South Wales voltage reduction analysis

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Executive summary

This report presents the analyses of whether changes in 11kV AVC settings in South Wales had an effect on electrical demand, consumption and feeder voltage. The changes were from 11.4 kV ± 200V to 11.3 kV ± 165V and were made in a selection of substations in the South Wales area in the latter part of 2014.

Data is used from a selection of the monitoring network established as part of the Low Voltage Network Templates project (LVNT). The majority of changes to the voltage settings occurred in November and December of 2014 and the primary analysis is a comparison of demands before and after this period. In addition, voltage data monitored at substations and feeder ends was assessed with reference to the statutory limits of 230V +10%, -6%.

Summary of findings:

- Demand analysis was performed on over 700,000 data points from over 600 substations. Voltage analysis used over 10 million data points from substations and over 27 million from voltage monitors.
- A statistically significant reduction in demand was associated with substations that had changes in 11kV AVC settings. No significant change was found in substations that did not have changes in settings.
- Using all available daily data, the reduction was estimated to be 1.5% in average demand with a 95% confidence interval of (1.1% – 1.9%). This reduction was found to be robust to changes in the temporal resolution used for the analysis; 1.6% for monthly data.
- Using the methodology established in the LVNT project (LV Templates Closedown Report, Appendix B: South Wales Voltage Reduction), a 1.5% reduction would equate to an estimated reduction of 158.8GWh over a year, worth £16 million if all substations in South Wales were changed.
- The proportion of voltage measurements outside the statutory limits was very small, for example in November 2014 only 0.22% of ten–minute measurements at feeder end monitors were above 253V and 0.04% were below 216.2V.

Section 1

Introduction

The aim of this piece of work is to determine whether the change in 11kV AVC settings in South Wales has had an effect on electrical demand, consumption and feeder voltage. Changes were from 11.4 kV $\pm$ 200V to 11.3 kV $\pm$ 165V and were made in a selection of substations in the South Wales area in the latter part of 2014.

This report contains a number of analyses of the potential effects of these changes at both substations and feeder ends. Data is used from the monitoring network established as part of the Low Voltage Network Templates project. Section 1 of this report gives details of the available measurement data and the creation of a working dataset for analyses. In Section 2, demands at substation level are considered in relation to the change in voltages. Details of weather corrections, which allow comparisons between years, followed by a comparison of demands before and after the changes in voltages take place. There are two main strands to the detection of potential changes: (i) a comparison of demand data for substations which have had changes between similar time periods over the years of study and (ii) an analysis of whether a (significant) change can be detected without knowing the actual dates of change. In the former, after weather correction, demands in January 2015 (after voltage changes) are compared to those in January 2013 and January 2014 (before voltage changes). A statistical analysis of changes in demands at both a monthly and daily level allows an assessment of whether any reductions associated with the changes in voltages are statistically significant allowing for overall patterns in demand over this period of time. In the second approach, the exact dates of the voltage changes are not know and *change-point* models are used to try and assess when there might be a fundamental change in the underlying levels of demand.

In addition to the analyses of demand and the possible changes associated with the changes in the 11kV AVC settings, in Section 3 there is an analysis of voltage profiles at both substation and feeder ends. Voltages are examined over time and compared to statutory limits.

1.1 Monitoring in the Low Voltage Network Templates project

The Low Voltage Network Templates (LVNT) project was an Ofgem funded Tier 2 project run by Western Power Distribution. Full details of the LVNT project can be found at http://www.westernpowerinnovation.co.uk. The aim of the LNVT project was to see whether there was a simple method, outside of costly widespread monitoring, that could assist in providing the visibility needed in order to effectively design, plan and operate the LV distribution network. Taking daily patterns from substations as the object of interest, the aim was to create clusters of substations within which daily patterns are more similar than those in other clusters. Statistical clustering as performed on demands measured every ten minutes at ca. 800 substations located throughout South Wales. The result of the project was ten distinct LV Templates being identified which classified demand at the substation level according to daily load patterns.

The study area was South Wales. The rationale for choosing this area was to collect and analyse data on areas of WPDs network that had similar characteristics to that of the other DNOs. The study area from which data was gathered includes geographical locations ranging from inner-city, urban, suburban, and rural to industrial sites. Additionally the monitored substations cover a wide range of customer mixes; from those highly dominated by residential customers, to those exclusively industrial and commercial. The data comprised of measurements made on 10 minute intervals of voltage, current, real power delivered (kW) and power received at LV substations and voltages at remote feeders-ends.

Since May 2012 the data delivery was fully automated, via WPD to a dedicated secure server at the University of Bath. At the end of the LNVT project there were over 1/2 billion substation and in excess of 101 million feeder-end data points for analyses. Since the official end of the LVNT project, monitoring has continued together with data delivery to the University of Bath and subsequent analysis. The analysis performed within this project and reported here uses these data for the period of 2013-2015.

1.2 The state of the monitoring data

This analysis of the effects of the reduction in voltages at substations uses data from the LNVT monitoring equipment for the period 2013-2015. The analysis in this report uses a selection of the monitors installed as part of the LVNT project. As of 31/01/2015 measurements were available from 637 substations and 2760 voltage monitors. It is noted that during this period these totals include those monitors that may not have consistently provided data throughout the entire period. Figure 1.1 shows a schematic of the available data from substations. Of the 637 substations, after sense–checking the data 617 were deemed suitable for voltage analysis and 604 for demand analysis. Of these 617, 409 had a change

in voltage for which the date of the change was known for 142 substations and unknown (at the time of writing) for 267. The choice of which substations had the change in voltage settings was not based on any pre–specified criteria but was, in pragmatic terms, random.

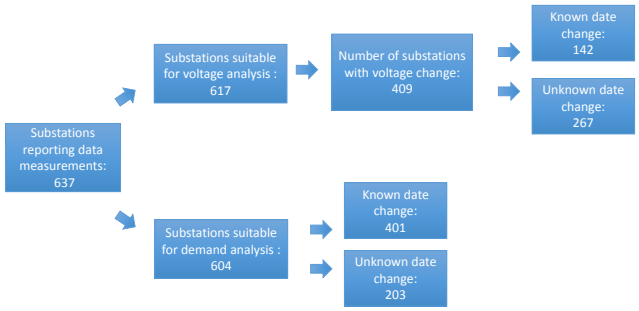

Figure 1.1: Schematic showing the number of substation monitors providing data for analysis.

The location of the substations can be seen in Figure 1.2 in which the locations of substations that had voltage changes are shown by red dots and those that didn't not change by blue dots.

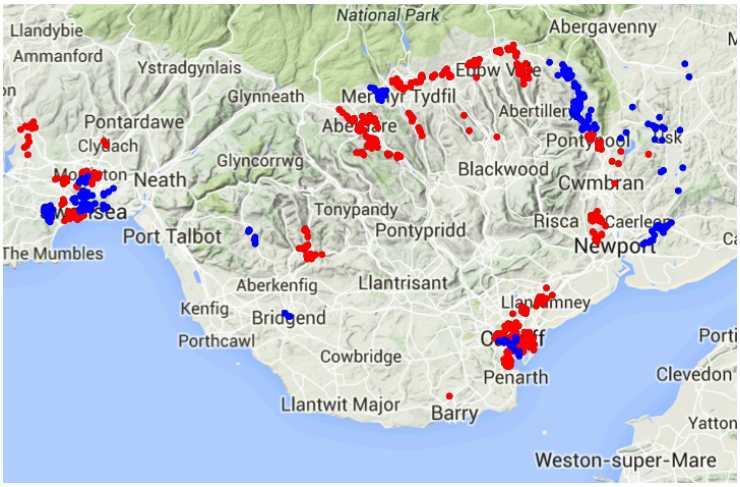

Figure 1.2: Locations of substations providing data for the analysis. Substations that had changes in 11kV AVC settings are denoted by red dots and those with no change by red dots.

Figure 1.3 shows a schematic of data availability at feeder end monitors. Voltage data was available from 2760 feeder end monitors. Of the 617 substations providing data at the time of the project, 420 could be linked to at least one voltage monitor at feeder ends. The total number of feeder end voltage monitors that could be linked to substations providing data was 1776 (for November 2014, other months may vary slightly). For the 409 substations that had their voltage changed, 288 had associated voltage monitors at feeder ends resulting in 1184 feeder end monitors in total (again, for November 2014 only, other months may vary slightly).

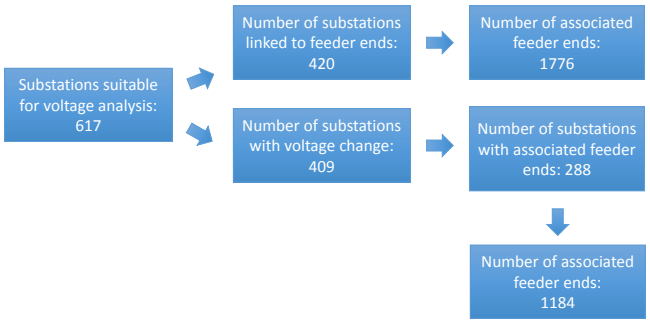

Figure 1.3: Schematic showing the number of voltage monitors at feeder ends providing data for analysis.

Section 2

Demand analysis

The aim of the analyses of demand data is to ascertain whether there is any discernible changes that are associated with the change in 11kV AVC settings. The majority of the voltage changes occurred in November and December of 2014 and the primary analysis is a comparison of demands before and after this period.

For this, daily demand data monitored at 604 substations deemed to have suitable data were extracted for January 2015, January 2014 and January 2013 from the database described in Sections 1.1 and 1.2. Of these 604 substations, 401 had the change in settings and 203 did not.

The primary statistical analysis of these data uses a *paired* approach in which demand data for each substation is matched across years. This allows for the dependence that might be expected within measurements from the same substation to be acknowledged and correctly incorporated into the assessment of whether observed changes are statistically significant.

A comparison between two years could be performed using a *paired t-test* or non-parametric equivalent, the *Wilcoxon rank sum test*. These consider the differences between the average monthly demands for each individual substation and offer an initial assessment of whether there have been changes over the period in which the settings were changed.

