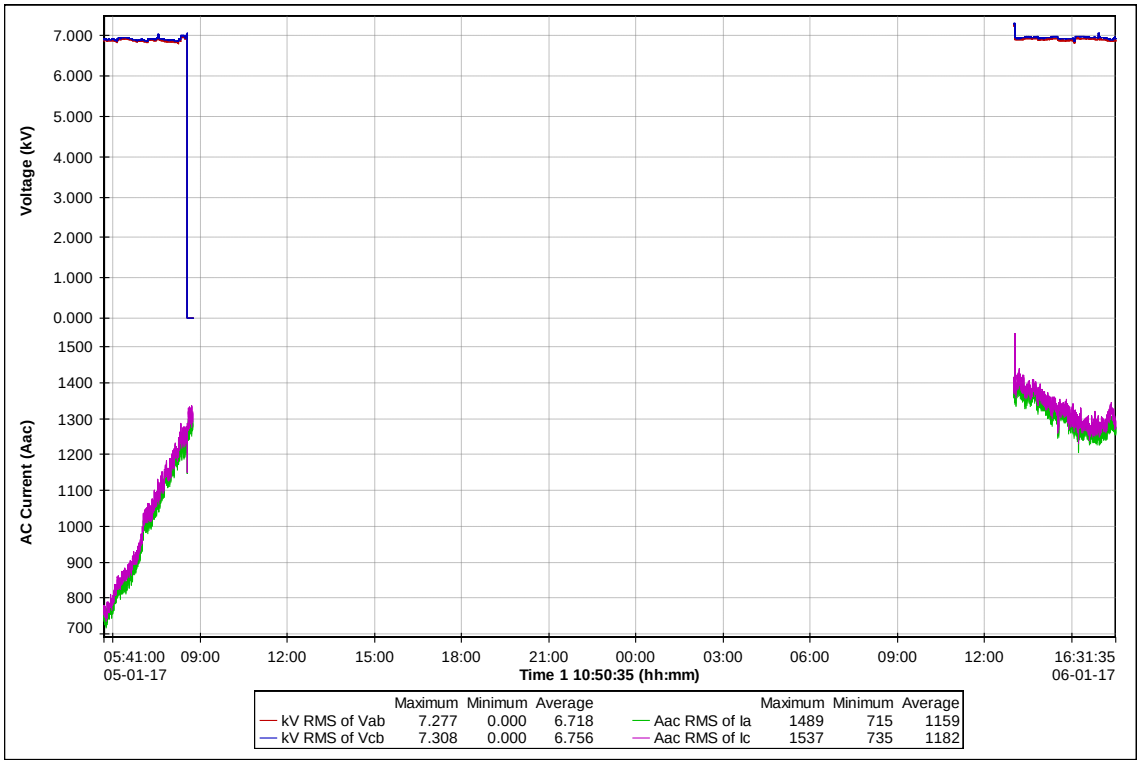


Graph 3. Volts and Current for the recorded period 01/02/17 to 05/04/17.

There were two interruptions to the voltage seen during the four months, a short one of ~12 seconds on 04/12/16, and a second on 05/01/17. On this second occasion power did not return until over a day later. Graphs 4 and 5 refer.

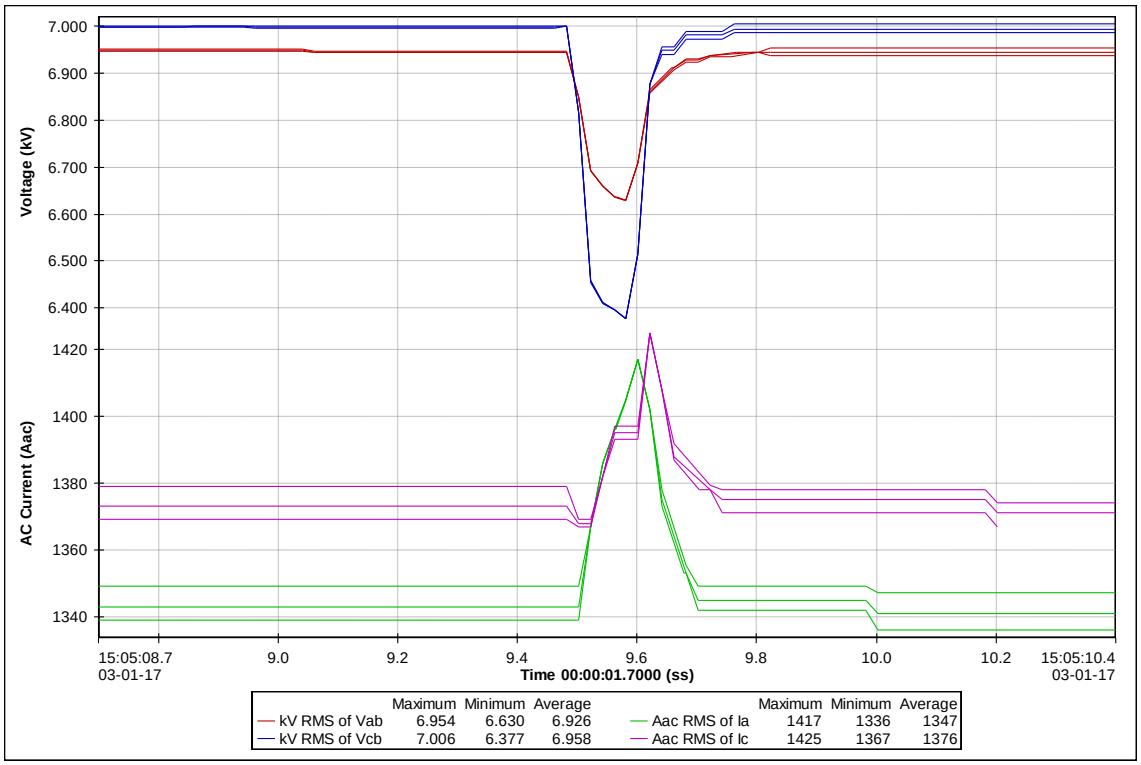


Graph 4. Voltage (but not current) lost for ~12.5 secs on 04/12/16.

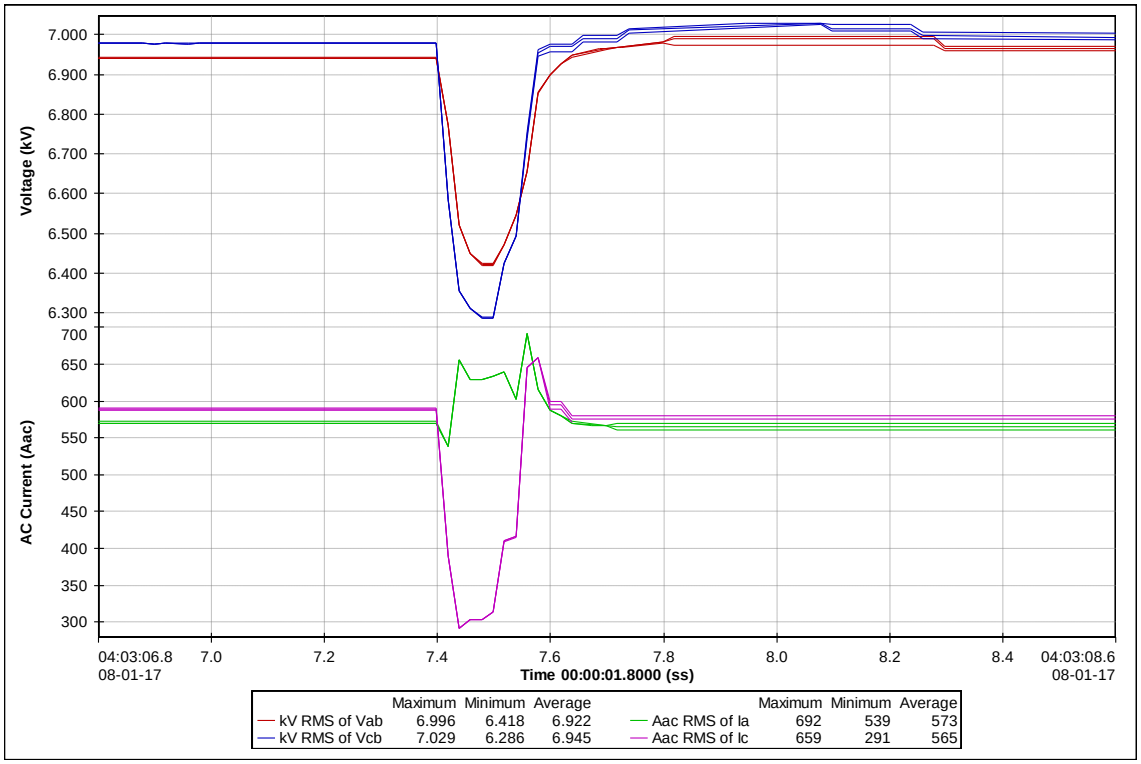


Graph 5. Voltage only lost again from 8:33 on 05/01/17until 13:00 on 06/01/17.

