EEA Conference & Exhibition 2009

19-20 June 2009

Christchurch, New Zealand

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Abstract

High and increasing voltage Total Harmonic Distortion (THD) and 5th harmonic voltage levels have been measured in recent years on Orion NZ Ltd's rural 11 kV distribution network in Canterbury, New Zealand. On occasion, at Points of Common Coupling (PCC), the THD has exceeded the 5% limit and the 5th harmonic has exceeded the 4% limit. It has been suspected that these summer season high harmonic levels are due to the large existing and increasing density of farm irrigation deep well pump loads. It is likely that adverse effects on the network and neighbouring loads would become apparent if the increasing harmonic levels are left unchecked.

A practical and theoretical investigation was conducted by the Electric Power Engineering Centre (EPECentre), University of Canterbury, on behalf of Orion to determine what are the primary causes of the high harmonic levels and provide mitigation options. Several farms with installed irrigation pumps were visited and the harmonic current and voltage levels were measured when the pumps were operating. Substation measurements were also simultaneously taken. A computer harmonic model of the local 11 kV network and loads was created that provided an accurate description of actual network conditions. An examination of Orion's system from the view of harmonic management was performed.

The investigation revealed that the most significant cause of high harmonics levels is the comparatively large harmonic current injections by local irrigation pumps using Variable Speed Drives. A secondary cause is resonances in the network, often dynamically created by Power Factor (PF) capacitors switching online at various farms. To keep the rural network infrastructure in an effective and sustainable operating condition, mitigation measures are needed. Options researched included simulations of harmonic filters placed at various network points, and the use of alternate vector group transformers. Suggestions are made regarding objectives for harmonic limits at different network voltage levels, so as to determine harmonic limits for load installations.

1 Introduction and methodology

Orion NZ Ltd own and operate the distribution network in central Canterbury, New Zealand, covering both urban and rural areas. High harmonic voltage levels have been reported in various parts of the rural 11 kV network. The network presently experiences high levels of Total Harmonic Distortion (THD) exceeding the 5% limit on occasion, and often exceeds the 4% harmonic limit for the 5th harmonic, at Points of Common Coupling (PCC) during the summer. Orion had suspicions that these high levels were caused by irrigation pumps connected to the network, because they coincide with the peak season for dairy farming in

Canterbury. Figure 1 shows the summer loading pattern that the observed feeder provides.

It was not known whether these high levels were due to some type of harmonic resonance or simply due to the harmonic current levels being injected. If a harmonic resonance, what was the resonance between? Moreover, the harmonic current spectrum of the irrigation pump drives was unknown.

Two field surveys occurred in May and September 2008, and these involved Electric Power Engineering Centre (EPECentre), University of Canterbury and Orion personnel. Three separate farms that connected to the same rural 11 kV feeder were targeted. Each farm operated a different type/model of irrigation pump. Power flow and harmonic current and voltage levels were recorded at each farm before and while the irrigation pump was operating. The harmonic voltage levels at the rural substation were simultaneously measured.

A computer harmonic model was created using line impedance and load data. Measured irrigation pump harmonic current injection information was used in the computer model to predict harmonic voltage levels at various network points. Validity of the computer model could be assessed by comparison of the voltage predictions to the field survey voltage measurements. Siemens PSS SinCal software was used for the harmonic calculations. The computer model was used to assess the effect of irrigation pumps, harmonic filters and the degree to which the system resonances occur.

To examine the Orion system from the view of harmonic management, another simple model of an Orion rural system was developed, comprising of a rural zone substation and its feeders. This solely studied the 5th harmonic. Various objectives for harmonic limits at different voltage levels were chosen so as to find options for harmonic current limits for loads.

2 Harmonic model data and measurements

Orion supplied 66 kV, 33 kV and 11 kV network diagram and irrigation pump load information, including line impedance parameters and lengths, transformer ratings at each

