Improving Rural Power Quality in New Zealand

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Abstract

Power Quality (or more accurately Voltage Quality) has become a significant issue in New Zealand with the changing nature of the loads. In the rural sector high prices for dairy products has resulted in many farms converting to dairy farming. Often these farms are situated in dry areas where intensive irrigation is required to maintain adequate grass growth for the herds. These irrigators use submersible pumps that are often fed from variable speed drives (VSD). This has caused harmonic problems in the rural network, particularly in control and protection equipment. Field measurements have been made to understand and quantify the problem and these have shown harmonic levels above N.Z. regulatory limits. To retrofit harmonic filters to the existing VSDs was impractical due to the lack of space in pumping sheds and the inability to retrospectively require farmers to install them. Hence an alternative method of harmonic cancellation was investigated. In order to achieve harmonic cancellation, strategic Dyn11 transformers were replaced with Dzn0 transformers. This investigation involved computer simulations followed by testing on a trial installation before more widespread deployment was adopted. This paper overviews the development of this technique for controlling rural harmonic levels and shows the results from implementing this on the Orion N.Z. network.

1. Introduction

Large variable speed drives (VSDs) are increasingly being used to drive irrigation pumps in the rural areas and the effect of these is clearly seen in the harmonic levels on rural electrical networks. It is better to fix the harmonic problem at the source and the VSD drive manufacturers have standard harmonic filters as optional extras, as well as some offering low-distortion drives as another option. Therefore it is desirable to consider harmonic distortion levels when planning a new installation and these options can be implemented. To retrofit harmonic filters to the existing VSDs was impractical due to the lack of space in pumping sheds and the inability to retrospectively require farmers to install them. An earlier study looked at providing harmonic filters at the district substation [1]. This has the advantage of adequate space and one filter to cover many VSD drives, however the simulations showed it was a poor solution due to the size of the filter required for adequate reduction in harmonic levels. The study also indicated a substantial improvement could be achieved by phase shifting the harmonics in order to obtain harmonic current cancellation.

2. Harmonic Assessment

2.1 VSD Harmonic Current Injection

To verify the harmonic currents injected by an irrigation pump driven by a VSD, measurements were made on one such pump on 18 May 2008. The waveform and harmonic currents measured using a Fluke41 when the 160 kW drive was at approximately 65% of full power are displayed in Fig. 1. This clearly shows a large 5^{th} harmonic component. The manufacturer of this drive also provides Harmonic Calculation Toolbox (MCT31) which is based on the solution of the basic six-pulse converter shown in Fig. 2 [2,3]. Application of this toolbox gives the predicted harmonic current levels which are shown in Table 1. The measured harmonic current levels (Table 2) agree very well with the predicted levels. The small discrepancies can be attributed to the pre-existing harmonic distortion levels and imbalance in the phases.