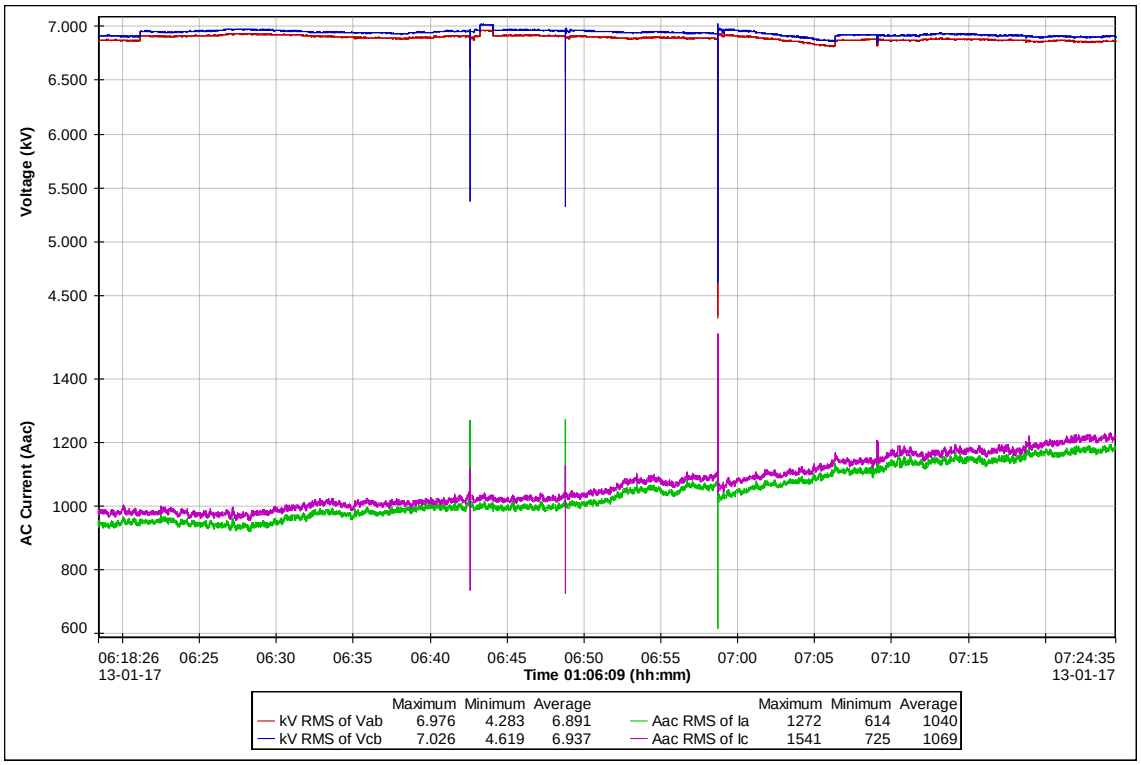
There were two isolated moderate voltage events on 03/01/17 and 08/01/17, and a group of three on 13/01/17. The first two isolated ones are shown in Graphs 6 and 7, the group in Graph 8 and the third of the three (the most severe) is shown in Graph 9.



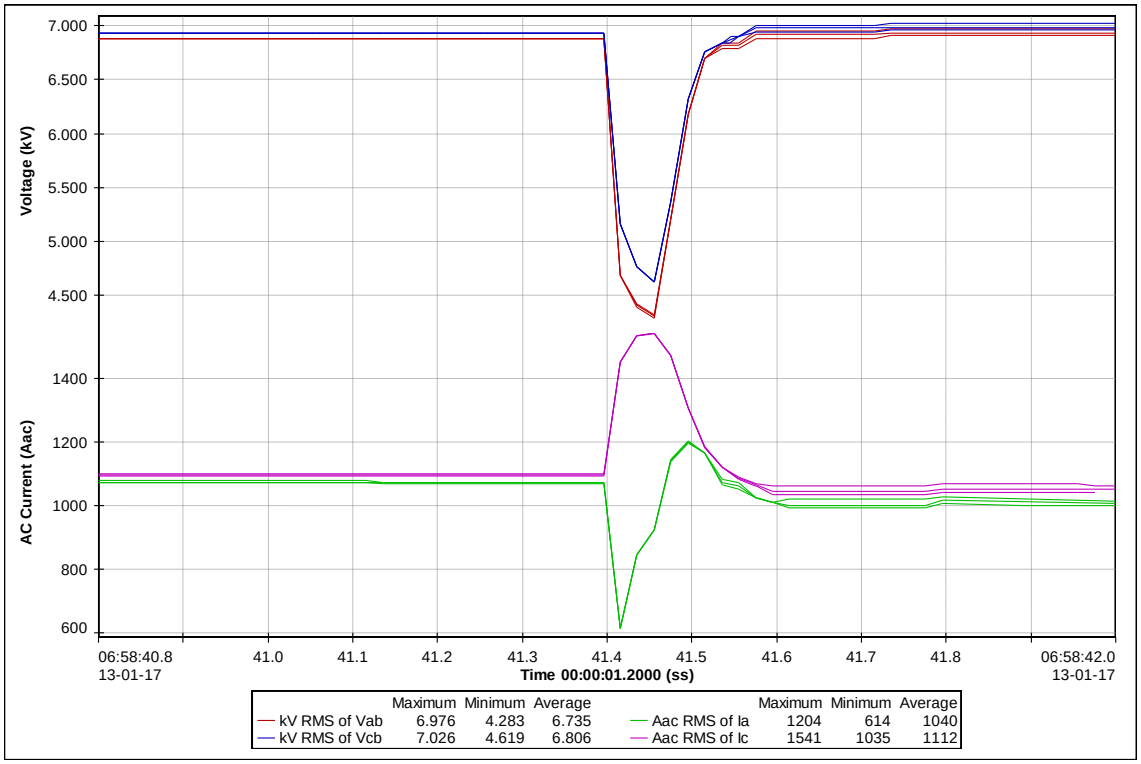
Graph 6. Isolated voltage event on 03/01/17



Graph 7. Isolated voltage event on 08/01/17

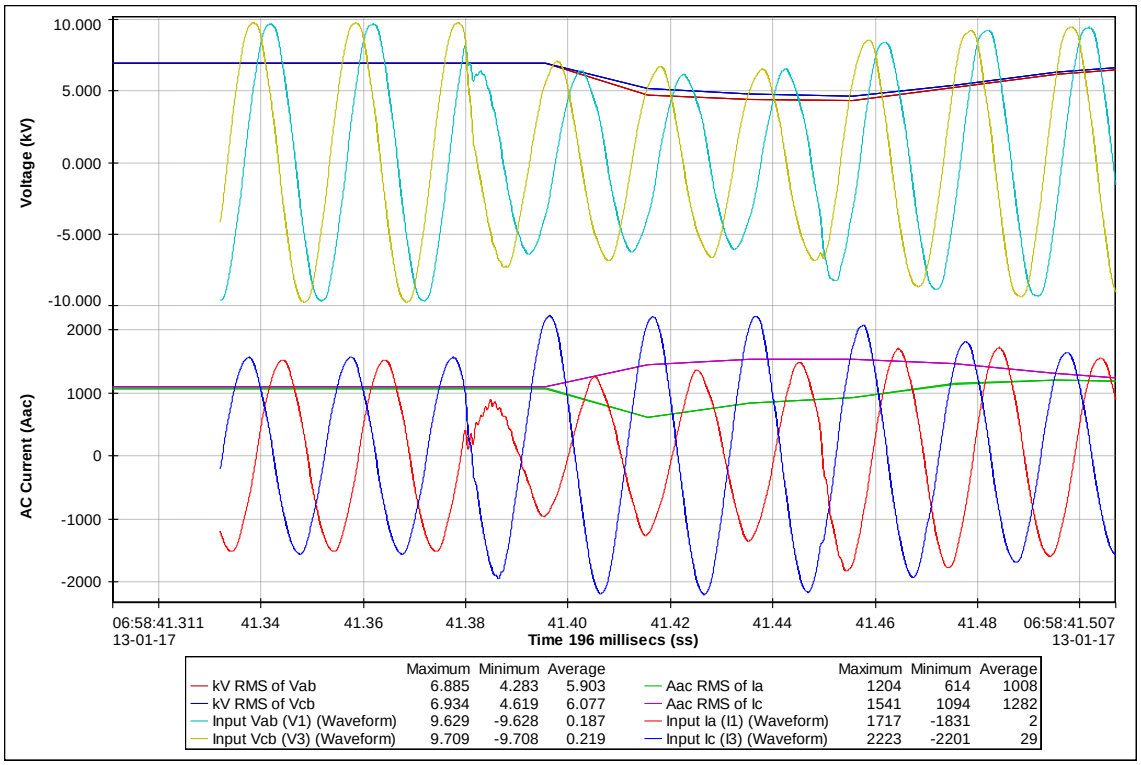


Graph 8. Group of three voltage events on 13/01/17



Graph 9. Third and last of the group of three voltage events on 13/01/17.