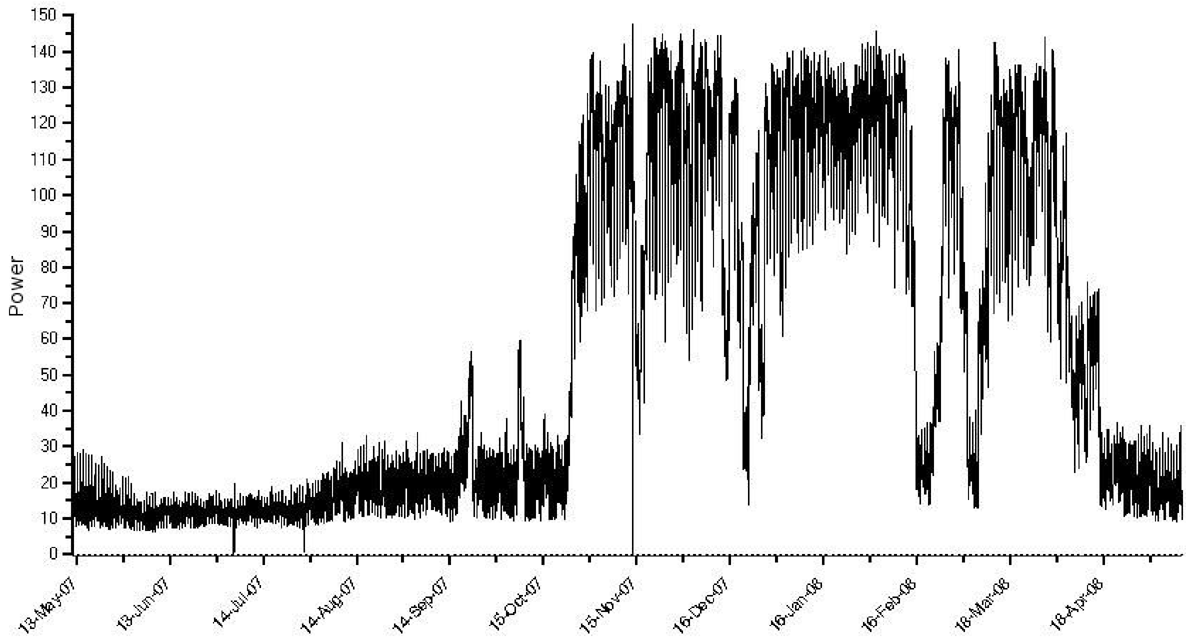


Figure 1: Summer loading pattern for the rural feeder under observation.

load point, pump model and type, power rating and PF correction capacitor data. This allowed detailed feeder modelling, which also incorporated Orion's network back to the Grid Exit Point (GXP) and the 200 kV grid.

Three farms which operated irrigation pumps were visited on two separate field surveys. In each case, it was outside the summer period (when the irrigation pumps normally operate). This allowed the effect of each pump to be assessed in isolation from the neighbouring irrigation pumps. For the pumps with PF capacitors, in addition to harmonic voltage levels, pump, capacitor and incoming line harmonic currents were measured separately.

First field survey (May 2008):

> **Farm 1 –** 200 kVA 11000/415 V transformer. Irrigation pump load is a **Danfoss Variable Speed Drive (VSD)**, 140 kW. No harmonic filters were installed. No PF compensation capacitance.
>
> **Farm 2 –** 200 kVA 11000/415 V transformer. Irrigation pump load is a **Hitachi** pump with resistor soft start, 105 kW. 35 kVA PF compensation capacitance.

Second field survey (September 2008):

> **Farm 3 –** 200 kVA 11000/415 V transformer. Irrigation pump load is a **Franklin** pump Direct-On-Line (DOL), 55 kW. 45 kVA PF compensation capacitance.
>
> **Farm 2 revisited –** The second farm from the first field trip was revisited so as to make additional measurements of the running pump with the PF capacitors disconnected.

Although Farm 1 had a Danfoss VSD, the results obtained are typical of this type of technology and other brands of VSD would be similar. The Danfoss VSD has two optional harmonic filters that can be installed; AHF010 (resultant THD-I < 10%) and AHF005 (resultant THD-I < 5%). Danfoss harmonic calculation software was used to predict the raw harmonic currents expected to be injected when harmonic filters were installed at Farm 1.

Measured harmonic voltage levels were compared to those predicted by the computer harmonic model to determine its ability to represent the actual system. Measured harmonic background noise was subtracted from operating pump measurements, taking into account harmonic phase angles. Close agreement between the measurements and computer model was observed. At Farm 1, the 5^{th} harmonic voltage had an approximately 160º phase difference with the 5^{th} harmonic voltage background noise. This caused the measured 5^{th} harmonic voltage magnitude at the rural substation to decrease when the Farm 1's VSD was running. However, while this decrease occurred while the Farm 1 pump VSD operated, it is expected that when multiple VSDs are operating, the harmonic currents will add together. Hence initially the 5^{th} harmonic level will reduce as the VSD harmonics counter the background 5^{th} harmonic voltage level, then increase as the VSDs' 5^{th} harmonic current injection dominants.

3 Comparison of harmonic current injections of irrigation pump loads

The first comparison is concerned with the harmonic current injections from each model of pump tested. This effectively describes the distorting ability of each model of pump (where smaller is less distortion), irrespective of the pump size or location. It does not include resonant harmonic currents between any PF capacitors and the network, and assumes that percentage values do not significantly change with power level. This was considered reasonable as these pumps typically operate near full load.

Figure 2 shows data for the main harmonics of typical interest. Of note is the large 5th, 7th and 11th harmonic current injections of the Dansfoss VSD when no harmonic filters are fitted. This is reflected in the large Danfoss VSD current THD (35.7%). These values are 8 to 16 times larger than the Hitachi or Franklin pumps, and would be of concern when combined with a relatively low fault level network often found in rural areas. When the Danfoss VSD has the optional AHF010 or AHF005 harmonic filters fitted, it was calculated that the typical current injections would be of a similar magnitude to the Hitachi and Franklin pumps.