Where there are more than two years, a more complex approach is required. For this random effects models are used to allow for the dependence in demands within substations where there are more than two time–points and also offer great flexibility in investigating other patterns in the data.

Random effects models were used for both monthly averages (for each substation by year) and also for daily measurements of demand. The increase in complexity when using daily data may be offset by the ability to work with a

large sample size and the ability to investigate changes at a higher temporal resolution. For example possible sub–month patterns may be masked when using monthly averages.

A secondary analysis aims to detect whether changes in the voltage settings can be detected without prior knowledge of the times at which those changes occurred. *Change–point models* attempt to detect underlying changes in the data generating mechanism which would manifest in changes in the observed data. Here, time-series of daily average demands are used for 2014 (Jan 1st – Dec 20th) with the aim of assessing whether changes can be detected and, if so, checked to see whether they coincide with known dates of changes in the voltage settings. This approach can also be applied to cases where the exact date at which the settings is not known as no information on when they may have occurred are used in the modelling procedure.

2.1 Data

For the analyses of demands over the specified time period, data was sense-checked from the 653 available substations and 604 were deemed suitable for this analysis. Data was extracted and daily average demands calculated for each substation for each year using measurements from the 144 ten minute periods.

2.1.1 Weather corrections

In order to ensure that demands were comparable between years they were adjusted for weather. Weather corrections were available in the form of uncorrected consumption values for each half hour for the entire South Wales area together with weather corrected version. From these, correction ratios were calculated which were then applied to the demand data. Figure 2.1 shows the weather corrections for January 2013, 2014 and 2015 which were applied to the demand data in this analysis.

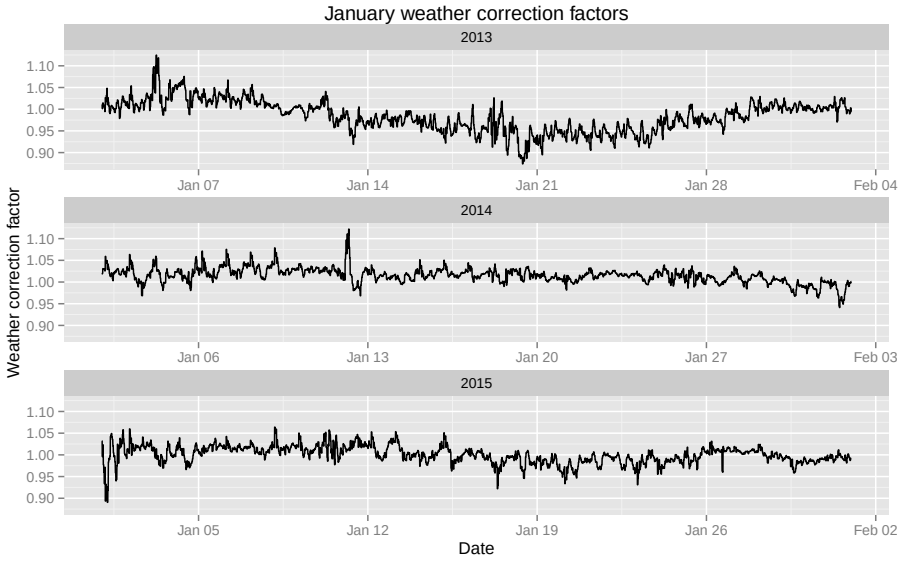

Figure 2.1: Weather correction factors for January 2013, 2014 and 2015.

2.2 Changes in demand

Initial testing comprised of detecting differences between average demands for January 2015 and January 2014. The testing was based on the differences observed for each substation which were then combined to result in a single summary of the difference, together with an assessment of the statistical significance of any change. Figure 2.2 shows an example of daily demands measured at a substation for these two months and indicates a decrease in the mean in January 2015, after the changes in voltage settings had been made. Corresponding plots for the other substations can be seen in the appendix.

Figure 2.2: Weather corrected ten minute demand data for substation 552858. Data is for January 2014 (left hand side) and January 2015 (right hand side). The horizontal lines show the average demand for each of the months.

Using all the available data, a comparison between the monthly averages by substation for January 2014 and January 2015 (before and after the changes to voltage settings) showed a significant decrease in demands for those substations that had changes in settings but not in the those that did not have the change.

For a number of substations the differences between the monthly averages for January 2014 and January 2015 were larger than could be attributed to changes in voltage. Sense–checking the data included excluding differences that are likely to be due to data anomalies and other factors. Using a sense–checking cut–off of 20kW for the difference between monthly averages (for January 2014 and 2015) resulted in an estimate for the reduction in demand for substations which had a change in voltage settings of 1.42% (1.36 kW from a baseline in January 2014 of 95.9) between January 2014 and January 2015 which was statistically significant ($p < 0.0001$ for a paired t–test and $p < 0.0001$ for the non–parametric alternative, Wilcoxon rank sum test). The equivalent estimate when using all of the available data was 1.7% and for a cut-off of 50kW was 1.6%. All other cut–off points used to subset the data resulted in an estimate of the reduction of 1.4%.

It should be noted that these initial tests are just for two years. Random effects models were constructed provide a framework which incorporated data from all substations and all three years to be considered together. These models allowed for three states: (i) no change at all; (ii) chosen for change but change had not yet occurred and (iii) change had occurred.

When applied to monthly average demands, a significant difference (15.1%, p=0.02) was seen between the average demands for substations which had the settings change and for those that did not. The average demands for those with and without the change were 90.0 kW and 76.4 kW respectively. This is likely to be due to the characteristics of the substations which were chosen to have the change in settings. Overall they tended to be more urban (84% ground mounted vs. 70% in the non-chosen group), have higher transformer ratings (median 500 vs. 315) and a high proportion of industrial and commercial customers (median 20% in Elexon categories 3 to 8 vs. 10%).

When using both daily and monthly data, the same patterns were seen in the results. Using monthly data a reduction in demand associated with changes in the voltage settings was observed and was estimated to be 1.60%. Using daily data this reduction was estimated to be 1.5% (1.38 from a baseline of 92.2 kW). This equates to a decrease of 12.088MWh in consumption. This reduction is highly statistically significant, $p<0.0001$, reflecting the large sample size available when using daily data.

2.3 Detecting changes

In this secondary analysis we assess whether statistical change–point models can be used to detect underlying changes in demand where no information is supplied as to when changes (to voltage settings) may have occurred. In order to test the efficacy of this approach it is firstly applied using data from substations where the date of change is known (although it is not used in the analysis). This allows an assessment of whether any estimated changes correspond to the actual date of change. The method is then applied to data from substations where it is known that there is a change but where the exact time of change is not known. For this analysis, daily (weather corrected) average demands are used for 2014 (Jan 1st – Dec 20th).

Applying the models directly to the demand data would result in detecting changes due to seasonal patterns rather than any change in voltage settings and so the first step in the analysis is to de–seasonalise the data. This is done by fitting a smoothed curve through the time-series data which represents the underlying pattern, the residuals (differences) between the data and this curve then provide a de–seasonalised series. The smoothed curve is fit using *penalised*

splines, which are a form of polynomial regression where the smoothness of the line is chosen to guard against over–fitting the data. Figure 2.3 shows an example of this. In the top left panel the original (weather corrected) series of demand data are shown together with the smoothed line representing seasonal patterns. In top middle panel, the de–seasonalised series is shown in which the seasonal pattern has been omitted. Figure 2.3 also contains the results of applying change point models with different constraints on the number of changes that are allowed. In this case, the maximum number of changes shown are four, two and one. If the model is able to detect a difference that might be driven by the change in voltage settings then a single change in the underlying demand would be permitted and it would be detected at the point of the vertical orange line which shows, in this example, when the change was made. In this example, there is indication that a change has occurred on the 4th December, which is the date of the actual change, as shown by the vertical orange line. The corresponding plots for other substations can be seen in the appendix.

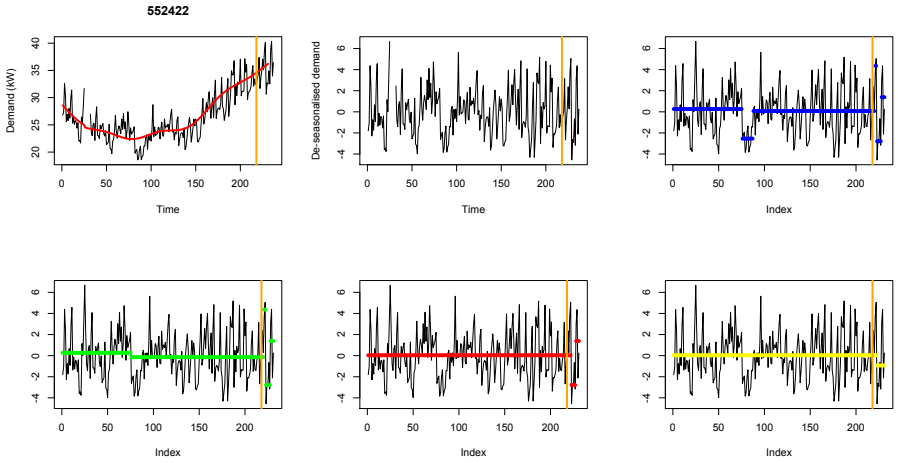

Figure 2.3: Daily demand data for substation 552422 and results of change–point analyses. The top left panel shows the daily (weather corrected) demand data for 2014 together with a smoothed line representing seasonal patterns in demand. The top middle panel shows the de-seasonalised data. The top right panel shows the results of applying a change–point model with no restrictions on the number of changes (in this case there are 5 estimated changes resulting in 6 horizontal lines). The bottom row shows the results of change–point analyses with constraints on the maximum number of changes; four (bottom left panel), two (bottom middle) and one (bottom right). In all case, the vertical orange line shows when the changes in voltage settings were made.

Figure 2.4 shows the same information as Figure 2.3 for a substation where

the exact date of change is not known (hence no orange line). Here, restricting the number of possible changes to one results in a change in the underlying average demand on December 13th which would be in accordance with the known dates for changes.