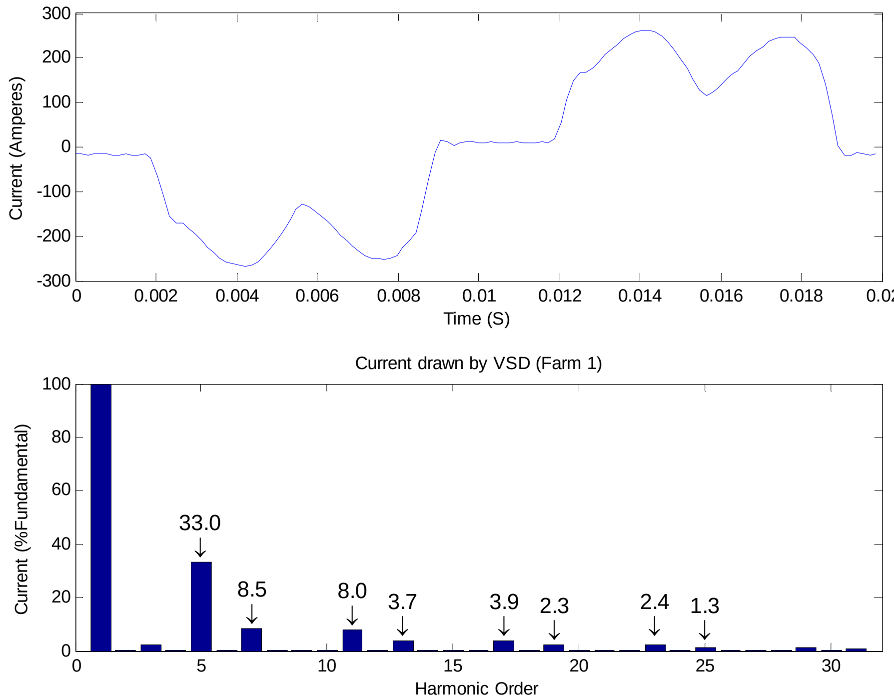

Figure 1. Current waveform drawn and harmonics injected a VSD.

Table 1. Predicted Harmonic Currents

Units	1	5	7	11	13	17	19	23	25	29	31
[%]	100	30	9.8	7.0	4.0	3.0	2.3	1.5	1.3	0.8	0.7
[A]	164	50	16.2	11.5	6.6	5.0	3.7	2.4	2.1	1.3	1.2

Table 2. Measured Harmonic Currents (Phase *a*)

Units	1	5	7	11	13	17	19	23	25	29	31
[%]	94.2	31.1	8	7.5	3.5	3.7	2.2	2.2	1.3	1.3	0.8
[A]	163	53.9	13.9	13.1	6.1	6.4	3.8	3.9	2.2	2.2	1.3

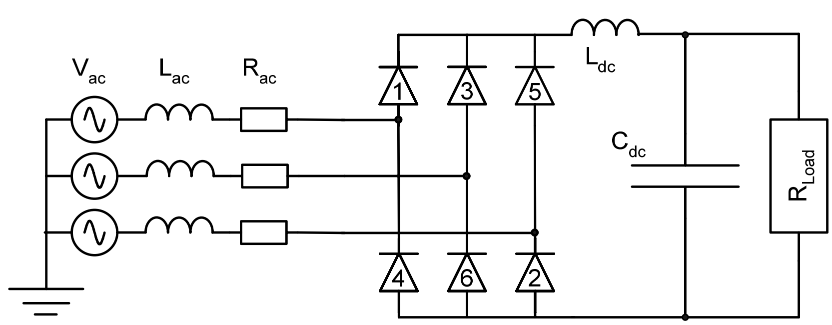

Figure 2. Basic Circuit Layout.

2.2 Diversity in Harmonic Currents

The next question is how much diversity is there in the harmonic currents injected by the various irrigation pumps. This was tested on 20 November 2008 when simultaneous measurements were made on four different VSDs fed from the same substation (Bankside). Fig. 3 (a) shows a polar plot of the 5th harmonic currents. The phase angles are relative to the terminal voltage waveform (no GPS synchronisation) and no adjustment has been made to the slight difference in voltage phase angle at the different farms. Even so this plot clearly shows a lack of diversity, which is exemplified when the phase *a* 5th harmonic currents are added vectorially, as shown in Fig. 3(b). By introducing more diversity into the harmonic currents, harmonic cancellation can be achieved much in the same way two 6-pulse bridges can be connected to form a 12-pulse converter in HVDC applications. This is achieved by utilizing the phase-shift across transformers with different winding configurations. In HVDC Δ/Y and Δ/ Δ are often used [4,5,6]. At present the 11kV to 415V transformers at the farms are Dyn11 transformers. The obvious choices are Dd0 or Yyn0 transformers which have no phase shift between MV to LV, and hence are 30 degree phase shifted with respect to the Dyn11 transformer supply. These however do not satisfy the requirements of having a delta on the MV side to trap triplen harmonics or providing a neutral point on the LV side. The solution is to use the slightly more complicated Dzn0 transformer. Figure 4 displays the current waveforms at the 11 kV and 415V from an electromagnetic transient simulation (PSCAD/EMTDC) of a VSD with different transformer connections.