4 Comparison of harmonic voltages at the rural substation 11 kV busbar

The second comparison, shown in Figure 3, shows how each of the pumps affect the rural substation 11 kV busbar harmonic voltage levels, considering their size and where they are located on the feeder. This comparison includes local resonances and typical feeder working conditions. These values were calculated using the computer harmonic model. Two values are given for each irrigation pump operating situation. The first is the increase in harmonic voltage level at the substation 11 kV busbar caused by a particular pump with all other local feeder pump installations not operating and disconnected. The second is when all other pumps connected to the feeder (21 pumps in total) were also operating at full load, but modelled with no harmonic current injection. In this case, all other PF capacitors were online and changing the network impedance. This second situation provided a more realistic scenario of summer network operating conditions.

A significant increase in voltage THD of 0.58% is seen at the substation busbar due to the Farm 1 Danfoss VSD (which does not have harmonic filters). This is seven times larger than

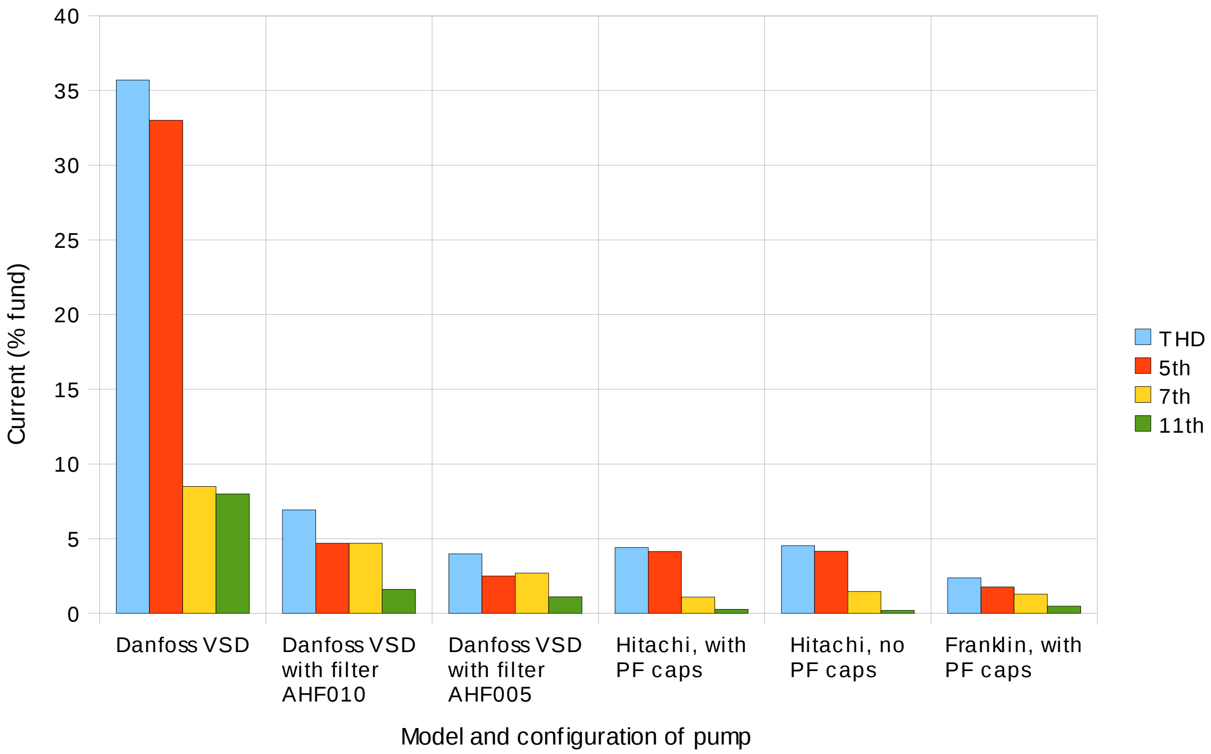


Figure 2: Comparison of harmonic currents (% fund) for various models of pump.

the Farm 2 Hitachi pump which has a similar power rating, and fourteen times larger than the Farm 3 Franklin pump which has about a 50% real power rating. The large harmonic currents of the Danfoss VSD, detailed in Section 3, can be observed in the increase in harmonic voltage levels of similar proportions to the current. As the many VSDs on the network are likely to inject harmonic currents with a similar angle to each other, the harmonic voltage effects due to the VSDs will be additive.