This last one is the hardest to be certain of – The initial few millisecs show reductions in voltage and current, then voltage phase separations alter, perhaps caused by collapse of B-phase voltage. Ic increases dramatically, while Ia drops, and Ia-Ic phase separation occurs, until both voltages and current recover appears after 3-4 cycles. Graph 10 shows the waveforms.



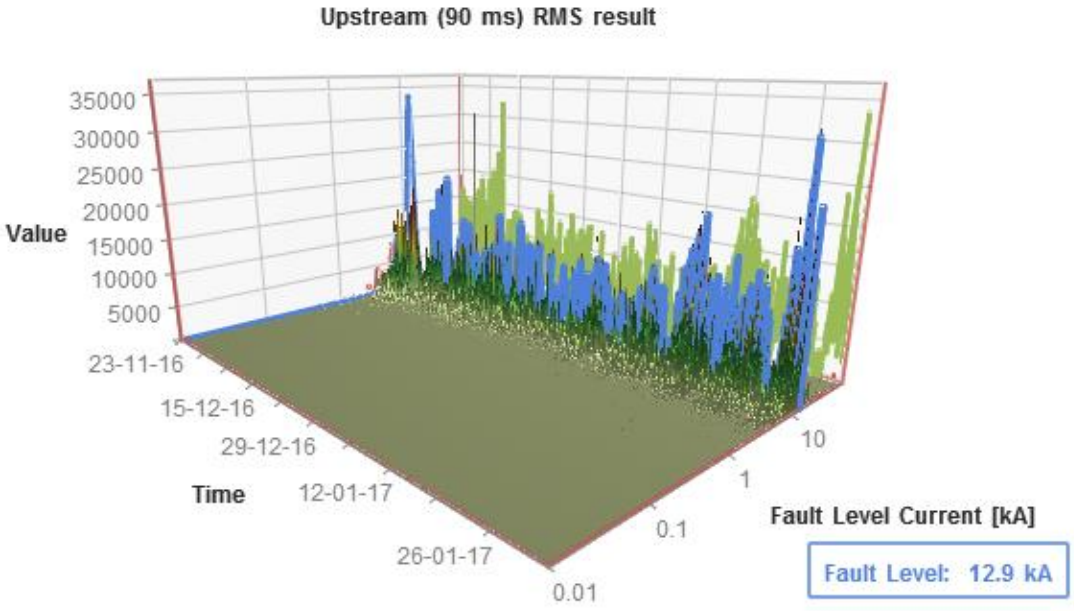
Graph 10. Waveforms associated with event on 13/01/17.

These voltage events do add authority to the downstream 10ms Peak Fault Level contribution.

Nelson Primary results, disturbances useful for Fault Level.

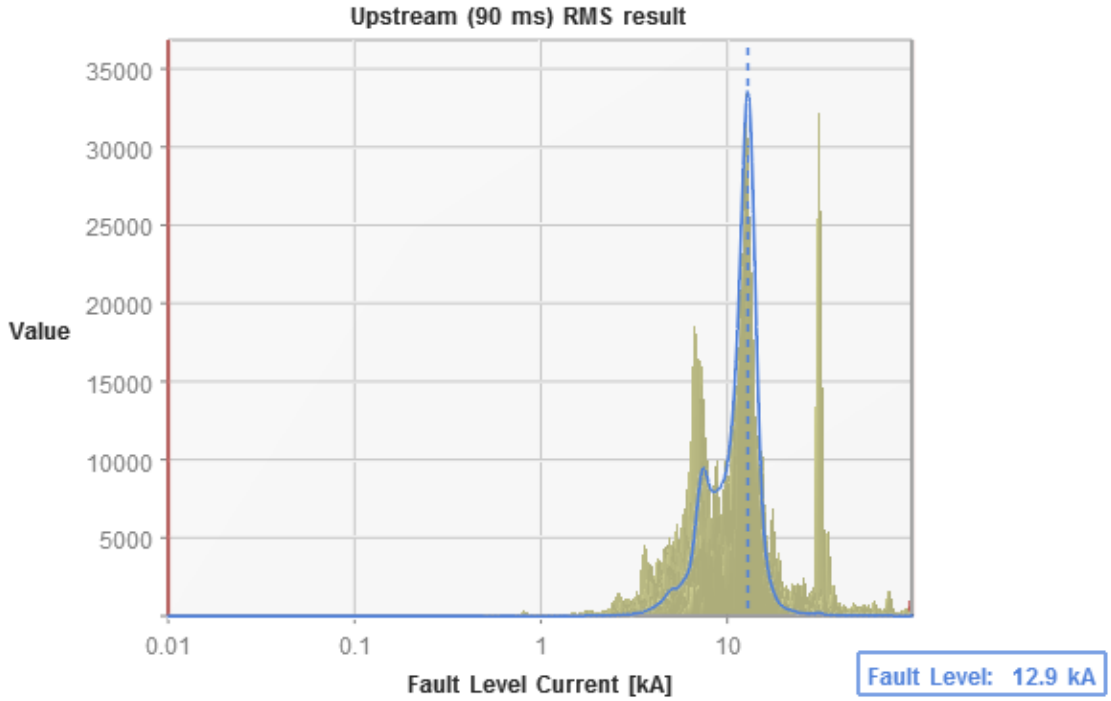
There were few substantial current spikes, but enough low level activity to yield good results.

Nelson Primary Fault Level Results



Graph 11. First half recording. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.

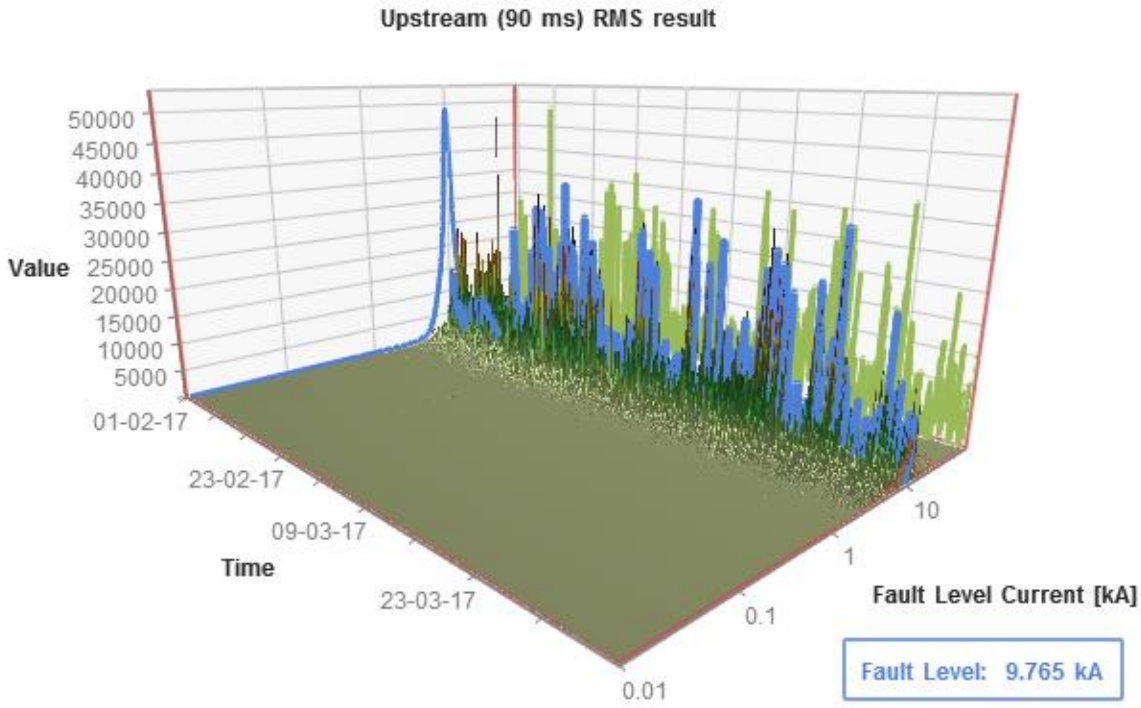
Graph 11 shows that the mean Upstream 90ms RMS Fault Level for the period 23/11/16 to 01/02/17 was 12.9 kA. Filtering of 2% was applied. Graph 12 shows the same thing in 2 dimensions.