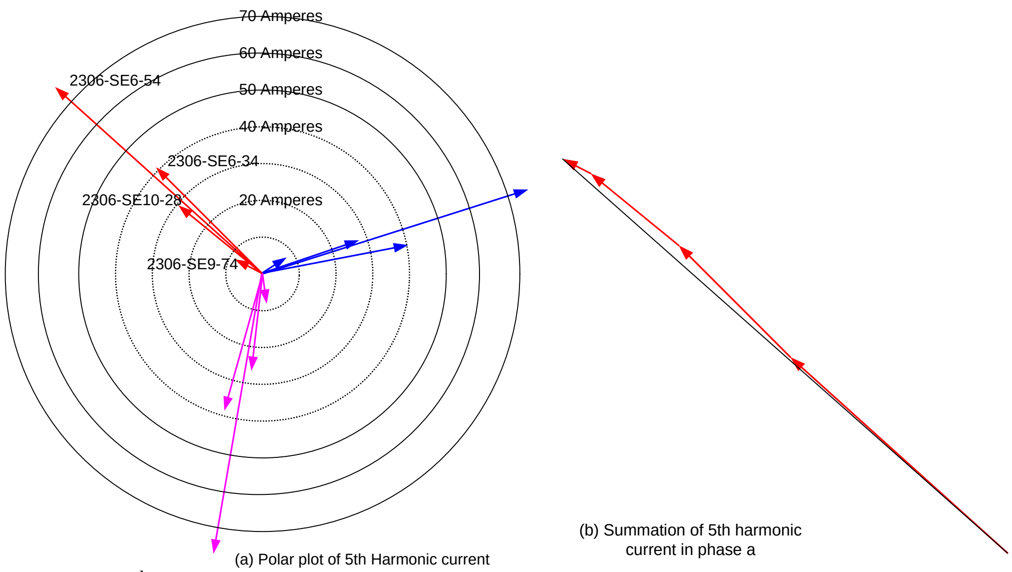

Figure 3. 5th Harmonic Current Phasors.

2.3 Testing the Concept of Dzn0 Transformer at Bankside

Before a more widespread use of Dzn0 transformer was adopted it was considered prudent to install one and to verify that harmonic cancellation would occur as expected. This test was performed on 2 July 2009. The transformer at Farm 1 was changed to a Dzn0 transformer while Farm 2's installation was not changed. Farm 2 is on the same feeder as Farm 1 and is reasonably close. A PQ meter was installed at Bankside substation to measure the harmonic currents and voltage on the 11 kV feeder feeding these two farms. Measurements were also taken at each farm. The procedure was to start Farm 2's VSD and then after a delay start Farm 1's VSD. Then

Farm 2's VSD was stopped and finally Farm 1's VSD. This gave a period where each was running on its own and a period when both operated.

Figure 5 shows a sample of the results obtained. When Farm 2's VSD turns ON there is a large increase in the 5^{th} harmonic current flowing in the 11 kV line. The 5^{th} harmonic voltage actually drops from approximately 1% to 0.6% as the VSD injection counters the background 5^{th} harmonic voltage. When Farm 1's VSD starts the 5^{th} harmonic current flowing in the 11 kV line drops and the 5^{th} harmonic voltage rises to its background level. When Farm 2's VSD stops, while leaving Farm 1's VSD running, the 5^{th} harmonic voltage jumps to approximately 1.7% and the 5^{th} harmonic current increases dramatically. This increase of 5^{th} harmonic voltage is because the 5^{th} harmonic current injection of this VSD is such as to reinforce the background harmonic voltage level. This test clearly demonstrated that the 5^{th} harmonic is cancelled by having two VSDs supplied from transformers with different phase shifts.