A large proportion of the voltage THD was due to the large 5th harmonic voltage (0.24%). This was a large voltage at the substation due to just one farm's irrigation pump operating. Of note was the modelled increase of this value to 0.37% due to the local impedance conditions changing when all the other nearby farms switched their irrigation pumps on (with their PF capacitors), which is likely in summer. The 5th harmonic voltage due to Farm 2 and its Hitachi pump also significantly increased from 0.04% to 0.14% when other farm pumps were operating. This is predominantly due to PF capacitors changing network impedance and causing resonances.

The addition of either of the optional Danfoss AHF010 and AHF005 harmonic filters were calculated to reduce the harmonic voltage effect of the Farm 1 Danfoss VSD to a similar level experienced when Farm 2's Hitachi pump or Farm 3's Franklin pump is operating. While the AHF005 filter is slightly more effective than the AHF010 filter, either filter provides a vast improvement over a Danfoss VSD with no filter.

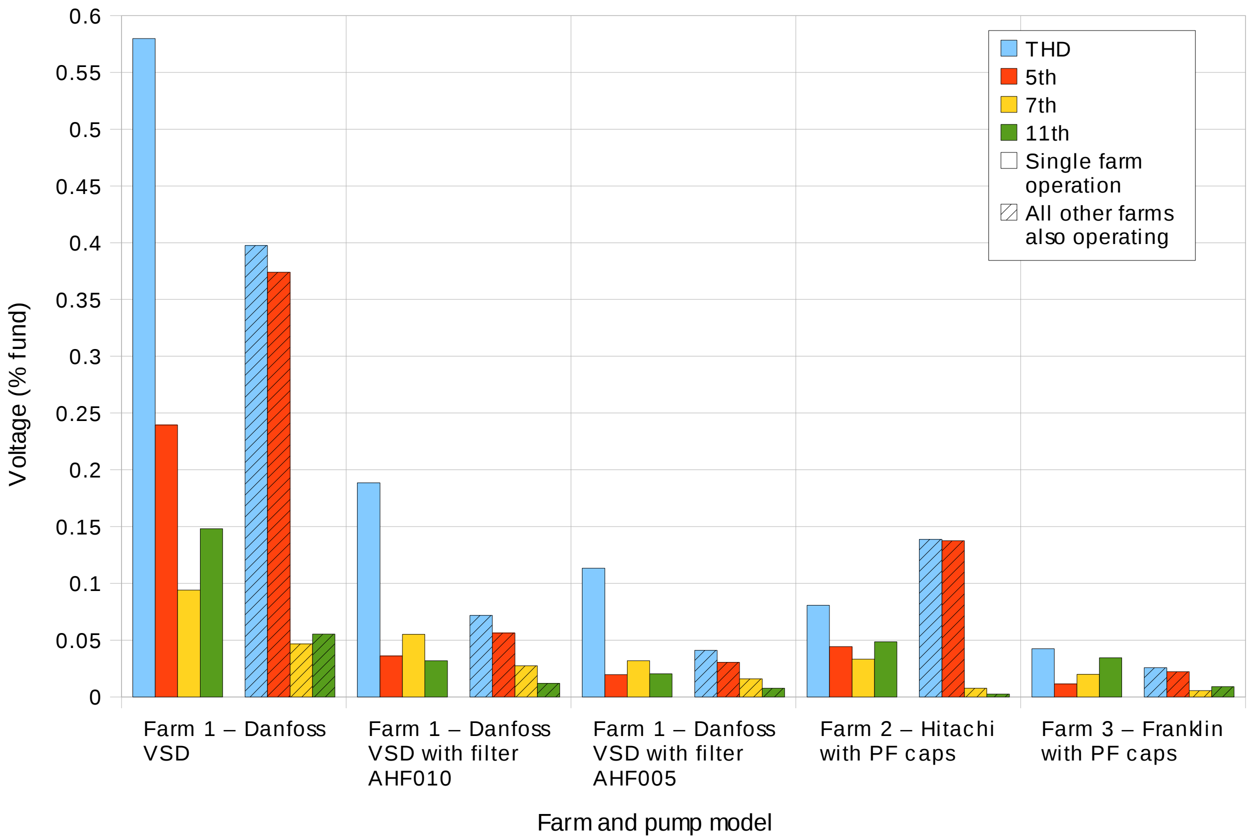


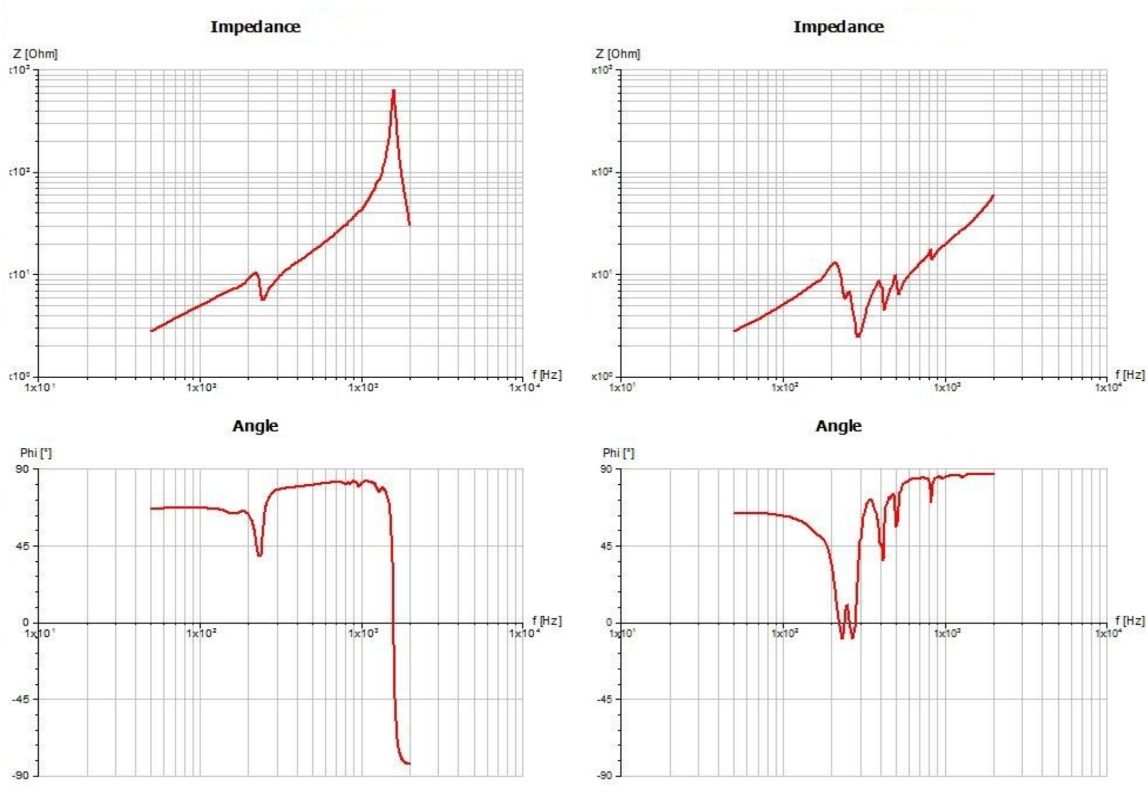
Figure 3: Comparison of harmonic voltages (% fund) at substation 11 kV busbar due to single farm pumps operating. Other farm pump effects were only due to all PF caps switching online.

5 Harmonic impedance at the rural substation

The impedance seen at the rural substation 11 kV busbar when all of the local feeder irrigation pumps were either all disconnected or all operating (with their PF capacitors online) is shown in Figure 4.

Multiple resonance points from approximately the 5th to the 15th harmonic are seen when all of the pumps were turned on, primarily due to the various PF capacitors coming online. While not shown here, separate resonant points of varying frequencies and magnitudes were seen as individual pumps were switched on. Different combinations of pumps and PF capacitors also creates differing impedance profiles.