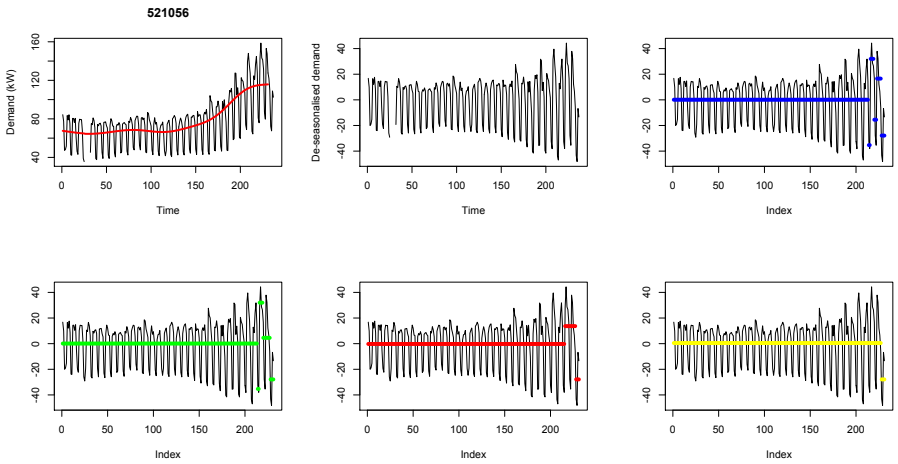

Figure 2.4: Daily demand data for substation 521056 and results of change–point analyses. The top left panel shows the daily (weather corrected) demand data for 2014 together with a smoothed line representing seasonal patterns in demand. The top middle panel shows the de-seasonalised data. The top right panel shows the results of applying a change–point model with no restrictions on the number of changes (in this case there are 5 estimated changes resulting in 6 horizontal lines). The bottom row shows the results of change–point analyses with constraints on the maximum number of changes; four (bottom left panel), two (bottom middle) and one (bottom right). In this case the exact date of change in voltage settings is not known.

This method shows promise and performs well for a number of the substations. For ca. 40% of the substations that had the change in settings but where the exact date was unknown the models indicated changes within the period of November to December (the timeframe during which the majority of changes would have been made). Where is it not possible to detect changes it may well be due to a lack of information at the end of the year after the changes were made. At present there is somewhat of a disparity between the amount of data that is available before and after the changes were made. Since the majority of changes to the voltage settings were made during November and December 2014, at the time of the analysis data was only available for between 2 and 6 weeks after the changes were made. Even so, the results of this analysis are encouraging and as monitoring continues the ability to accurately detect changes in the underlying levels of demand will increase.

Section 3

Voltage profiles

3.1 Voltage monitored at substations

Here we use voltage data monitored at substations to assess adherence to the statutory limits of 230V +10%, -6%. Analysis was performed for November 2014 and 2013 and June 2014 and 2013, representing winter and summer. Of the known dates of voltage changes, 40% were during October or November 2014. Here we present an analysis of the data for November and summarise the findings for June. The full analysis for June can be found in the appendix.

Substations were selected for inclusion in the following analysis based on whether they were providing sensible data as of 31/01/2015. Substations were also required to have an average voltage of between 150V and 300V for whole duration of the period tested. If substations met these requirement they were deemed available for analysis.

3.1.1 November 2014

Within the voltage data collected from November 01/11/2014 - 30/11/2014, 444 substations were available for analysis. Of these 444 substations, 310 had feeder end voltage monitors that also provided data associated with them. Data was available for 1301 such voltage monitors at feeder ends. Figure 3.1 shows voltage data for all 444 substations for every ten minute period in November 2014.

Of the 444 substations considered here, 18 substations had a measurement above 253V and 18 below 216.2V for at least one ten minute period during November. Figure 3.2 shows the voltage profiles for those 18 where at least one 10-minute period exceeded the statutory limit and Figure 3.3 for the 18 where at least one 10-minute period was lower than the statutory limit.

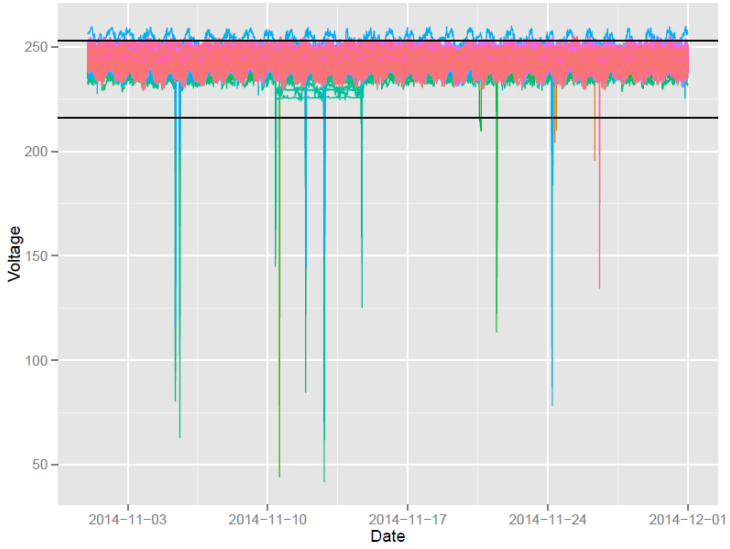

Figure 3.1: Voltage data measured at 444 substations. Measurements are for each ten minute periods in November 2014. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

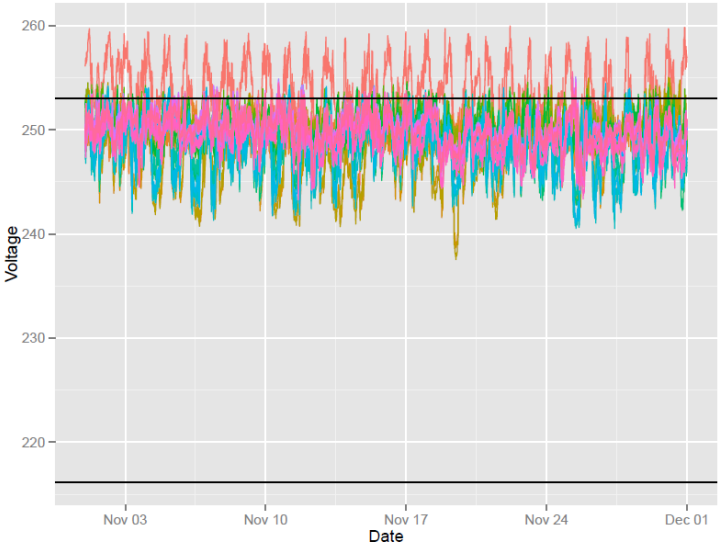

Figure 3.2: 10-minute voltage data plotted for each substation where at least one 10-minute period exceeds the statutory limit.

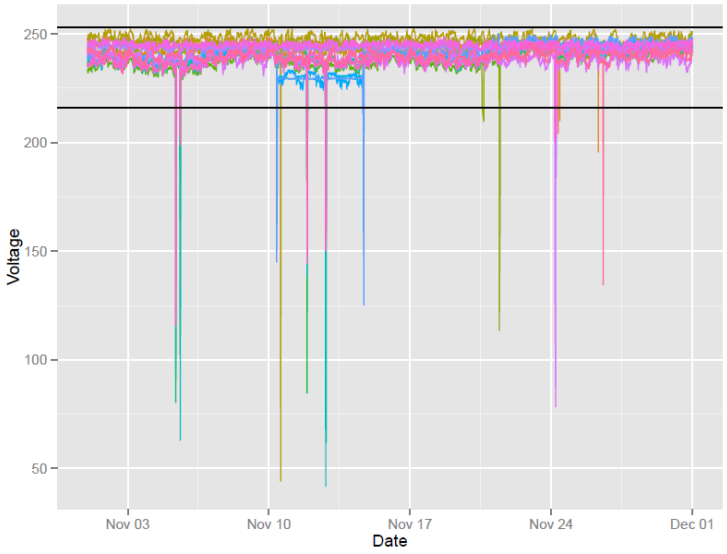

Figure 3.3: 10-minute voltage data plotted for each substation where at least one 10-minute period falls beneath the statutory limit.

Figure 3.4 shows the percentage of ten minute periods exceeding the 253V for each day in November 2014, with and average of 0.1969% over the month. Figure 3.5 shows the percentage of ten minute periods below the 216.2V for each day in November 2014, with and average of 0.0033% over the month.

Figures 3.6, 3.7, 3.8, and 3.9 show breakdown of the occurrences of these excursions, showing that in both cases the points outside the limits arise from a small number of substations.

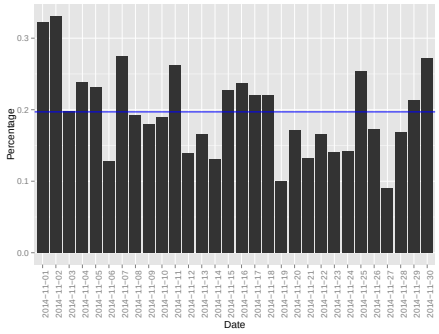

Figure 3.4: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in November 2014 of all substations. The blue horizontal line represents the monthly average of exceedances.

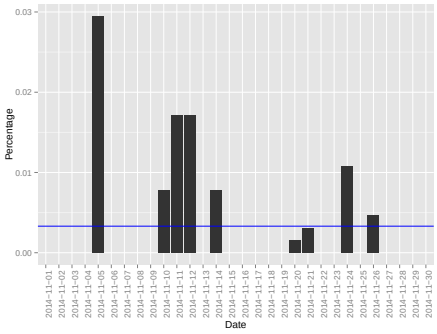

Figure 3.5: Black bars represent the percentage of 10-minute periods below the statutory limit per day in November 2014 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

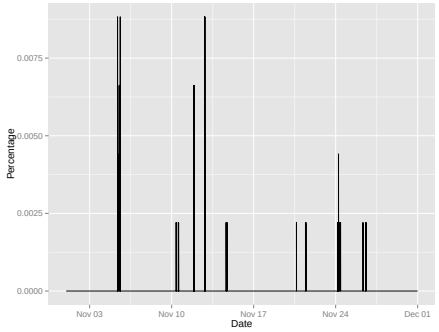

Figure 3.8: Percentage of substations which fall beneath the statutory limit in each 10-minute period.