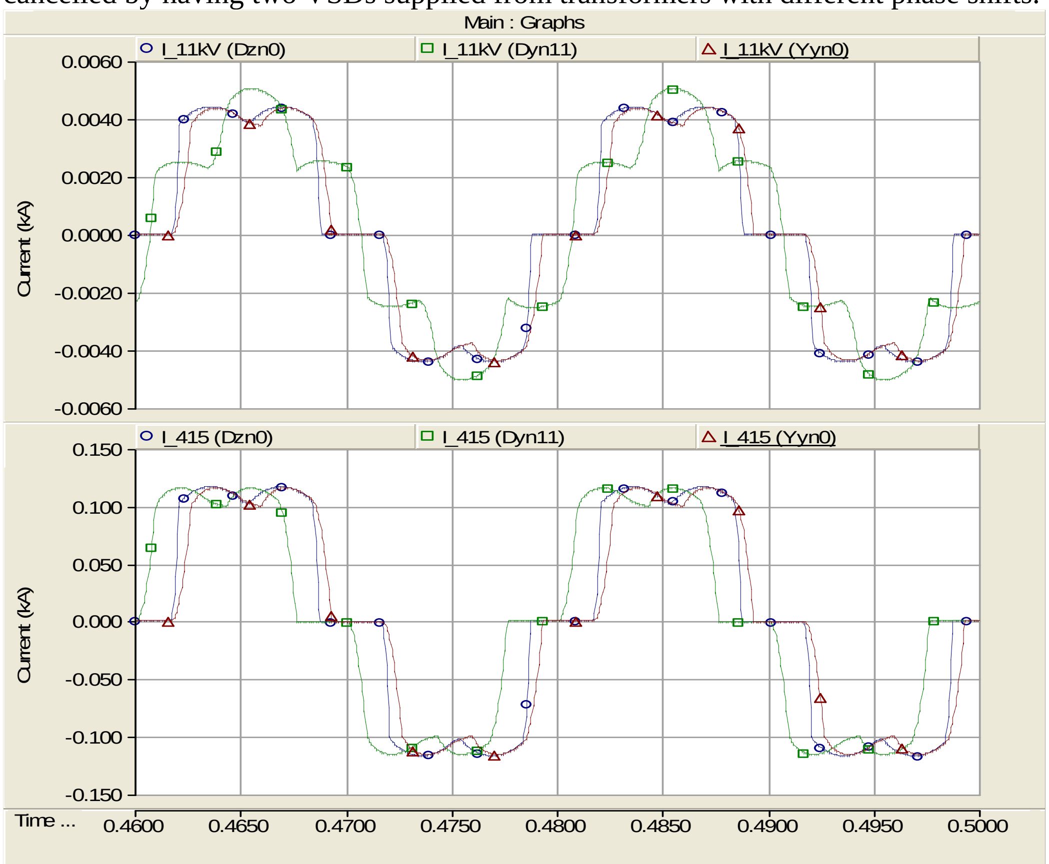

Figure 4. Time waveforms from PSCAD/EMTDC simulation.

2.4 Rollout of Dzn0 Transformers at Darfield

High levels of 5^{th} harmonic distortion on the 11 kV at Darfield substation has caused interference with equipment at Darfield substation. Recordings showed that during the summer of 2008/09, the total voltage harmonic distortion (V_{THD}) appearing on the 11 kV supply from Darfield District Substation sometimes exceeded 8% while the regulatory limit is 5% (ECP36). Figure 6 displays the V_{THD} for the phase-to-phase voltage between phases A & B (Red & Yellow) on the 11 kV busbar at Darfield during January 2009. To perform a comparison of harmonic levels between years it is desirable to have a period when the irrigation load has been at its maximum for a consistent length of time. The weather during the summer of 2008/09 was cold and damp and often not all the irrigators were running. Although the highest V_{THD} for the summer 2008/09 did not occur during January 2009, it has been considered the best month to perform a comparison between years, as there were no significant dips in load due to rain.