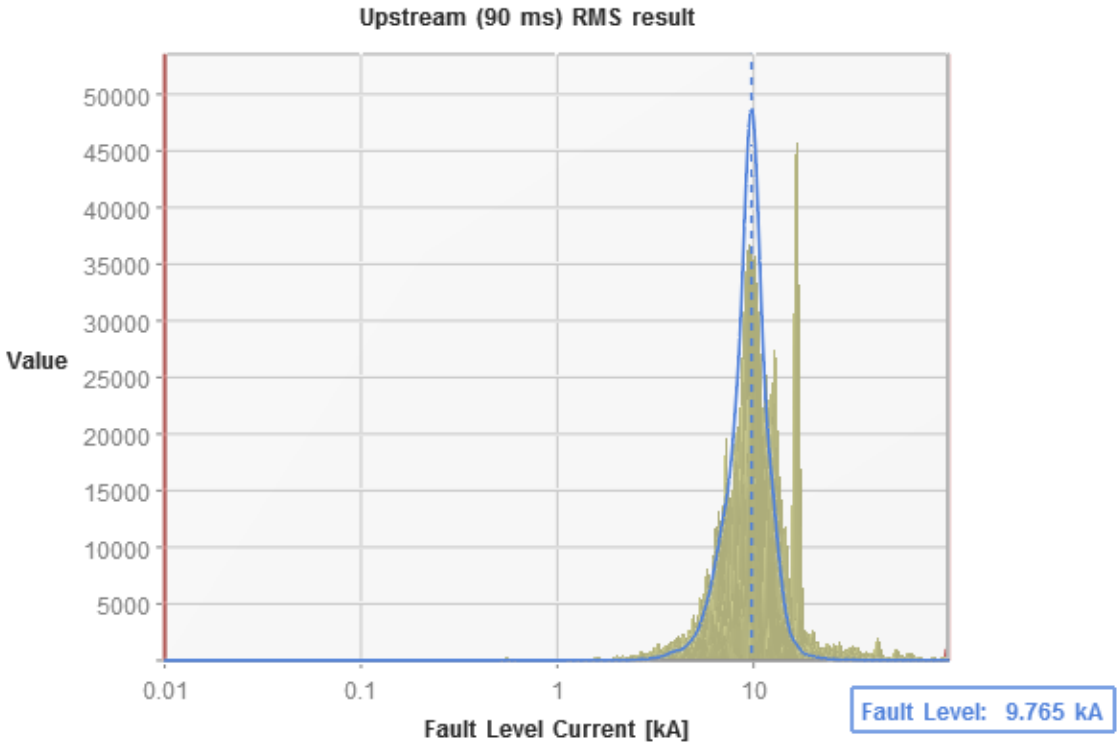
Graph 12. First half recording. Upstream RMS Fault level at 90ms. 2D Distribution shown with 2% filtering.

From the above it can be seen that as at Blackbull there is some disturbance energy suggesting a population at a level lower than the aggregate 12.9kA. This is examined later in Graphs 23 and 24.

Graphs 13 and 14 show the Upstream RMS Fault Level at 90ms for the second half period.



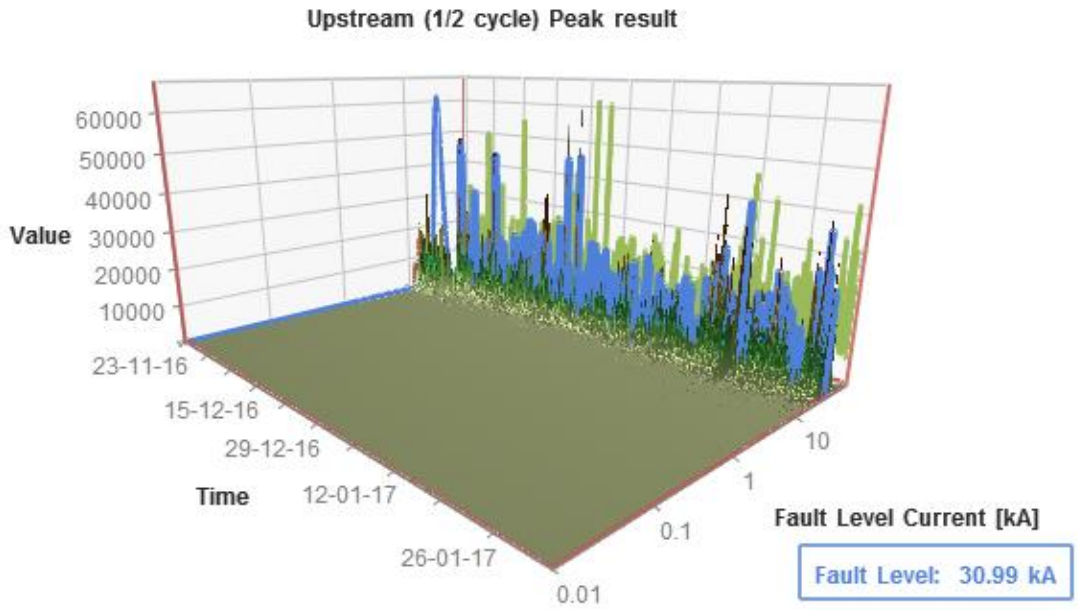
Graph 13. Second half recording. Upstream RMS Fault level at 90ms. 3D Distribution shown with 2% filtering.



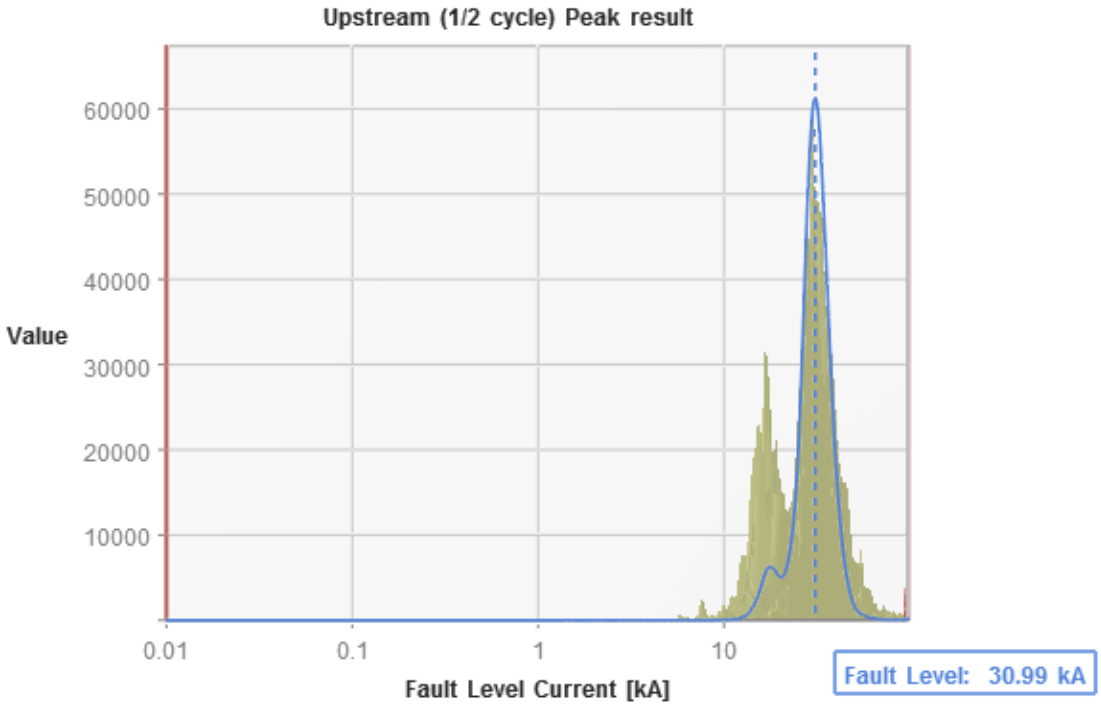
Graph 14. Second half recording. Upstream RMS Fault level at 90ms. 2D Distribution shown with 2% filtering.

It is less clear that there is more than one population here, however there appears to be a significant change in Fault Level between the bulk values in the first and second halves of the overall recording. The bulk value for RMS Break Fault Level at 90ms for this second half is 9.77kA. This is also examined later.

Graphs 15 and 16 show the Peak Make upstream Fault Level contribution at 10ms for the first half of the recording, from 23/11/16 to 01/02/17. The aggregate figure over the whole period is 30.99kA.