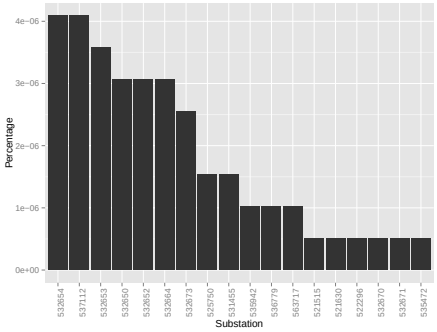

Figure 3.9: Percentage of 10-minute periods where each substations falls beneath the statutory limit in November 2014.

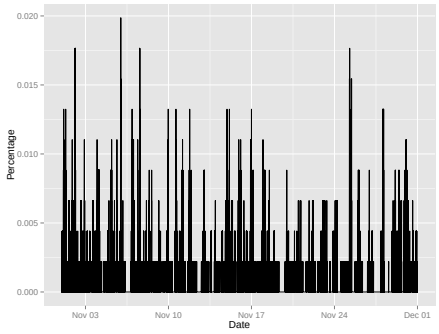

Figure 3.6: Percentage of substations exceeding the statutory limit in each 10-minute period.

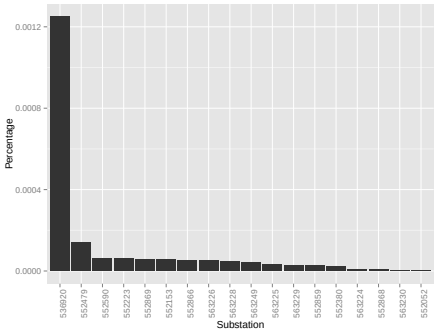

Figure 3.7: Percentage of 10-minute periods that each substations exceeds the statutory limit in November 2014.

3.1.2 November 2013

Within the voltage data collected from November 01/11/2013 - 30/11/2013, 602 substations were available for analysis. Of these 602 substations, 410 had feeder end voltage monitors that also provided data associated with them. Data was available for 1775 such voltage monitors at feeder ends. Figure 3.1 shows voltage data for all 602 substations for every ten minute period in November 2013.

Of the 602 substations considered here, 19 substations had a measurement above 253V and 15 below 216.2V for (at least one) ten minute period during November 2013. Figure 3.11 shows the voltage profiles for those 19 where at least one 10-minute period exceeded the statutory limit and Figure 3.12 for the 15 where at least one 10-minute period was lower than the statutory limit.

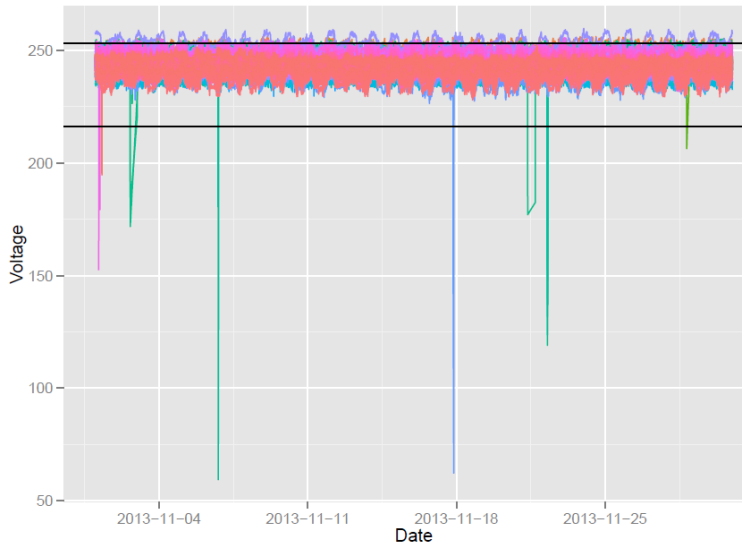

Figure 3.10: Voltage data measured at 602 substations. Measurements are for each ten minute periods in November 2013. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

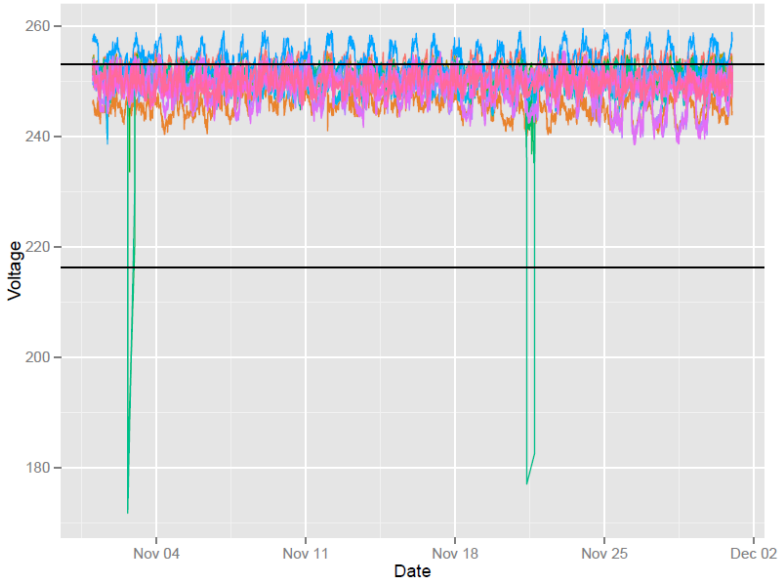

Figure 3.11: 10-minute voltage data plotted for each substation where at least one 10-minute period exceeds the statutory limit.

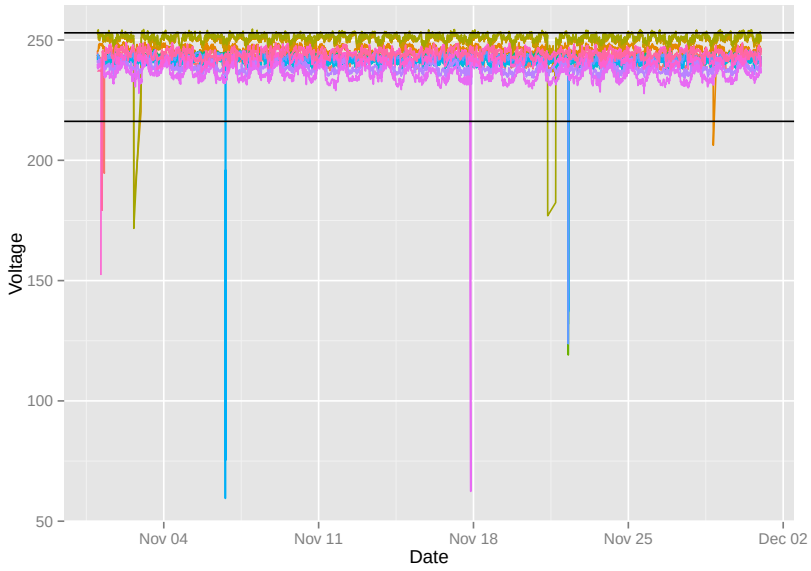

Figure 3.12: 10-minute voltage data plotted for each substation where at least one 10-minute period falls beneath the statutory limit.

Figure 3.13 shows the percentage of ten minute periods exceeding the 253V for each day in November 2013, with and average of 0.2508% over the month. Figure 3.14 shows the percentage of ten minute periods below the 216.2V for each day in November 2013, with and average of 0.0010% over the month.

Figures 3.15, 3.16, 3.17, and 3.18 show breakdown of the occurrences of these excursions, showing that in both cases the points outside the limits arise from a small number of substations.

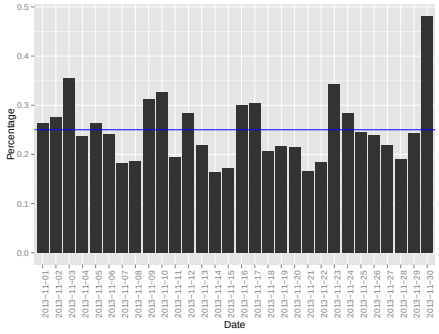

Figure 3.13: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in November 2013 of all substations. The blue horizontal line represents the monthly average of exceedances.

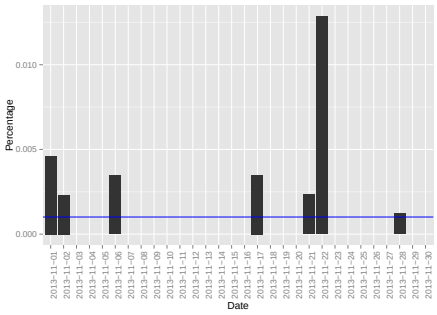

Figure 3.14: Black bars represent the percentage of 10-minute periods below the statutory limit per day in November 2013 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

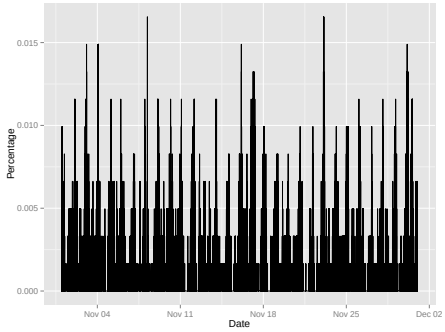

Figure 3.15: Percentage of substations exceeding the statutory limit in each 10-minute period.

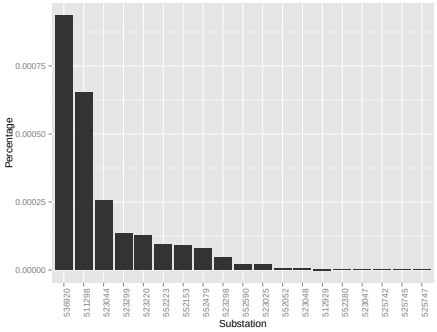

Figure 3.16: Percentage of 10-minute periods that each substations exceeds the statutory limit in November 2013.