Some of the resonance points were very close to the 5th, 7th and 11th harmonics. This would accentuate the harmonic voltages generated at the substation. An example of this is shown in Figure 3 where the 5th harmonic voltage increased when the other farms were switched on. Also measured on the field surveys was a large 11th harmonic current flowing between the Farm 2 PF capacitor and the network. This harmonic current was approximately ten times larger than that to the pump itself. This would be causing additional unnecessary stress to this PF capacitor, resulting in detrimental costs and no benefits to Farm 2. It was not known where this current was being injected.



(a) *(b)*

Figure 4: Impedance seen at the rural substation 11 kV busbar when (a) no farm pumps were operating and (b) all local feeder farm irrigation pumps (with PF caps) were operating.

6 Other mitigation options

Besides installing local harmonic filters to VSDs, the use of substation harmonic filters or farm transformers with different vector groups was investigated.

Several trials were made in the computer model of adding 5th harmonic shunt filters to the rural substation 11 kV busbar to provide a sink for local 5th harmonic currents, and thus lower the 5th harmonic voltage generated there. An indicative example was the addition of a RLC shunt filter (series tuned RLC branch), tuned to the 5th harmonic with a Quality Factor of 50. In the situation where all local feeder irrigation pumps were operating, but only the Farm 1 Danfoss VSD was injecting harmonic currents, a 0.5 MVA filter would be required at the substation to reduce the 5th harmonic voltage levels there to a similar level as that which would be gained adding locally the optional Danfoss AHF005 harmonic filter to the Farm 1 VSD. This filter is fairly large and was only for supporting the single Danfoss VSD at Farm 1. Additional capacity would be required for harmonics from other VSDs, although it is likely the requirements would not scale linearly.