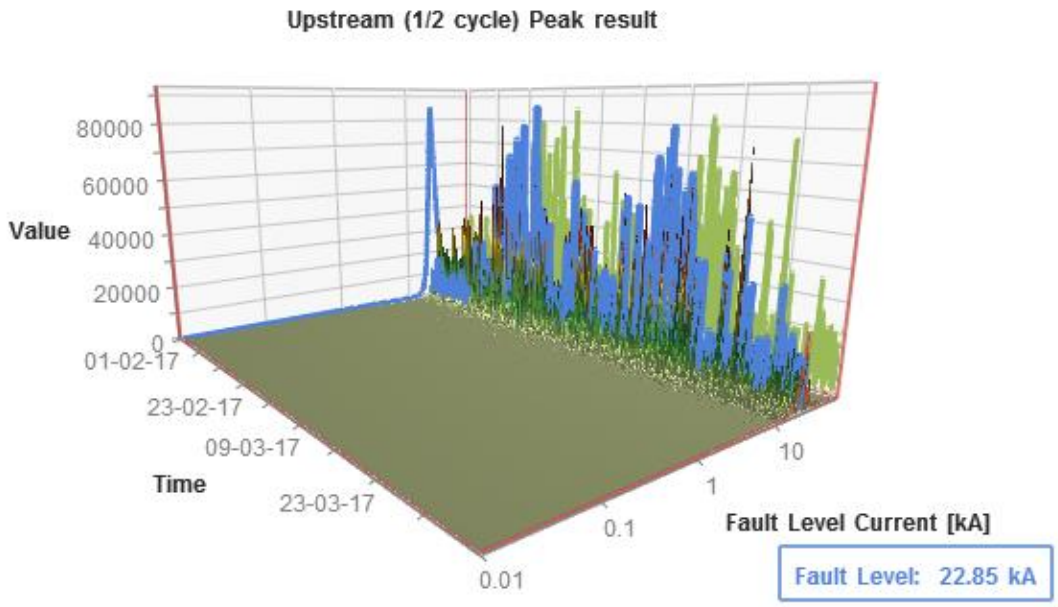


Graph 15. First half recording. Upstream Peak Fault level at 10ms. 3D Distribution shown with 2% filtering.

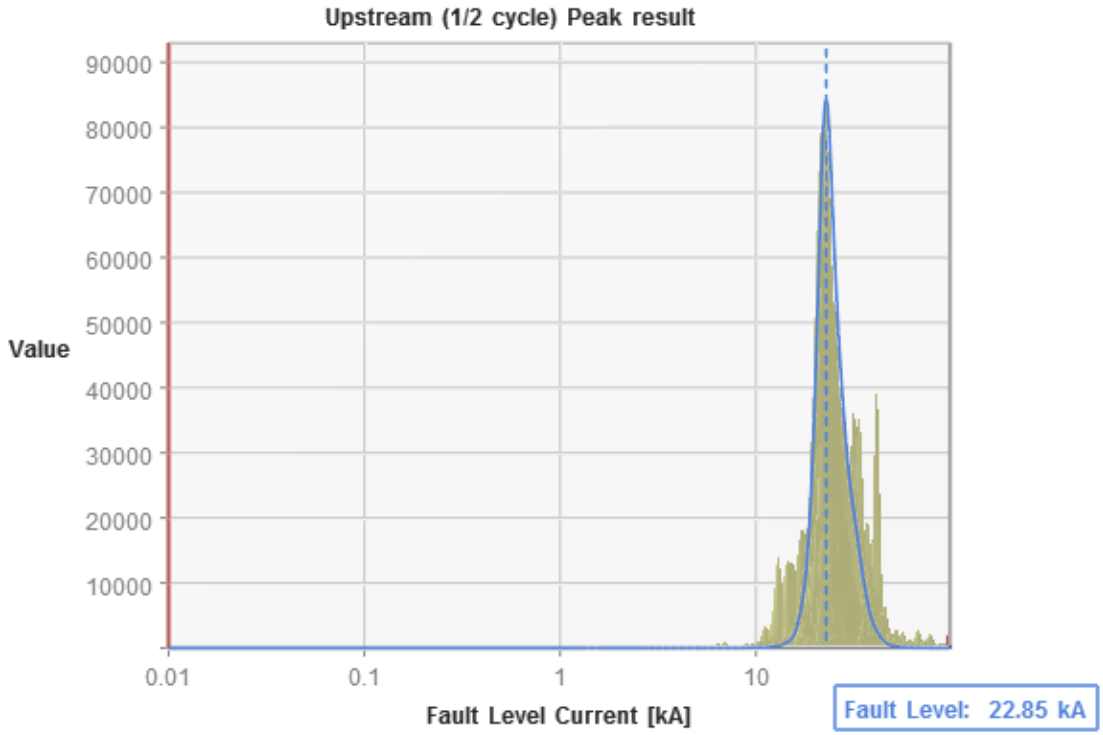


Graph 16. First half recording. Upstream Peak Fault level at 10ms. 2D Distribution shown with 2% filtering.

Graph 17 shows that the Upstream Peak 10ms Fault Level contribution for the period 01/02/17 to 03/04/17 was 22.85kA. This is significantly lower than for the previous period, and to be expected based on the reduction observed in the RMS Break Fault Level above. Graph 18 shows the same thing (Upstream Peak at 10ms) in 2 dimensions.

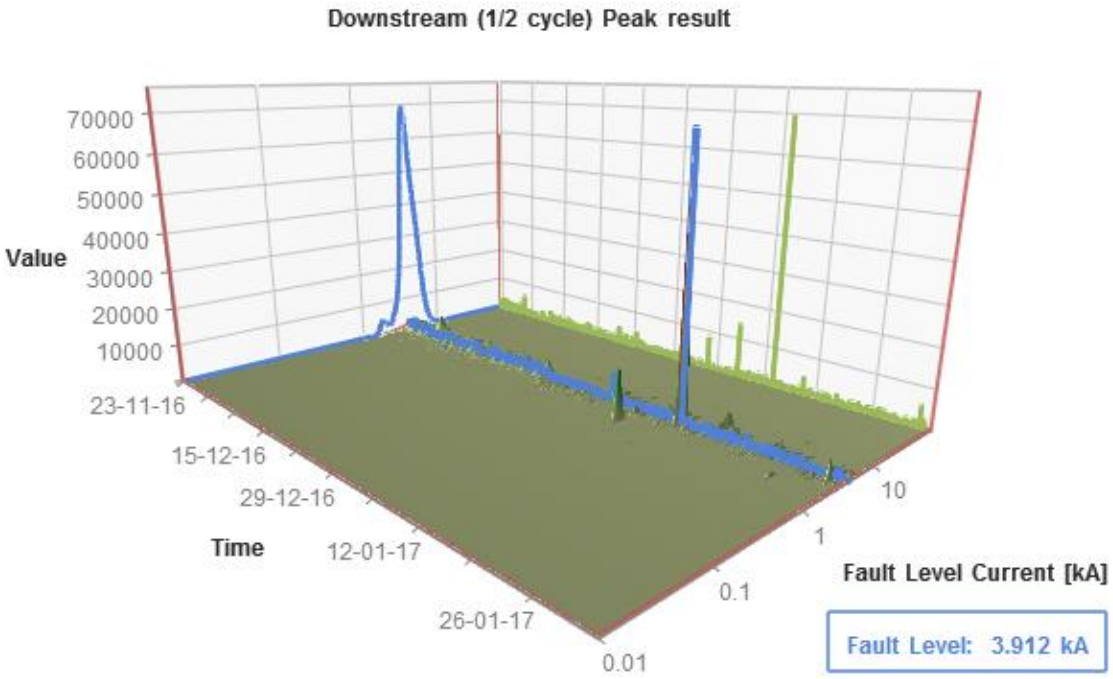


Graph 17. Second half recording. Upstream Peak Fault level at 10ms. 3D Distribution shown with 2% filtering.