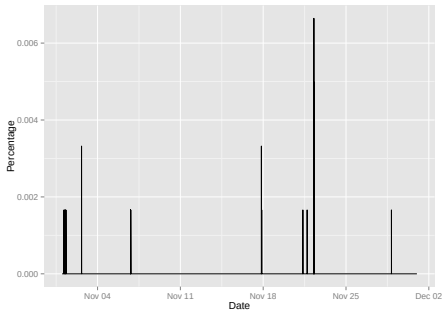

Figure 3.17: Percentage of substations which fall beneath the statutory limit in each 10-minute period.

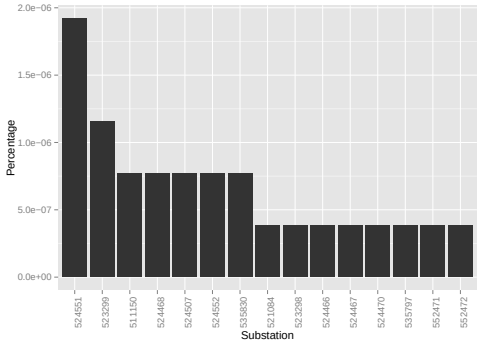

Figure 3.18: Percentage of 10-minute periods where each substations falls beneath the statutory limit in November 2013.

3.2 Voltage monitored at feeder ends

As in 3.1, we present an analysis of the voltage data monitored, this time at feeder ends, for November. The equivalent for June can be found in the appendix.

Voltage monitors were selected for inclusion in the following analysis based on whether they were providing sensible data as of 31/01/2015. They were also required to have an average voltage of between 150V and 300V for whole duration of the period tested. If the voltage monitor met these requirement they were deemed available for analysis.

3.2.1 November 2014

For November 2014, 2748 voltage monitors had 10-minute voltage data available for analysis. Of these 2748 monitors, 1772 had working voltage monitors associated with substations suitable for analysis. Figure 3.19 shows voltage data from these 1772 feeder end monitors for every ten minute period in November.

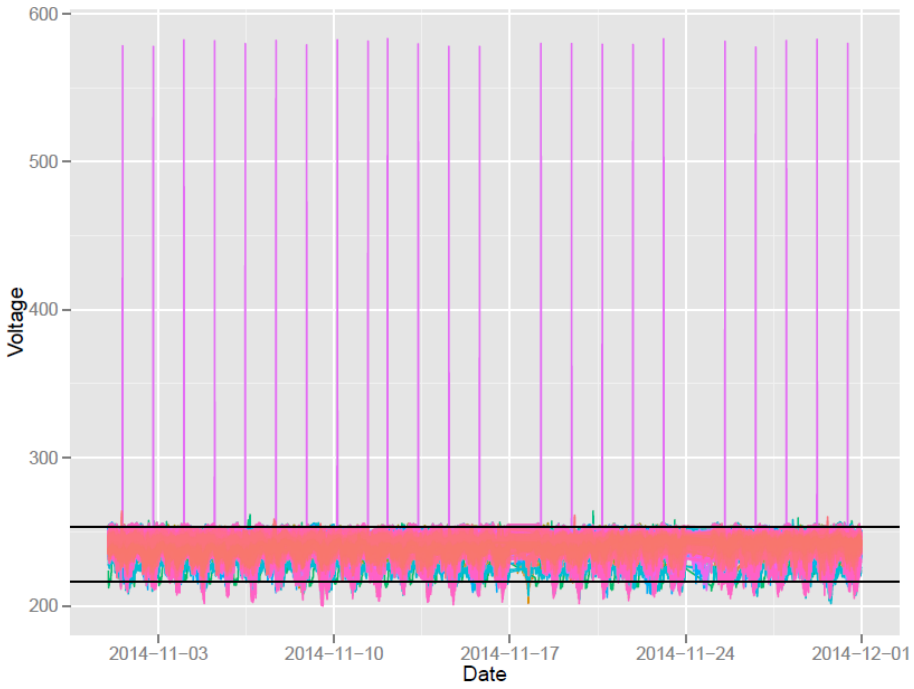

Figure 3.19: Voltage data measured at 1772 feeder ends. Measurements are for each ten minute periods in November 2014. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

Of the 1772 feeder end monitors considered here, 91 had at least one ten minute period above 253V and 34 below 216.2V for during November. Figure 3.20 shows the voltage profiles for those 91 where at least one 10-minute period exceeded the statutory limit and Figure 3.21 for the 34 where at least one 10-minute period was lower than the statutory limit.

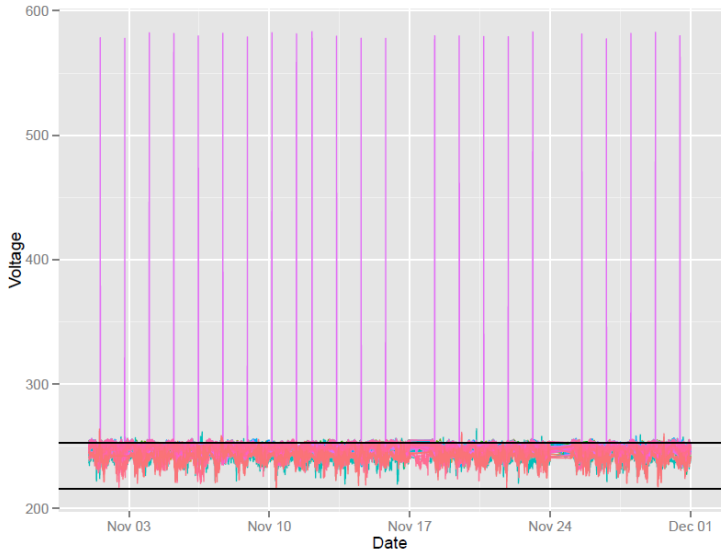

Figure 3.20: 10-minute voltage data plotted for each feeder end where at least one 10-minute period exceeds the statutory limit.

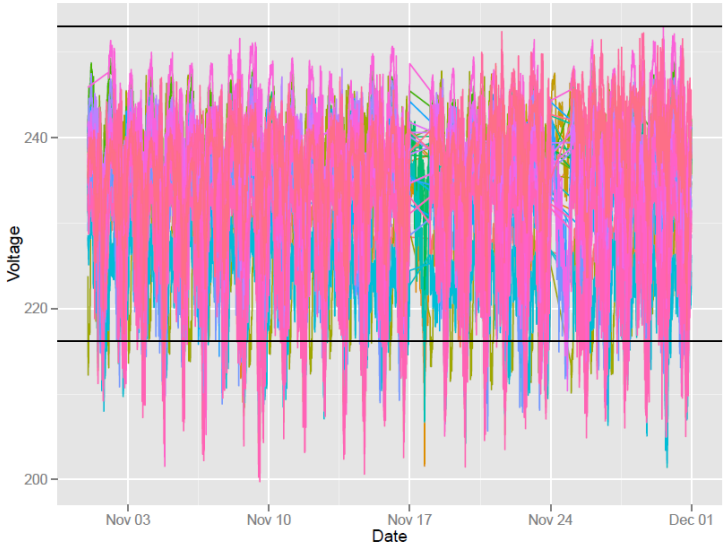

Figure 3.21: 10-minute voltage data plotted for each feeder end where at least one 10-minute period falls beneath the statutory limit.

Figure 3.22 shows the percentage of ten minute periods exceeding the 253V for each day in November 2014, with and average of 0.2221% over the month.Figure

3.23 shows the percentage of ten minute periods below the 216.2V for each day in November 2014, with and average of 0.0443% over the month.

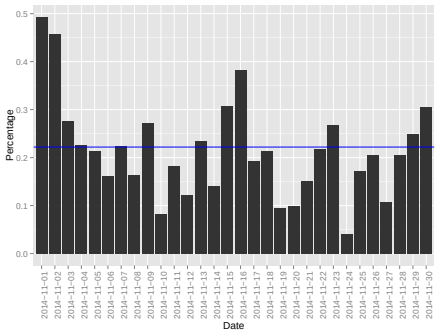

Figure 3.22: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in November 2014 of all substations. The blue horizontal line represents the monthly average of exceedances.

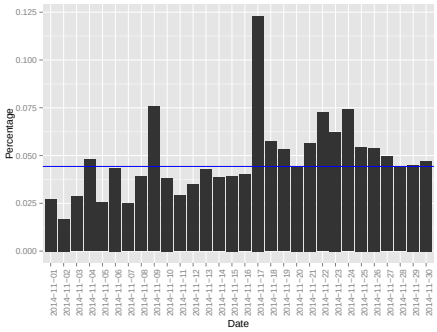

Figure 3.23: Black bars represent the percentage of 10-minute periods below the statutory limit per day in November 2014 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

Figures 3.24, 3.25, 3.26 and 3.27 show a breakdown of the occurrences of these, showing that in both cases the points outside the limits arise from a small number of feeder end monitors.

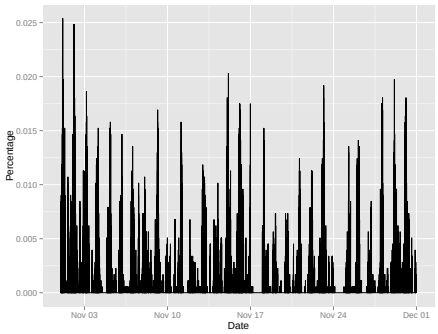

Figure 3.24: Percentage of voltage monitors exceeding the statutory limit in each 10-minute period.

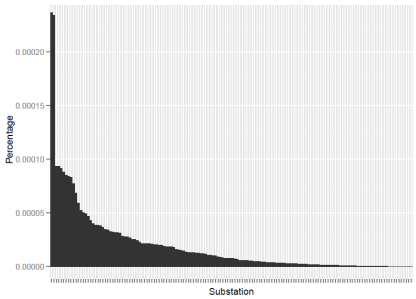

Figure 3.25: Percentage of 10-minute periods that each voltage monitors exceed the statutory limit in November 2014.