For any substation filter, there is the additional issue of the harmonic currents flowing long distances across the rural network from various farms to the substation. This situation may affect equipment at other neighbouring farms and connections as well. Harmonic current flows were not uniformly distributed across the network. Some PF capacitors had significantly more harmonic current flow between them and the network than PF capacitors at other farms. In addition, the Danfoss VSD also injected relatively large harmonic currents at other frequencies. While these are somewhat smaller than the 5th harmonic current injected, additional substation filters could be needed for these frequencies.

The use of transformers with different vector groups, and hence phase shifts, can be used to lower harmonic currents injected into a system, and this is used in HVDC extensively to eliminate 5th and 7th harmonics. The transformer at Farm 1 (Danfoss VSD) uses a Dyn11 vector group connection. Another farm (Farm 4) near to Farm 1 also has a VSD irrigation pump installation with the same rating as Farm 1. The calculated effects of installing a Dzn0 transformer at the nearby Farm 4 while pumps at both Farm 1 and Farm 4 were running are shown in Table 1, and were while all other local feeder farm irrigation pumps and PF capacitors were connected but modelled with no harmonic current injection. At the rural substation 11 kV busbar, the 5th harmonic voltage was almost removed (0.05%) when a Dzn0 transformer was installed at the nearby Farm 4. This was lowered from 0.79% when both farms were operating using Dyn11 transformers. A similar situation occurred for the 7th harmonic voltage.

In this case, the two farms are very close and are of equal power magnitude, so that the

Table 1: Harmonic voltage effects (%) at Farm 1, another nearby VSD farm (Farm 4) and the rural substation 11 kV busbar when a Dzn0 transformer was installed at Farm 4.

		Farm 1 LV busbar			**Farm 4 LV busbar**			**Substation 11 kV busbar**			
n	Freq	Only Farm 1 (Dyn11) operating	Farm 1 (Dyn11) and Farm4 (Dyn11) operating	Farm 1 (Dyn11) and Farm4 (Dzn0) operating	Only Farm 4 (Dyn11) operating	Farm 1 (Dyn11) and Farm4 (Dyn11) operating	Farm 1 (Dyn11) and Farm4 (Dzn0) operating	Only Farm 1 (Dyn11) operating	Only Farm 4 (Dyn11) operating	Farm 1 (Dyn11) and Farm4 (Dyn11) operating	Farm 1 (Dyn11) and Farm4 (Dzn0) operating
THD		5.53	5.65	5.54	5.45	5.59	5.44	0.4	0.43	0.83	0.18
5	250	3.88	3.93	3.89	3.82	3.89	3.8	0.37	0.41	0.79	0.05
7	350	1.44	1.48	1.4	1.42	1.46	1.37	0.05	0.04	0.09	0.01
11	550	2.11	2.17	2.17	2.09	2.14	2.14	0.06	0.05	0.1	0.1
13	650	1.17	1.2	1.2	1.15	1.19	1.19	0.04	0.03	0.07	0.07
17	850	1.62	1.67	1.57	1.6	1.66	1.55	0.05	0.05	0.1	0.01
19	950	1.06	1.1	1.02	1.05	1.09	1.01	0.04	0.04	0.07	0

cancelling effect was good. The same large harmonic currents still flowed over the 11 kV network between the farms, and this may present problems in other situations where the farms are further apart, especially if the farms are connected to different feeders or substations. Also, cancelling effects would not be as effective if the current injections from one VSD is larger than the other, and the effect is lost if one of these farm pumps is not operating at any point in time. However, the use of Dzn0 transformers is not expected to cause larger harmonic currents in the network than if they are not used.

7 Harmonic management in rural substations

To examine the Orion system from the view of harmonic level management, a model was developed of a typical rural substation and its MV feeders and loads, as shown in Figure 5. This model, with comparisons to Australian networks, was intended to aid in setting different limits across the different voltage levels and to suggest harmonic limits for loads. The study was made solely for the 5th harmonic component.

The model is based on representing harmonic quantities under time-varying quantities by their 95% values as used in IEC standards (the NZ code has 100% value limits). It was assumed that the maximum values might be about 10% larger. Other assumptions included that PF capacitor effects were not significant at the 5th harmonic and that the feeders were identical with loads distributed uniformly along them. Diversity was represented by IEC standard suggestions that for two sources giving separate harmonic voltages U_1 and U_2, $U_{total}=\sqrt[\alpha]{U_1^\alpha+U_2^\alpha}$ where $\alpha = 1.4$. The parameters for the model were chosen as: FL_1 = 50 MVA, FL_2 = 10 MVA, n = 4 feeders, load per feeder = 2 MVA.

Table 2 shows the 5th harmonic current results for various harmonic limit cases. For the original Orion harmonic objectives (3.6% at LV, 2% at 11 kV and 1.6% at 33kV), an average 5th harmonic current of 0.9%$_{fund}$ is allowed. This is very low compared to a typical 5% in Australia. The reasons are (i) the low LV limit of 3.6% compared with the IEC limit used by Australia of 5.5%, and (ii) the small voltage drop objective of 1.6% at 33kV to 2% at 11kV. For (ii), the rough arithmetic difference is 0.4%, compared with 2% used in Australia (based on IEC recommended values).