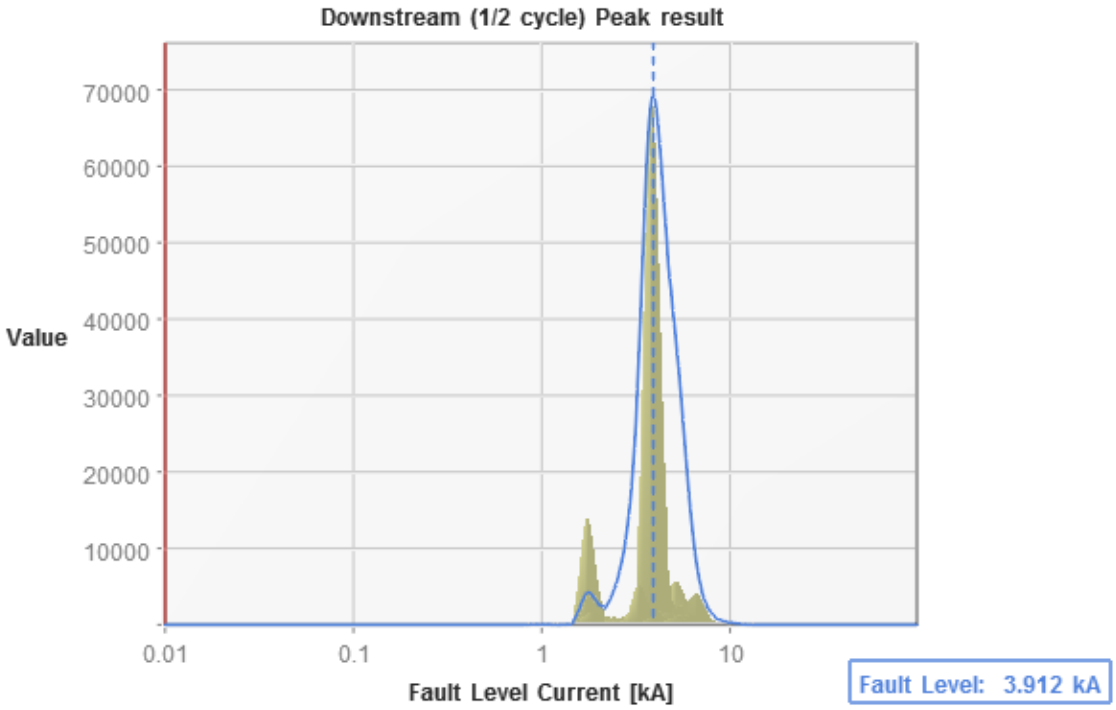


Graph 18. Second half recording. Upstream Peak Fault level at 10ms. 2D Distribution shown with 2% filtering.

Graphs 19 and 20 show the Downstream Peak contribution at 10ms for the first period 23/11/16 to 01/02/17.

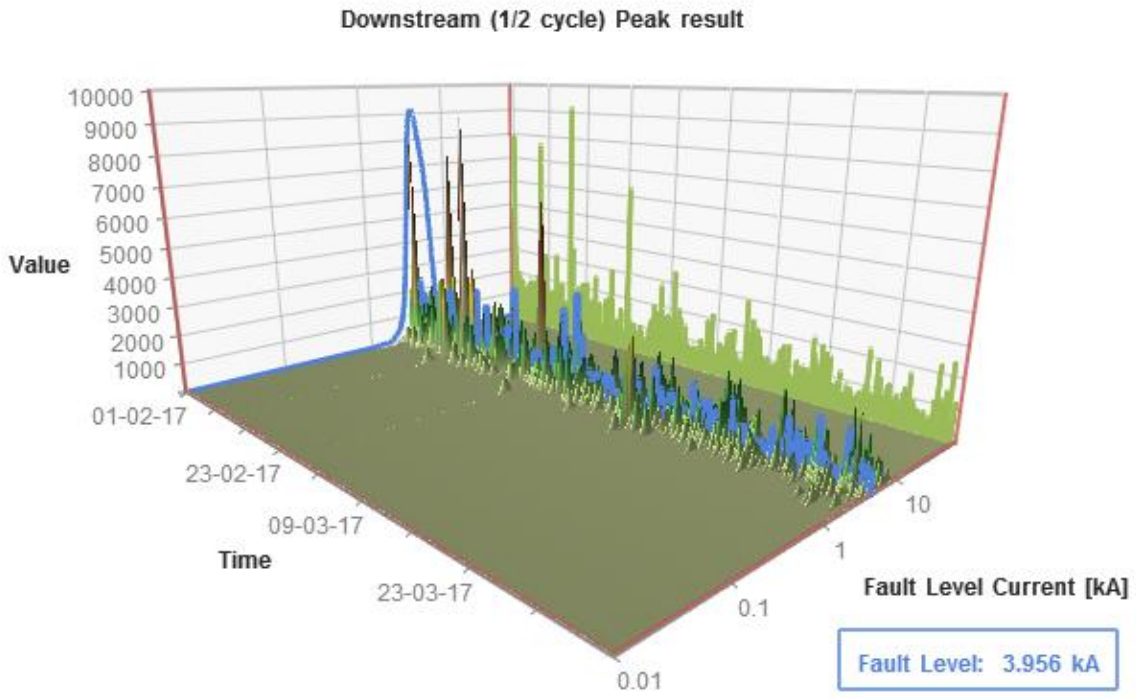


Graph 19 First half recording, Downstream Peak contribution at 10ms. 3D presentation with 5% filtering.

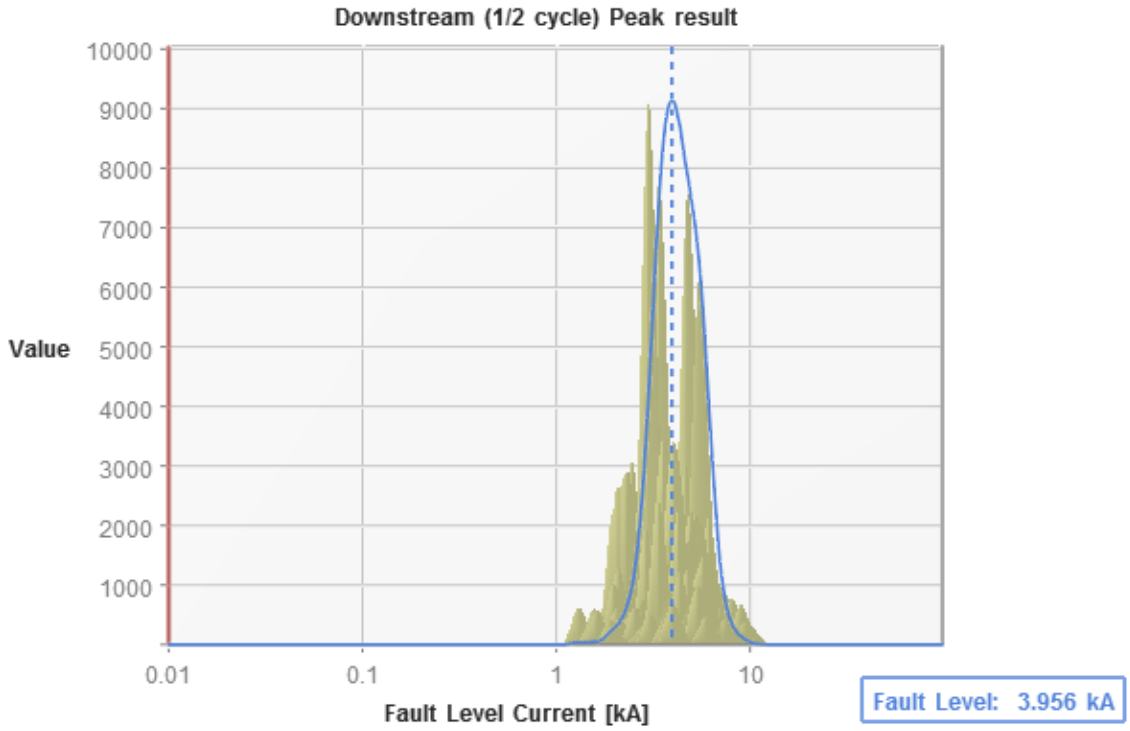


Graph 20 First half recording, Downstream Peak contribution at 10ms. 2D presentation with 5% filtering.

Graphs 21 and 22 show the Downstream Peak contribution at 10ms for the second period 01/02/17 to 03/04/17.