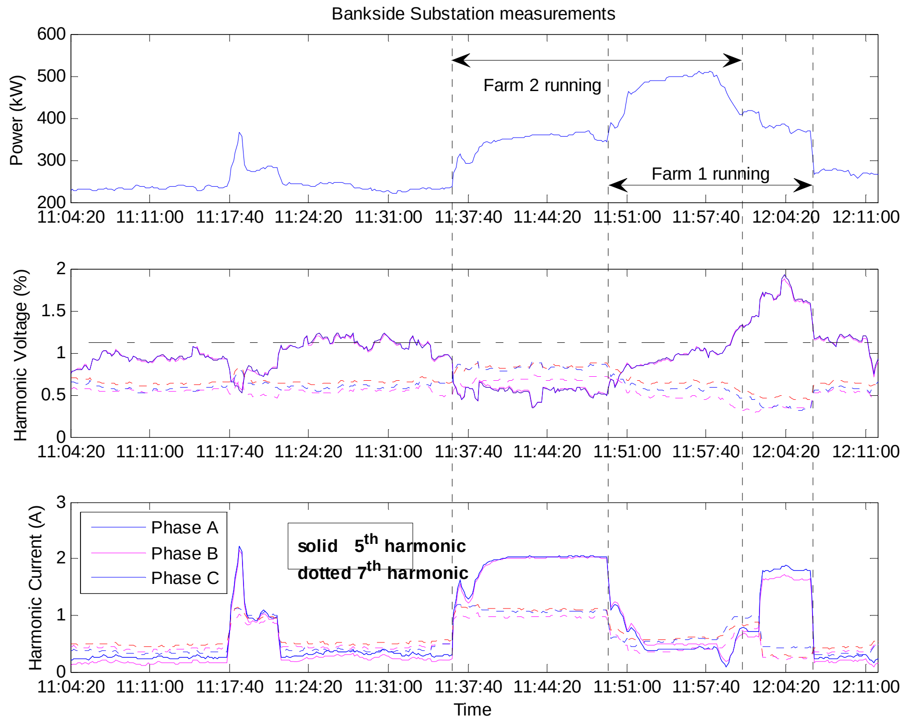

Figure 5. Recordings on a 11 kV feeder at Bankside substation.

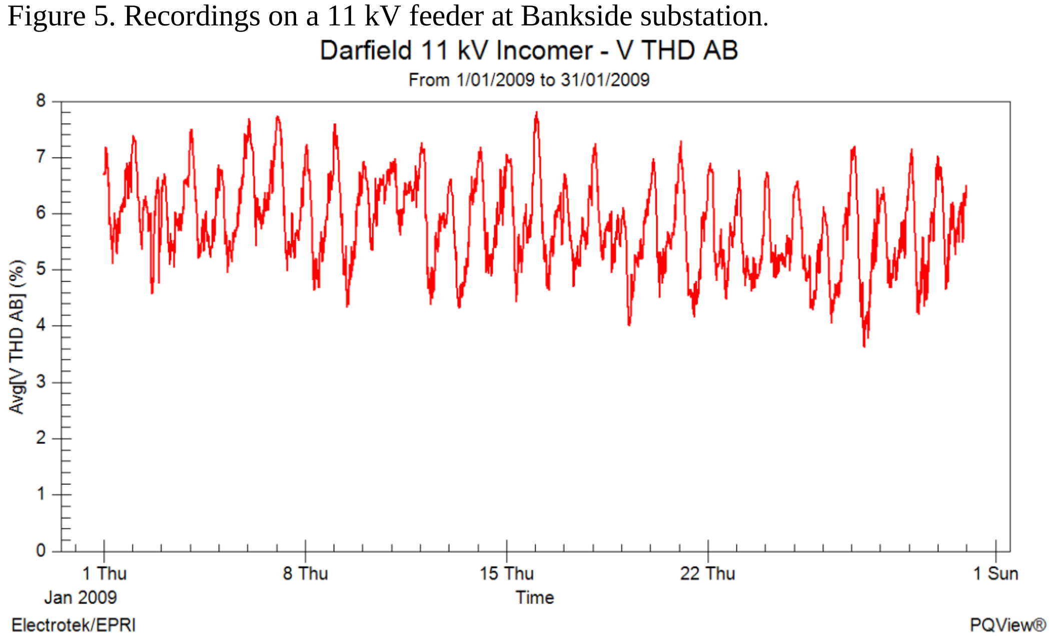

Figure 6. Voltage THD at Darfield 11 kV Busbar for January 2009.