To investigate issues (i) and (ii) separately, the following two further studies were performed. Firstly, using Australian/IEC figures for harmonic limits, which means increasing the LV limit to more than the present NZ code value. Secondly, using the NZ code value at LV and, due to the relatively flat harmonic profile of the code from 11 kV to 33 kV, a modified harmonic profile at MV. For the Australian/IEC limits case, typical Australian feeder parameters were used where FL_1 = 150 MVA, FL_2 = 20 MVA, n = 7 feeders, load per feeder = 3 MVA.

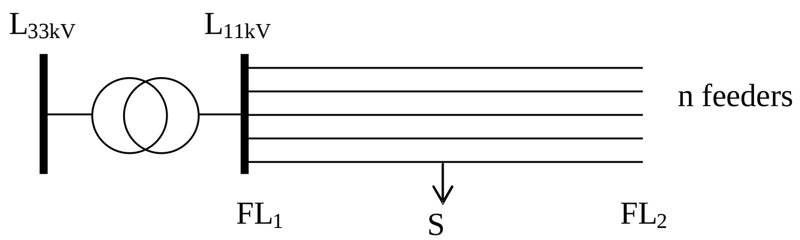


Figure 5: A model of a rural substation with harmonic limits L_{33kV} and L_{11kV}, fault levels FL_1 and FL_2 (for determination of impedance at supply busbar and feeder midpoint), and load S.

Table 2: Resulting 5th harmonic current limits (I_5) for various cases of 5th harmonic voltage limits. The limits are based on 95% values. The LV limit was reduced from the NZ code value to allow for 100% value to be ~1.1 times 95% value. Australian/IEC values are taken to apply to 95% values.

	Harmonic voltage limit (%)			
	LV	**11 kV**	**33 kV**	**I_5 (%f)**
Orion harmonic limits originally proposed	3.6	2	1.6	0.9
Australian /IEC limits	5.5	5.1	3.1	4.8
Orion LV limit and modified MV limits	3.6	3.3	1.6	2.8

By using the full Australian/IEC harmonic limits (increased LV limit as well as modified MV limit profile), the average 5th harmonic current increased to 4.8% with the system then tolerating 1.1MW of unfiltered VSDs (using 35% 5th harmonic current and modelled total load of 8 MW), which is about five 200 kVA installations. Having modified objectives at MV, with the LV harmonic limit maintained at the NZ code value, allowed a 3 times increase of the average 5th harmonic current from 0.9% to 2.8%, with the system then tolerating about 640 kW of VSDs, which is about three 200 kVA installations. This assumes there were negligible harmonics from the remainder of the load.

Using typical Australian feeder values gave almost 5% or a five times larger value than is obtained with the original harmonic limits. Reasons for the relatively lower NZ rural system value include the following factors. Firstly, the relatively low 2% 11 kV harmonic limit used by Orion compared with 5.1% used in Australia (based on IEC limits as given in AS/NZS 61000.3.6). Secondly, the harmonic voltage available for MV loads, related to the difference between the harmonic limits at 33kV and 11kV (0.4% used by Orion, 2% used in Australia. Thirdly, the relatively low average fault level relative to the load (average short-circuit ratio). For this rural substation, the average fault level relative to the load is 15 MVA (average of 10 MVA and 50 MVA, divided by 2 MVA/feeder equals 15 MVA). Australian suburban values could typically be 28MVA.

The impact of the above harmonic loadings on LV harmonic values depends upon whether the harmonic current is uniform in all loads or is concentrated at higher values in a few loads. With additional modelling of a typical rural 200 kVA distribution transformer, determination of the conditions which the 5th harmonic voltage drop in the LV circuit is small (0.4% or 1/10 of the code value), showed that the LV harmonic voltage would not be much larger than the MV harmonic voltage , providing the 5th harmonic current distortion is less than 2%.

For the case of uniform harmonic currents in all loads, harmonic currents of 2% gave additional LV voltage drops of 0.4%. This is likely to not directly increase the LV harmonic voltage by exactly this amount because of diversity effects. Hence, LV considerations might impose a slight reduction in allowed 5th harmonic current from the original values.

For the case of harmonic current concentrated in a few LV loads, then the situation was more serious. It implied that most LV loads would have little harmonic distortion and would have harmonic voltages close to the 11kV limit. The individual harmonic loads would carry harmonic currents several times greater than the 2% determined in the LV circuit and this would impact greatly on their harmonic voltage. A example would be for a VSD load (I_5=35%) having a 5th harmonic current about 17 times the value determined in the LV circuit, resulting in an additional harmonic voltage of about 7%. Diversity will reduce the effect of the nett LV harmonic voltage which is the combination of this value with the MV harmonic limit, but the value would still exceed the NZ code value considerably. Hence, an uneven distribution of LV harmonic loads can give high distortion at various LV nodes even though the MV system is apparently healthy.