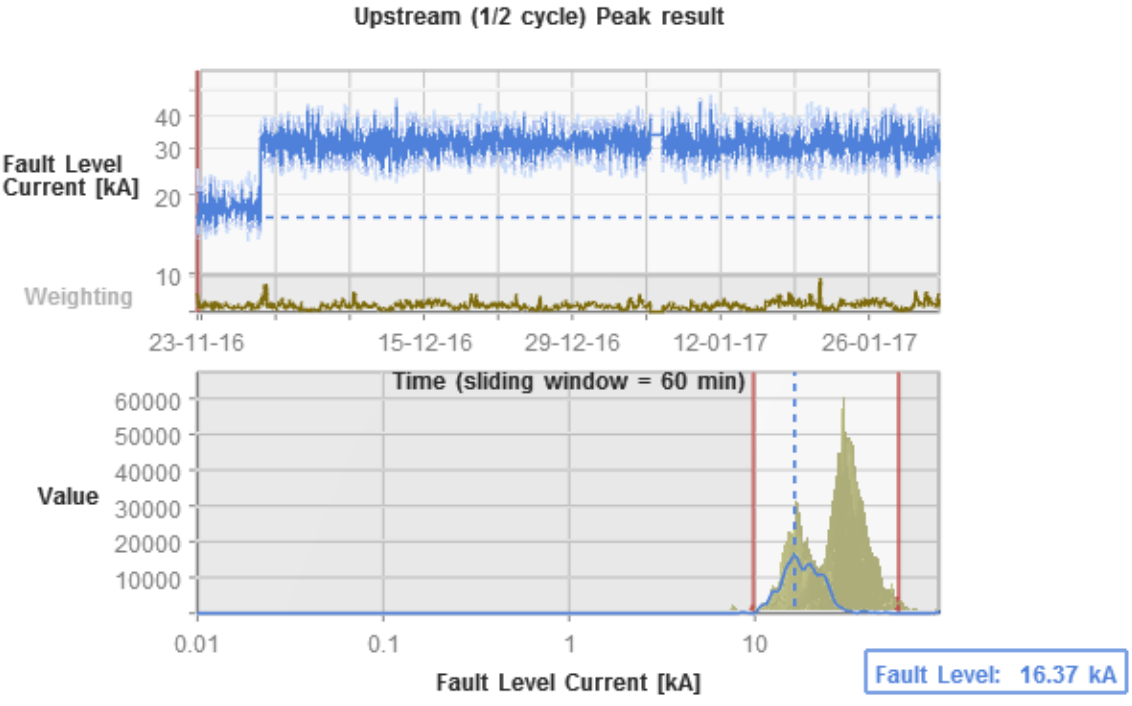
Graph 21. Second half recording, Downstream Peak contribution at 10ms. 3D presentation with 5% filtering.



Graph 22. Second half recording, Downstream Peak contribution at 10ms. 2D presentation with 5% filtering.

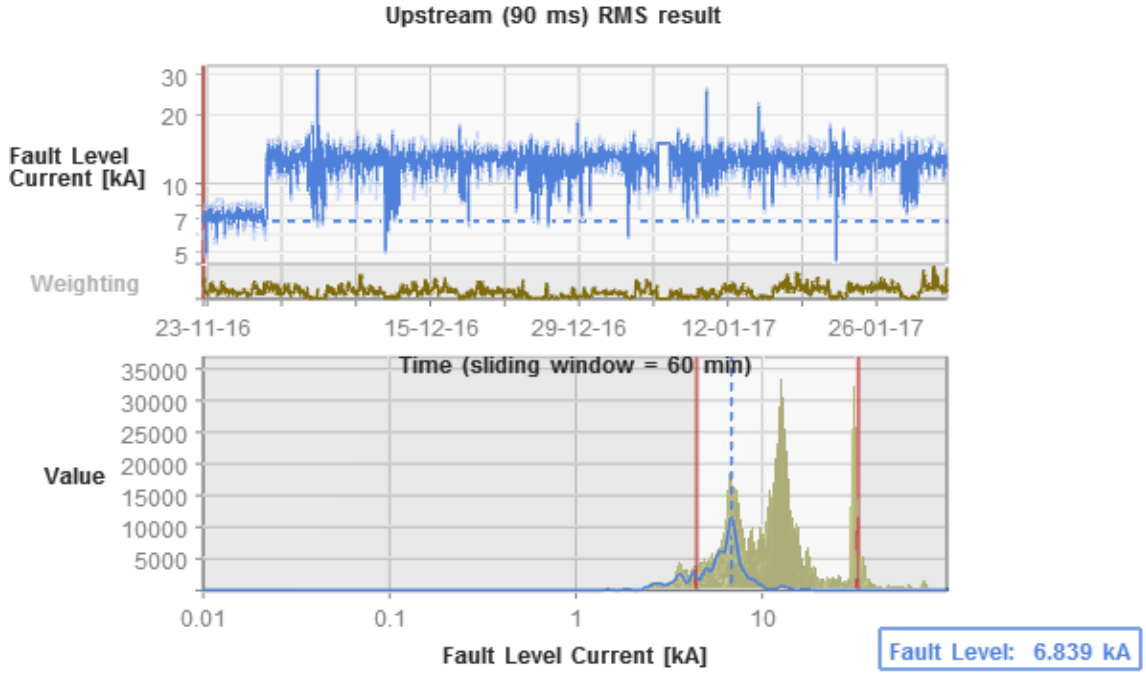
Fault Level changes occurring during the four months.

From Graph 12 above, it appears that there may be a secondary population of results in the first half of the recording. Presenting the data against time with a short 60 minute aggregation interval confirms this. Graph 23 shows that the Peak Upstream Fault Level contribution changing at about 14:00 on 29/11/16, from 17.56kA to 30.99kA. (The 17.56kA figure is obtained from six day aggregation not 60 minutes.)



Graph 23. Upstream ½ cycle Peak result with 60 minute aggregation interval.

Similarly the 90ms RMS result shows the same behaviour. Graph 24 refers.

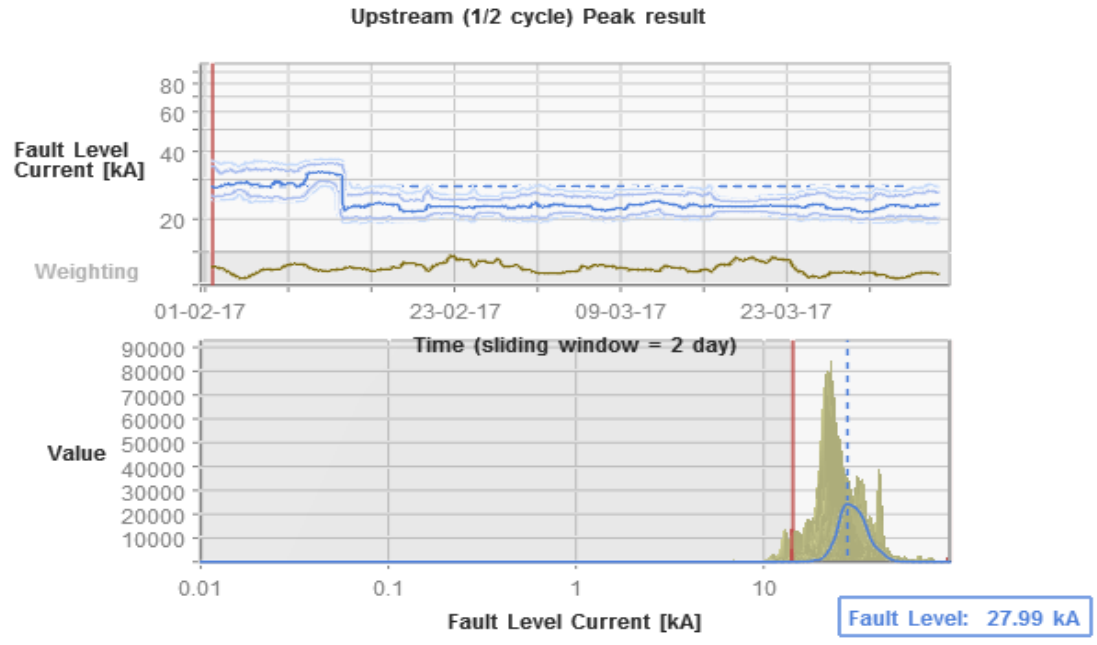


Graph 24. Upstream 90ms RMS result with 60 minute aggregation interval.

The RMS result changes from 7.26kA to 12.9kA (at about 14:00 on 29/11/17).