The maximum value was 7.8% and the average 5.8% with a standard deviation of 0.77%. Figure 7 shows the same information in a different way. This shows as a histogram the proportion of time the V_{THD} is within the specified bin (V_{THD} level) and a Cumulative Probability (CP) distribution function which shows the percentage time the V_{THD} is below a given level. It shows that the V_{THD} is below 5% only 18% of the time.

Over the 2009 winter there was an approximately 50% increase in the unfiltered VSD drive load connected to the Darfield network. This would have exasperated the harmonic distortion problems if some form of mitigation was not installed. Also during the winter of 2009, 5 existing standard Dyn11 11kV/415 Volt distribution transformers supplying VSD pumps in the Darfield 11 kV network were changed to Dzn0 units. This represents approximately half the VSD load connected to the Darfield substation. The Dyn11 transformers were returned to stock and have been/will be installed elsewhere in the network.

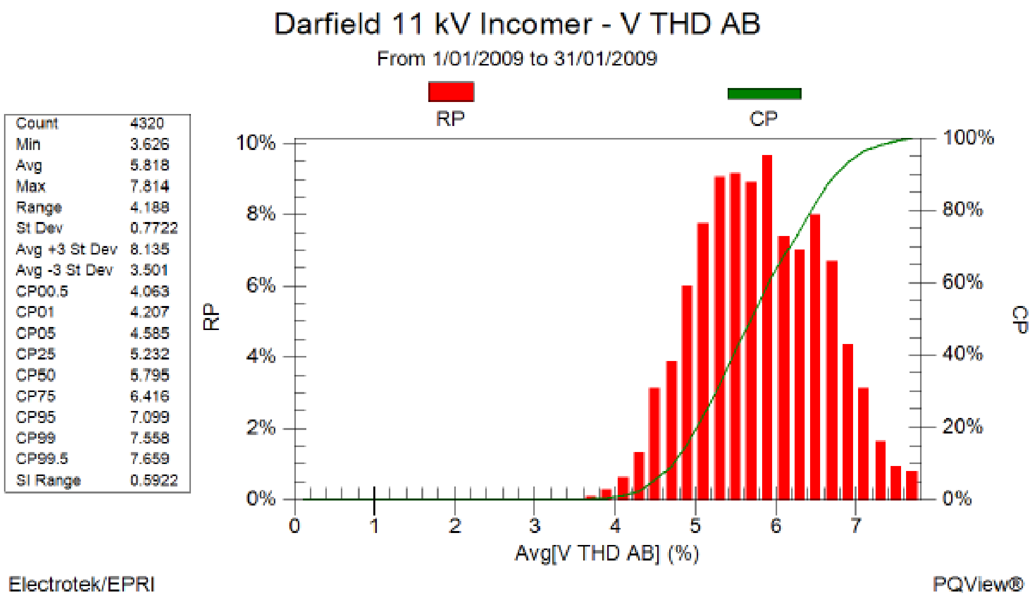

Figure 7. Voltage THD for January 2009 at Darfield substation.