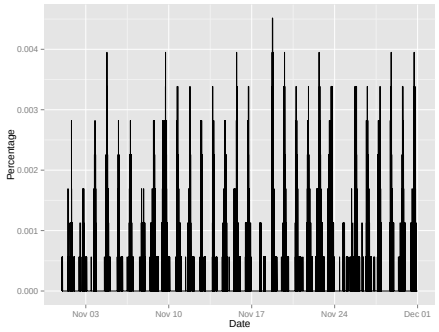

Figure 3.26: Percentage of voltage monitors below the statutory limit in each 10-minute period.

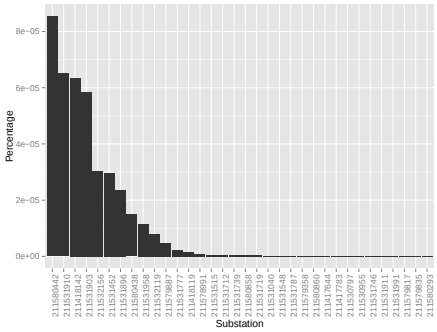

Figure 3.27: Percentage of 10-minute periods that each voltage monitors falls beneath the statutory limit in November 2014.

3.2.2 November 2013

For November 2013, 2813 voltage monitors had 10-minute voltage data available for analysis. Of these 2813 monitors, 1817 had working voltage monitors associated with substations suitable for analysis. Figure 3.28 shows voltage data from these 1817 feeder end monitors for every ten minute period in November.

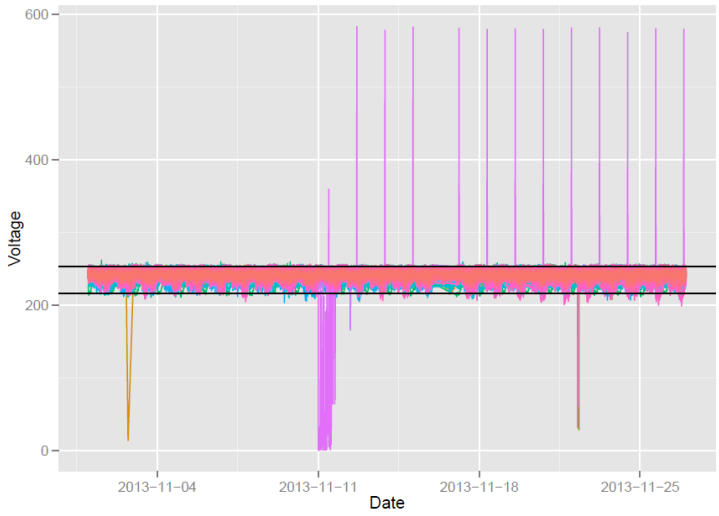

Figure 3.28: Voltage data measured at 1838 feeder ends. Measurements are for each ten minute periods in November 2013. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

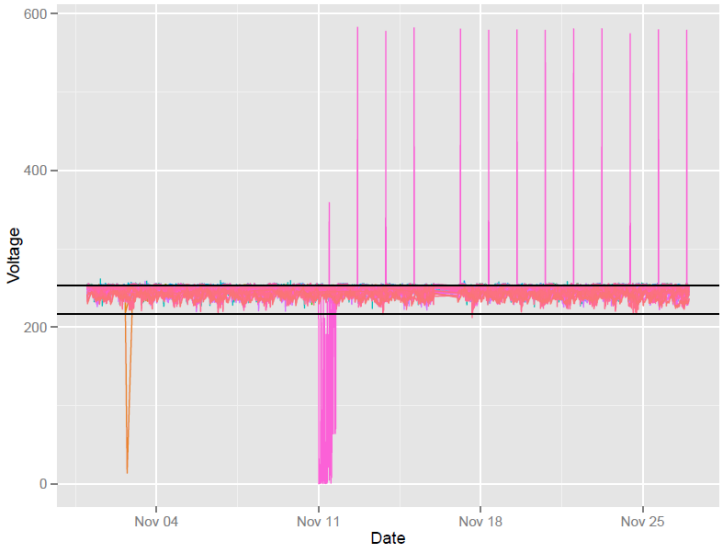

Figure 3.29: 10-minute voltage data plotted for each feeder end where at least one 10-minute period exceeds the statutory limit.

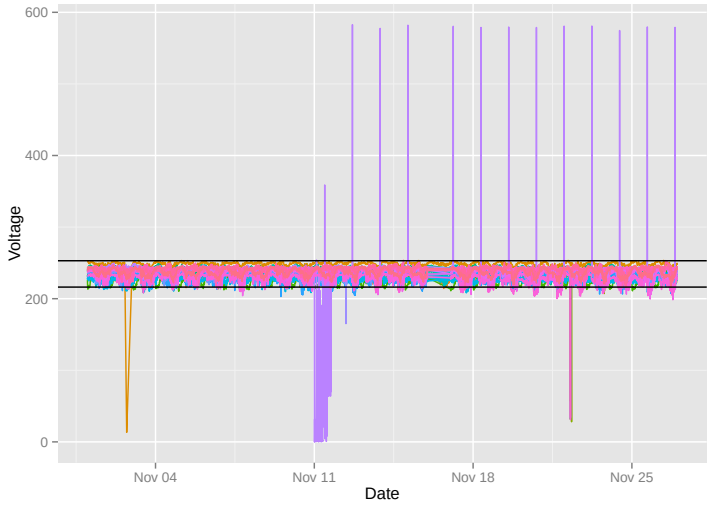

Figure 3.30: 10-minute voltage data plotted for each feeder end where at least one 10-minute period falls beneath the statutory limit.

Of the 1817 feeder end monitors considered here, 97 had a measurement above 253V and 34 below 216.2V for (at least one) ten minute period during November. Figure 3.29 shows the voltage profiles for those 97 where at least

one 10-minute period exceeded the statutory limit and Figure 3.30 for the 34 where at least one 10-minute period was lower than the statutory limit.

Figure 3.31 shows the percentage of ten minute periods exceeding the 253V for each day in November 2013, with and average of 0.2218% over the month. Figure 3.32 shows the percentage of ten minute periods below the 216.2V for each day in November 2013, with and average of 0.0245% over the month.

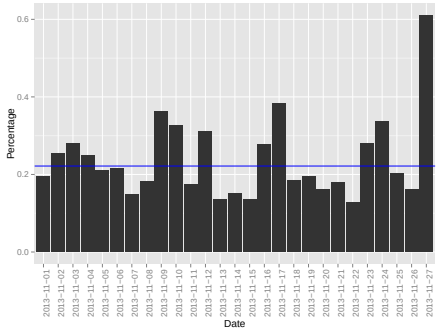

Figure 3.31: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in November 2013 of all substations. The blue horizontal line represents the monthly average of exceedances.

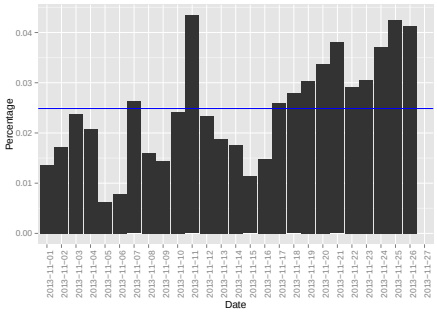

Figure 3.32: Black bars represent the percentage of 10-minute periods below the statutory limit per day in November 2013 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

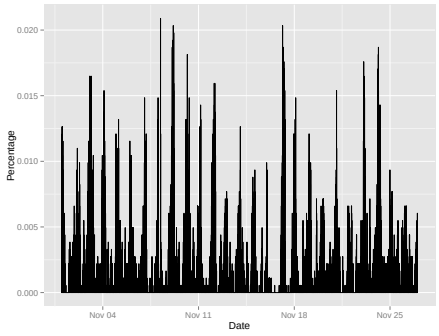

Figure 3.33: Percentage of voltage monitors exceeding the statutory limit in each 10-minute period.

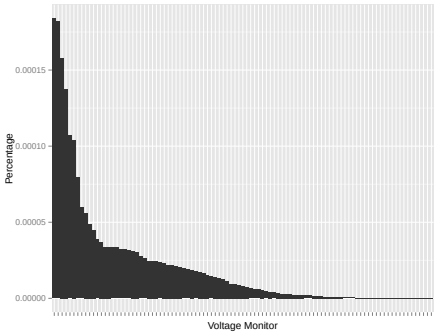

Figure 3.34: Percentage of 10-minute periods that each voltage monitors exceed the statutory limit in November 2013.

Figures 3.33, 3.34, 3.35 and 3.35 show a breakdown of the occurrences of these, showing that in both cases the points outside the limits arise from a small number of feeder end monitors.

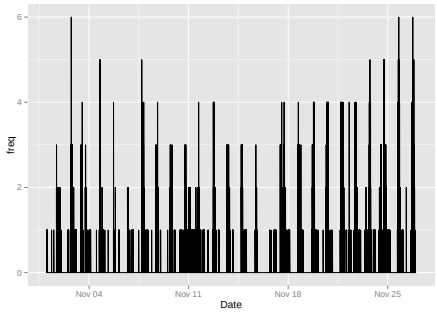

Figure 3.35: Percentage of voltage monitors below the statutory limit in each 10-minute period.

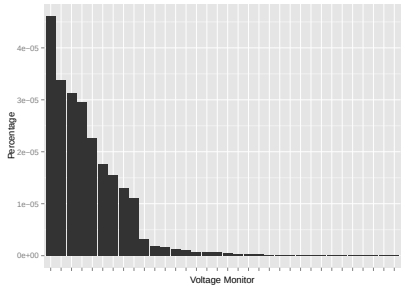

Figure 3.36: Percentage of 10-minute periods that each voltage monitors falls beneath the statutory limit in November 2013.