8 Conclusions

The investigation showed the Danfoss VSD without harmonic filters injected relatively large harmonic currents, especially at the 5^{th} (33%), 7^{th} (8.5%) and 11^{th} (8%), giving a current THD of 35.7%. These values were typically 8 to 16 times larger than the harmonic currents that the Hitachi or Franklin pumps injected. When the optional Danfoss harmonic filters (AHF010 and AHF005) were used, the Danfoss VSD current injection was predicted to drop to similar levels as what the Hitachi and Franklin pumps produced.

The high harmonic current injection by the Farm 1’s Danfoss VSD produced a similarly large harmonic voltage THD effect (0.58%) at the rural substation 11 kV busbar. This was seven times larger than the Farm 2 Hitachi pump (which has a similar pump power rating), and fourteen times larger than the Farm 3 Franklin pump (which has a 50% smaller pump power rating). The rural substation 5^{th} harmonic voltage change due to Farm 1's Danfoss VSD was 0.24%, which was also large compared to Farm 2 and 3. Also present from the Danfoss VSD was the 7^{th} (0.09%) and 11^{th} (0.15%).

In a realistic scenario of many farms operating their irrigation pumps simultaneously, the various PF capacitors at many farms significantly changed this feeder's network impedance, introducing a range of mild to large resonances including some near the 5^{th}, 7^{th} and 11^{th} harmonics. The impedance at the substation changed significantly in complex ways over time as various farms switched their irrigation pumps and PF capacitors on and off. Removing PF capacitors from irrigation pumps could reduce harmonic voltages, but this is not a practical solution due to voltage considerations and therefore the need to provide PF compensation support to irrigation pumps. Also, individual PF capacitors can draw large resonating currents with the network. The Farm 2 PF capacitors had an 11^{th} harmonic current flowing between it and the network which was approximately ten times larger than that to the pump itself, likely causing undue stress on the PF capacitors. This was due to the fact that detuning inductors were not provided with the capacitors.

The addition of either of the optional Danfoss harmonic filters (AHF010 or AHF005) would reduce the Danfoss VSD's harmonic current injection and harmonic voltage effect at the PCC across all harmonic frequencies to a similar magnitude to that of the Hitachi or Franklin pumps, with the more advanced AHF005 filter only providing marginally better results. To match the effect of installing Danfoss filters at the pump installation site, a large 5^{th} harmonic shunt filter at the rural substation would be required, but which also has additional problems of long distance harmonic currents and non-elimination of other harmonics.

While resonances were present in the local feeder, the proportional effect by their presence on the rural substation 11 kV busbar harmonic voltage levels was much smaller (perhaps 6 to 7 times) than the effect of the large harmonic currents injected by the Danfoss VSD.

In general, resonances are often present in the rural network and difficult to remedy, particularly because of the network conditions changing over time (hours or years). In this study, even if the resonances were removed, the reduction in harmonic voltage levels was not large. It is predicted that reduction of any large harmonic current injections by customers at the local site would prevent the currents reaching the MV network, improve the voltage waveform at the Points of Common Coupling, and therefore reduce harmonic voltage levels, even if local resonances were present. As the unfiltered Danfoss VSDs have significantly more harmonic current injection than Hitachi or Franklin pumps, installing harmonic filters on these VSDs would be the most effective solution. Other models of VSD are likely to have a similar profile. It may be useful for a utility to require future installations of loads that will inject large harmonic currents to also install local harmonic filters.

Use of phase shifting transformers with different vector groups, such as Dyn11 and Dzn0, could be used to mitigate high harmonic voltages at substations. This would be a useful technique if there are two nearby farm irrigation pumps with similar levels of harmonic current injection. Installing a Dzn0 transformer at one of these farms is predicted to cancel the 5^{th} and 7^{th} harmonic currents present further away in the network. The harmonic currents would still flow between the farms, and potentially cause problems if the farms are further apart and on different feeders or substations. Also, if only one farm pump is actually operating at any point in time, then the effect is lost. This may be a cheaper mitigation option where appropriate. It would be recommended that this option be considered temporary, as large harmonic currents would still be injected into the MV network.

An examination of the Orion system from the view of harmonic level management showed that a low (0.9%) 5^{th} harmonic current is allowed with present harmonic voltage limit objectives at different voltage levels. Change of limits at LV, 11 KV or 33 kV would allow significantly more tolerance of harmonic current injections. Concentration of harmonic current injections in a few loads significantly increases the harmonic voltages at LV levels.

Acknowledgements

Tas Scott, Orion NZ Ltd
Stephen Hirsch, Orion NZ Ltd
Bill Wilson, Orion NZ Ltd