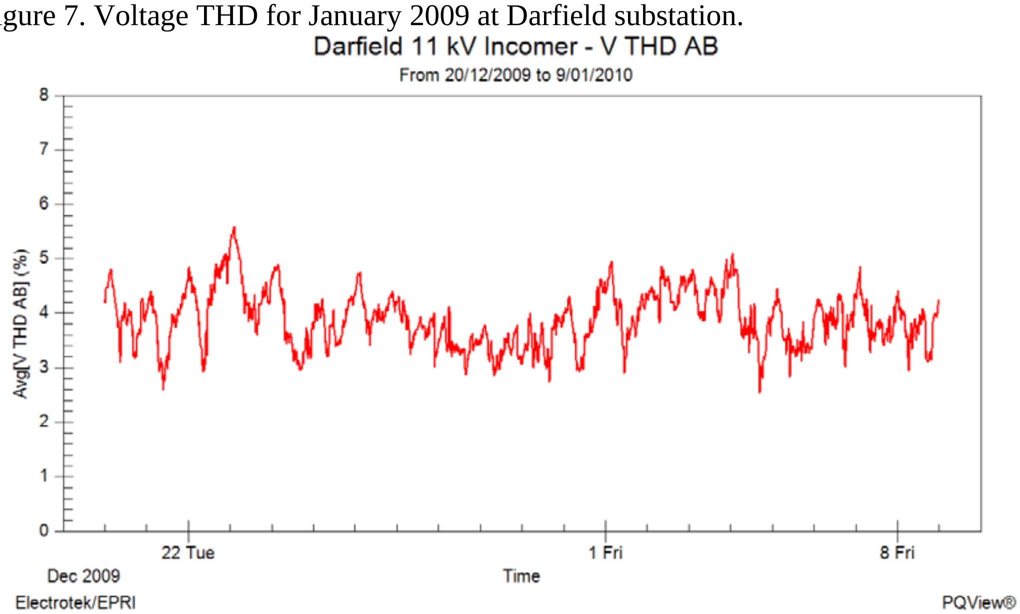

Figure 8. Voltage THD at Darfield 11 kV Busbar for December 2009/January 2010.

The V_{THD} was recorded from 20 December 2009 to 9 January 2010 and is displayed in Fig. 8. The maximum value was 5.6% and the average level 3.9% (standard deviation of 0.5%). The histogram and cumulative probability are shown in

Fig. 9. Note that 98% of the time the V_{THD} is below 5%. This is a dramatic reduction V_{THD} and this is in spite of a 50% increase in VSD load.

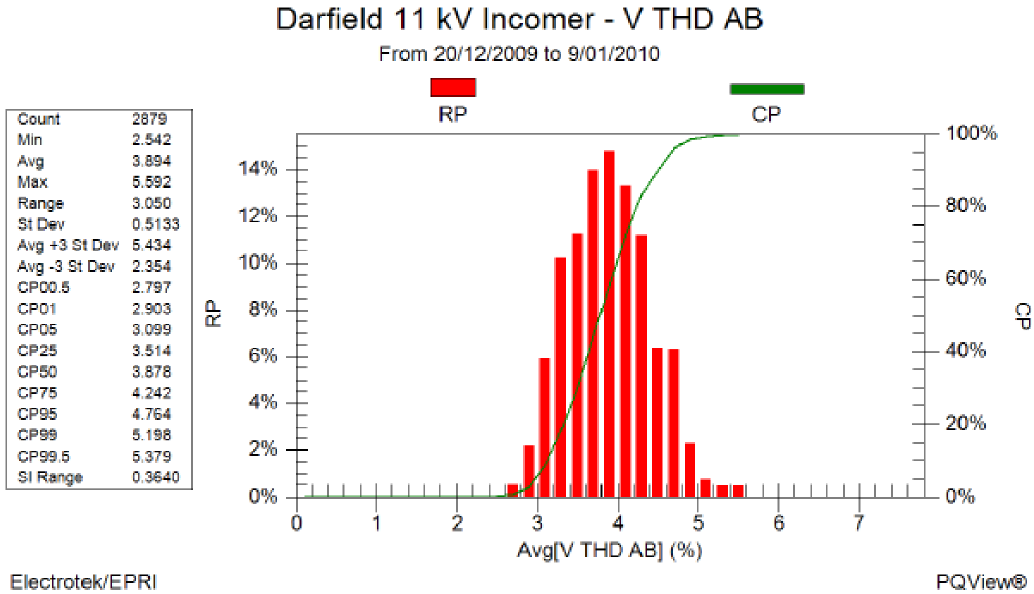

Figure 9. Voltage THD at Darfield 11 kV Busbar for December 2009/January 2010.

3. Conclusions

The field experience of using Dzn0 transformers to create a phase-shift in harmonic current components and thereby cancel some of the harmonic orders has been very successful. This technique ideally cancels the following harmonic orders: 5,7, 17,19, 29,31…etc. For complete cancellation the VSD load connected by the Dyn11 and Dzn0 transformers need to be matched, however, even when not matched only the residual harmonic currents will flow in the 11 kV feeder. Having only some VSDs running is not a big issue because there is a strong correlation between the use of the VSDs in the rural sector. If the season is dry normally all the dairy farmers will be irrigating and if wet all irrigators will generally be turned OFF.

4. Acknowledgements

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