3.3 Intersection of excursions

3.3.1 November 2014

As previously mentioned, 18 substations and 91 voltage monitors exceeded the statutory limit of 253V in November 2014, with an average percentage of ten minute periods over the month of 0.1969% and 0.2221%, respectively. Of these, 12 substations were associated with at least one voltage monitor. In total there were 75 voltage monitors providing data with at least one 10-minute excursion associated to these substations. Within November 2014, a substation excursions occurred simultaneously with its associated voltage monitor(s) excursion(s) 45.98% of the time. The remaining 54.02% of the time, a substation excursions occurred without a subsequent excursion from its associated voltage monitor(s).

Of the 18 substations and 34 voltage monitors falling below the statutory limit of 216.2V in November 2014, the average percentage of ten minute periods excursions was 0.0033% and 0.0443%, respectively. Of these, no substations were associated to any of the voltage monitors, hence there were no simultaneously excursions between substations and their associated voltage monitor(s) excursions.

3.3.2 November 2013

As previously mentioned, 18 substations and 97 voltage monitors exceeded the statutory limit of 253V in November 2013, with an average percentage of ten minute periods over the month of 0.2508% and 0.2218%, respectively. Of these, 15 substations were associated with at least one voltage monitor. In total there were 70 voltage monitors providing data with at least one 10-minute excursion associated to these substations. Within November 2013, a substation excursions occurred simultaneously with its associated voltage monitor(s) excursion(s) 62.04% of the time. The remaining 37.96% of the time, a substation excursions occurred without a subsequent excursion from its associated voltage monitor(s).

Of the 15 substations and 34 voltage monitors falling below the statutory limit of 216.2V in November 2013, the average percentage of ten minute periods excursions was 0.0010% and 0.0245%, respectively. While 4 substations were associated with at least one voltage monitor (with a total of 6 voltage monitors), there were no simultaneously excursions between substations and their associated voltage monitor(s) excursions.

3.4 Summary

Here we summarise the voltage findings November and for June. The full analysis for November can be seen above while the June analysis can be found in the appendix.

3.4.1 Substations

	November		June	
	2013	2014	2013	2014
Number of Substations suitable for analysis	602	444	592	437
Number of substations with at least one 10-minute period over statutory limits	18	18	27	28
Average percentage of 10-minute periods over statutory limits over month	0.2508%	0.1969%	0.4496%	0.8377%
Number of substations with at least one 10-minute period below statutory limits	15	18	12	13
Average percentage of 10-minute periods below statutory limits over month	0.0010%	0.0033%	0.0078%	0.0011%

Table 3.1: Comparison of voltage data of available substations for November and June, 2013 and 2014.

3.4.2 Voltage Monitors

	November		June	
	2013	2014	2013	2014
Number of voltage monitors suitable for analysis	1817	1773	1840	1199
Number of voltage monitors with at least one 10-minute period over statutory limits	97	91	135	132
Average percentage of 10-minute periods over statutory limits over month	0.2218%	0.2221%	0.3708%	0.5052%
Number of voltage monitors with at least one 10-minute period below statutory limits	34	34	14	15
Average percentage of 10-minute periods below statutory limits over month	0.0245%	0.0443%	0.0079%	0.0050%

Table 3.2: Comparison of voltage data of available voltage monitors for November and June, 2013 and 2014.

Appendix A

Voltage profiles - June

A.0.3 June 2014

Within the voltage data collected from June 01/06/2014 - 30/06/2014, 437 substations were available for analysis. Of these 437 substations, 301 had feeder end voltage monitors that also provided data associated with them. Data was available for 1262 such voltage monitors at feeder ends. Figure A.1 shows voltage data for all 437 substations for every ten minute period in June 2014.

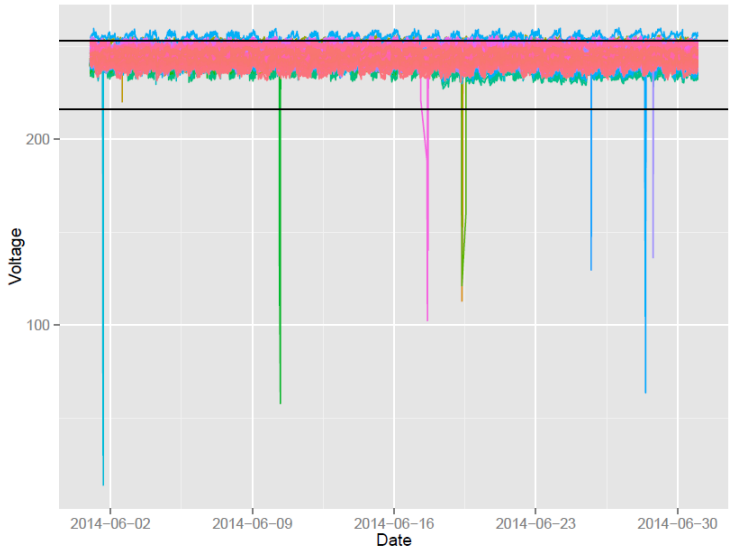

Figure A.1: Voltage data measured at 437 substations. Measurements are for each ten minute periods in June 2014. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

Of the 437 substations considered here, 28 substations had a measurement above 253V and 13 below 216.2V for (at least one) ten minute period during June 2013. Figure A.2 shows the voltage profiles for those 28 where at least one 10-minute period exceeded the statutory limit and Figure A.3 for the 13 where at least one 10-minute period was lower than the statutory limit.

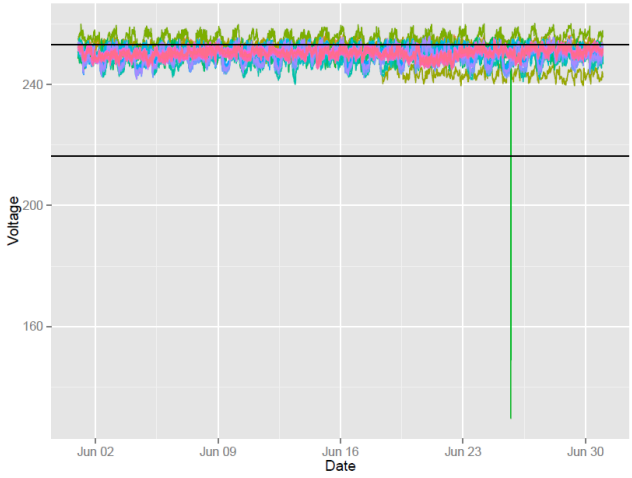

Figure A.2: 10-minute voltage data plotted for each substation where at least one 10-minute period exceeds the statutory limit.

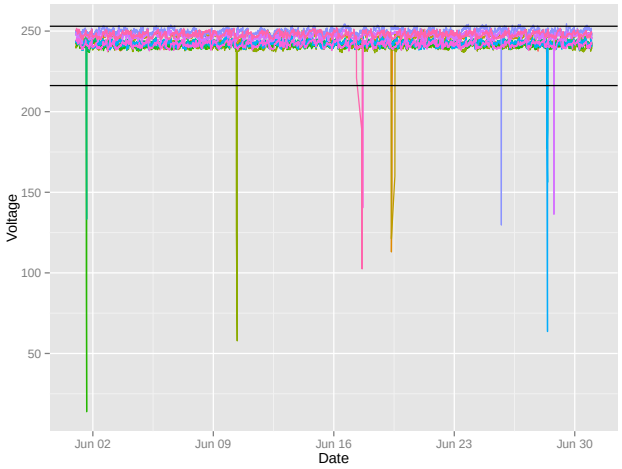

Figure A.3: 10-minute voltage data plotted for each substation where at least one 10-minute period falls beneath the statutory limit.

Figure A.4 shows the percentage of ten minute periods exceeding the 253V for each day in June 2014, with and average of 0.8377% over the month. Figure A.5 shows the percentage of ten minute periods below the 216.2V for each day in June 2014, with and average of 0.0011% over the month.

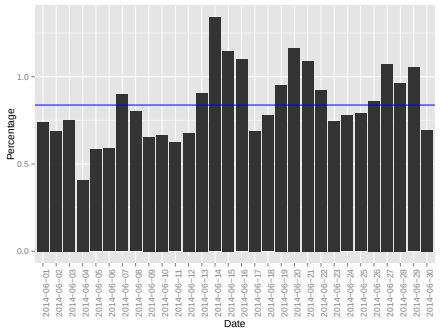

Figure A.4: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in June 2014 of all substations. The blue horizontal line represents the monthly average of exceedances.

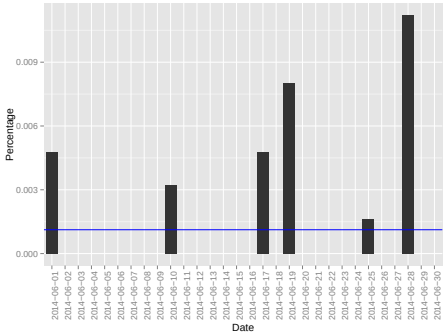

Figure A.5: Black bars represent the percentage of 10-minute periods below the statutory limit per day in June 2014 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

Figures A.6, A.7, A.8, and A.9 show breakdown of the occurrences of these excursions, showing that in both cases the points outside the limits arise from a small number of substations.

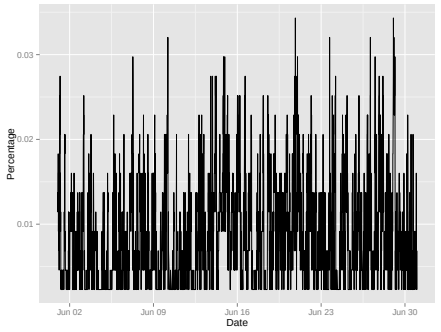

Figure A.6: Percentage of substations exceeding the statutory limit in each 10-minute period.

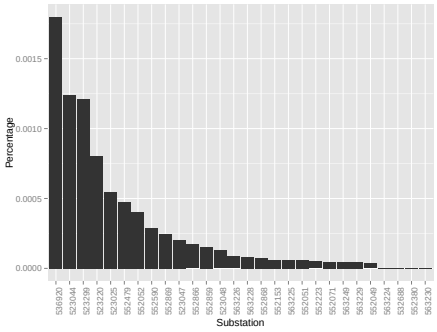

Figure A.7: Percentage of 10-minute periods that each substations exceeds the statutory limit in June 2014.