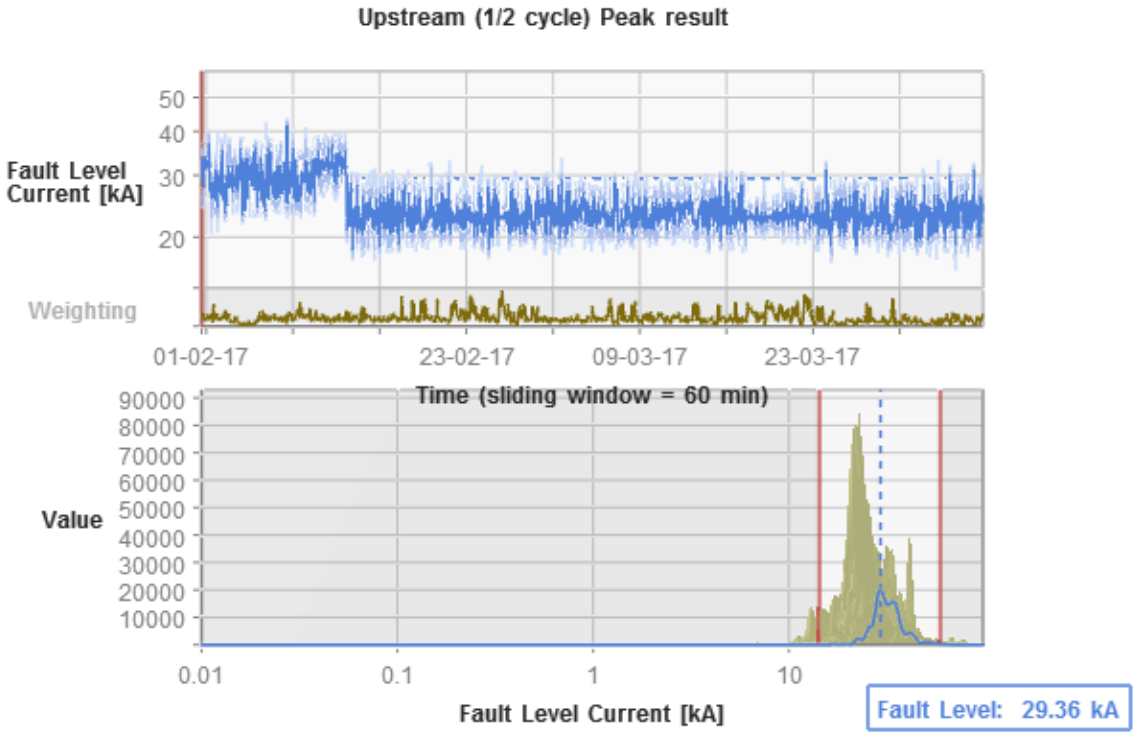
Looking for changes in Fault Level during the second half of the recording between 01/02/17 and 03/04/17, there is a period at the start in which the Fault level is close to the bulk of the FL values in the previous two months. During this 12 day period it appears that the Peak 10ms Fault Level value does change by ~14% from ~28.4kA to 32.44kA on 10/02/17 at ~18:00. The RMS Fault Level also at 10ms does not change much: from 12.65kA to 13.13kA max (3.8%), The RMS at 90ms cannot reliably be quantified because although the 2 day average appears to peak just before the drop on the 13/2, the weighting attached to those results is lower than elsewhere. The average Peak FL for the 12 days is 30.0kA. Graphs 25 to 28 refer to this.

Graph 25 shows the behaviour of the Peak ½ cycle value using a 2 day aggregation interval.



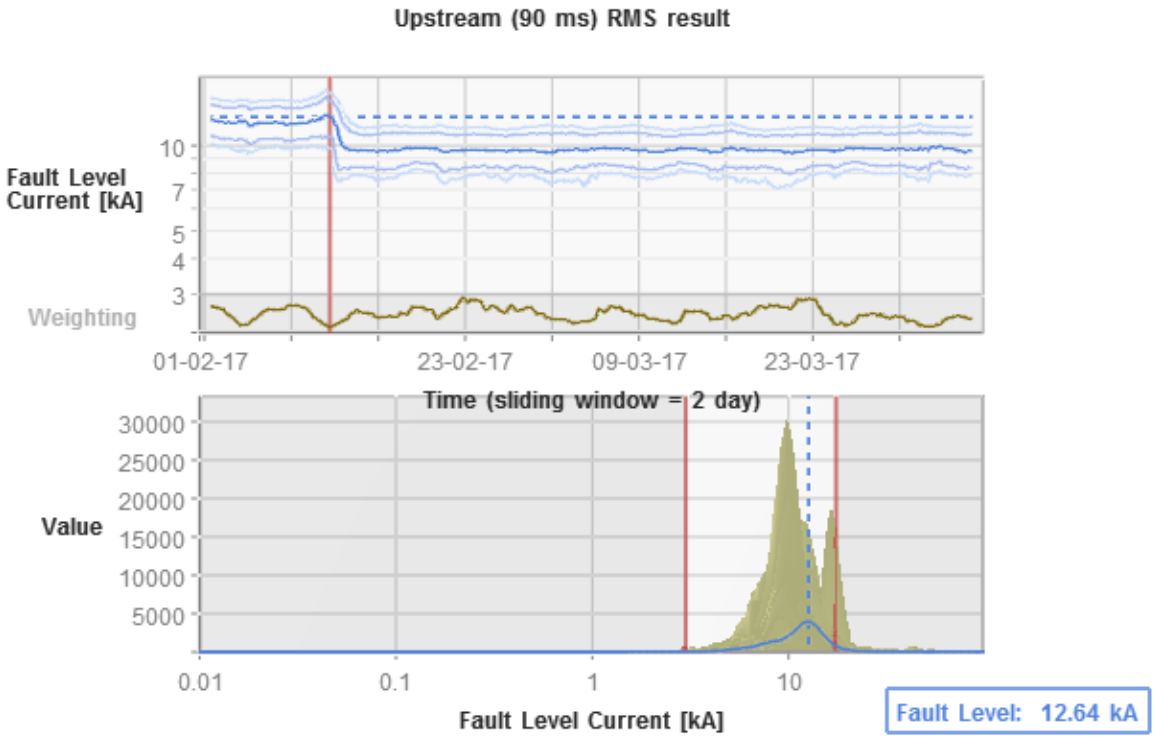
Graph 25. Second half recording, Peak ½ cycle value using a 2 day aggregation interval.

There are no large spikes having significant influence during that time. The pattern of load is constant though there is an abnormal current surge lasting about two hours on the 08/02/17, however showing the 60 minute aggregation interval suggests that this surge is not a major contributor and the change is consistent. Notice how the whole population rises on 10/2/17 before falling back 3 days later. Graph 26 refers.

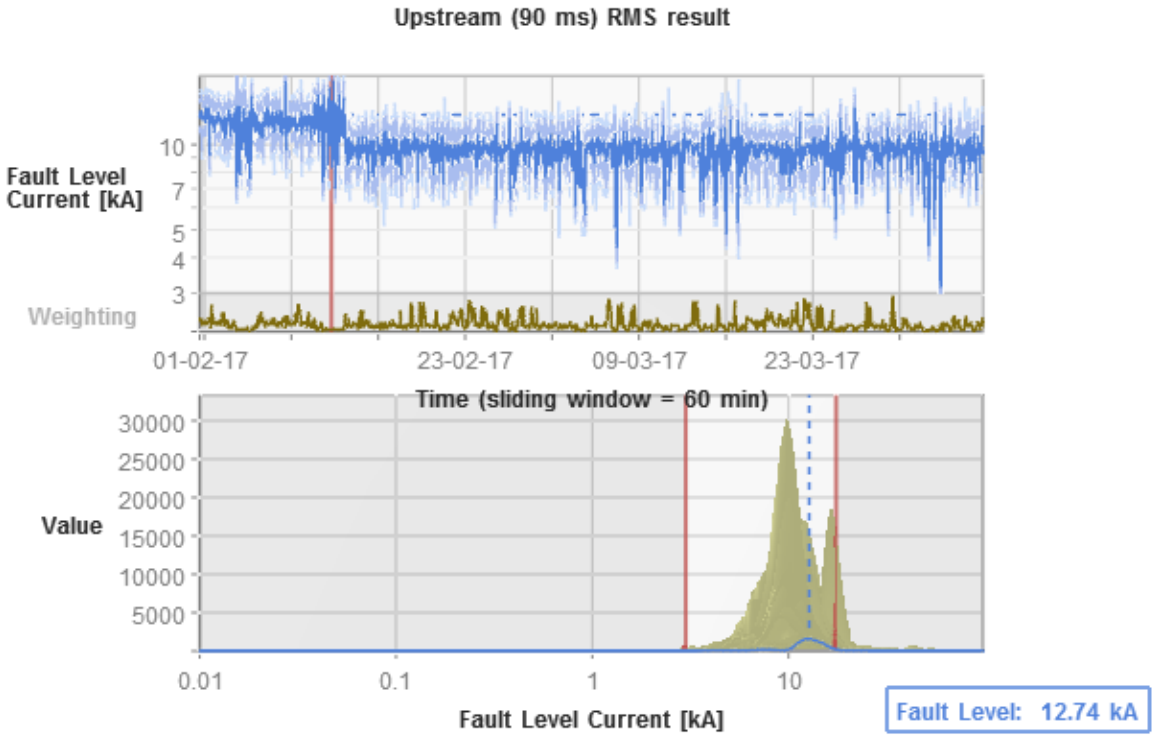


Graph 26. Second half recording, Peak ½ cycle value using a 60 minute aggregation interval.

Graphs 27 & 28 show the 90ms RMS result. Though there is an apparent rise around 11/02/17, the weighting is low and the lower edge of the noise population does not appear to change much.



Graph 27. Second half recording, RMS 90ms Fault Level value using a 2 day aggregation interval.



Graph 28. Second half recording, RMS 90ms Fault Level value using a 60 minute aggregation interval.

The 12 day aggregation for Peak ½ cycle and 90ms RMS Upstream results for the period 01/02/17 to 13/02/17 using 2% filtering are 30.0kA and 12.23kA respectively.