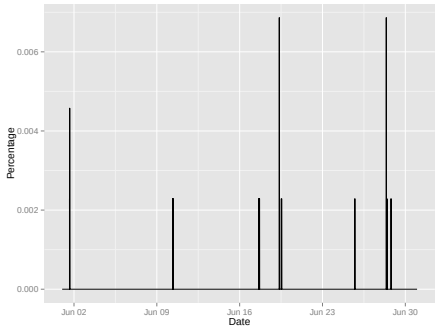

Figure A.8: Percentage of substations which fall beneath the statutory limit in each 10-minute period.

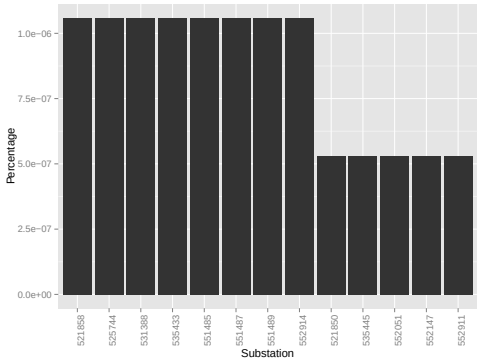

Figure A.9: Percentage of 10-minute periods where each substations falls beneath the statutory limit in June 2014.

A.0.4 June 2013

Within the voltage data collected from June 01/06/2013 - 30/06/2013, 592 substations were available for analysis. Of these 592 substations, 401 had feeder end voltage monitors that also provided data associated with them. Data was available for 1738 such voltage monitors at feeder ends. Figure A.1 shows voltage data for all 592 substations for every ten minute period in June 2013.

Of the 592 substations considered here, 27 substations had a measurement above 253V and 12 below 216.2V for (at least one) ten minute period during June 2013. Figure A.11 shows the voltage profiles for those 27 where at least one 10-minute period exceeded the statutory limit and Figure A.12 for the 12 where at least one 10-minute period was lower than the statutory limit.

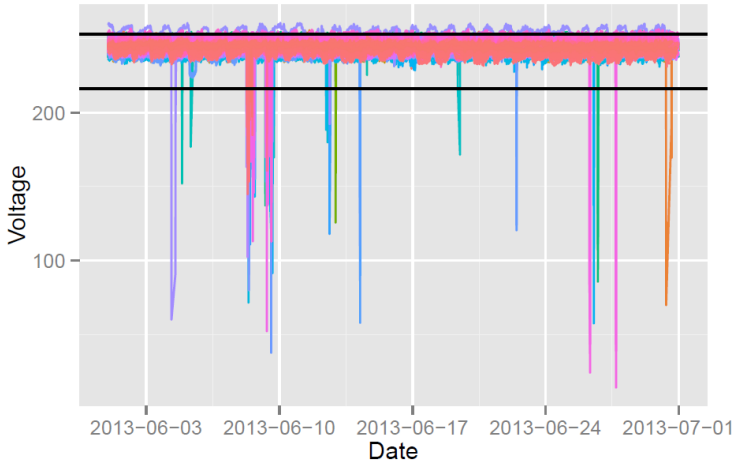

Figure A.10: Voltage data measured at 592 substations. Measurements are for each ten minute periods in June 2013. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

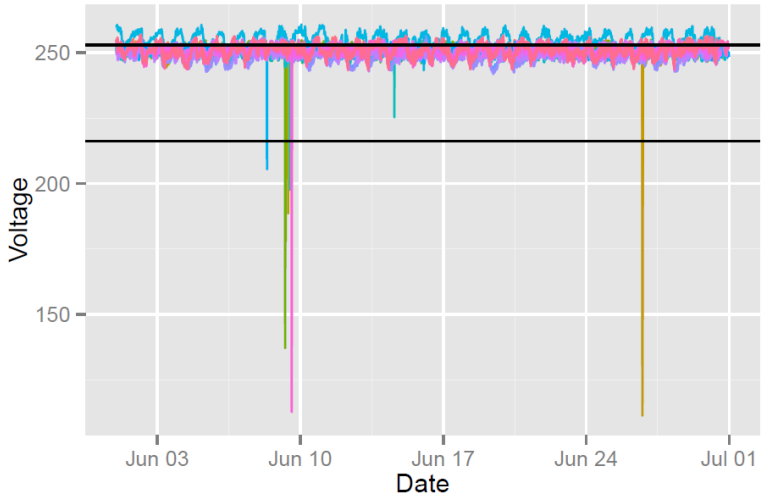

Figure A.11: 10-minute voltage data plotted for each substation where at least one 10-minute period exceeds the statutory limit.

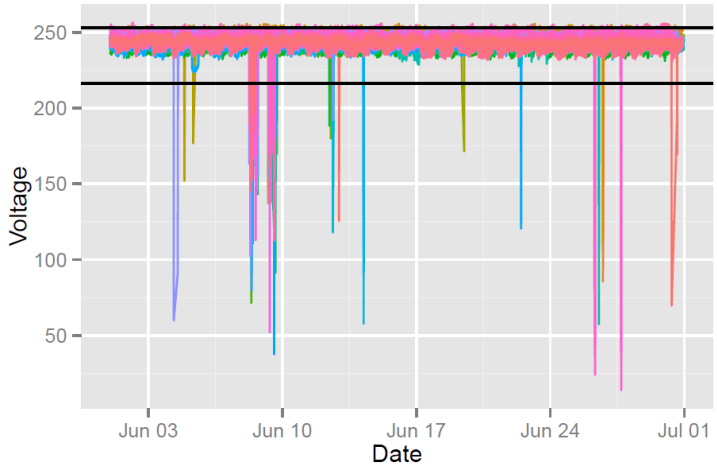

Figure A.12: 10-minute voltage data plotted for each substation where at least one 10-minute period falls beneath the statutory limit.

Figure A.13 shows the percentage of ten minute periods exceeding the 253V for each day in June 2013, with and average of 0.4496% over the month. Figure A.14 shows the percentage of ten minute periods below the 216.2V for each day in June 2013, with and average of 0.0078% over the month.

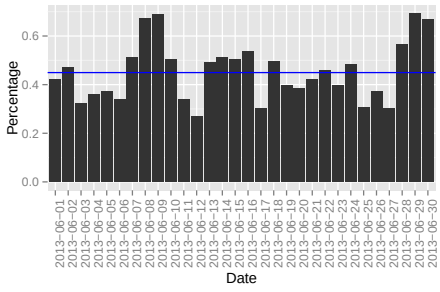

Figure A.13: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in June 2013 of all substations. The blue horizontal line represents the monthly average of exceedances.

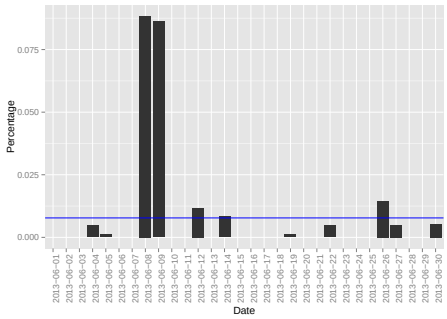

Figure A.14: Black bars represent the percentage of 10-minute periods below the statutory limit per day in June 2013 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

Figures A.15, A.16, A.17, and A.18 show breakdown of the occurrences of these excursions, showing that in both cases the points outside the limits arise

from a small number of substations.

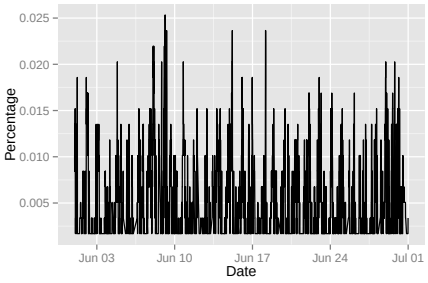

Figure A.15: Percentage of substations exceeding the statutory limit in each 10-minute period.

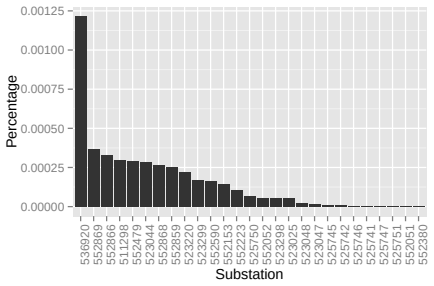

Figure A.16: Percentage of 10-minute periods that each substations exceeds the statutory limit in June 2013.

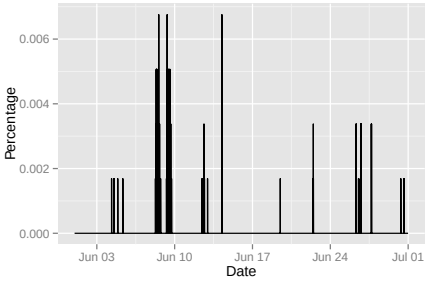

Figure A.17: Percentage of substations which fall beneath the statutory limit in each 10-minute period.

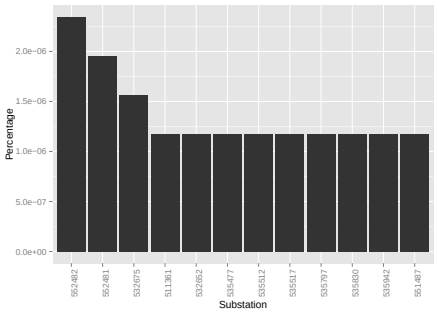

Figure A.18: Percentage of 10-minute periods where each substations falls beneath the statutory limit in June 2013.

A.1 Voltage monitored at feeder ends

Here, we present an analysis of the voltage data monitored, this time at feeder ends, for June.

A.1.1 June 2014

For June 2014, 2785 voltage monitors had 10-minute voltage data available for analysis. Of these 2785 monitors, 1792 had working voltage monitors associated with substations suitable for analysis. Figure **??** shows voltage data from these 1792 feeder end monitors for every ten minute period in June.

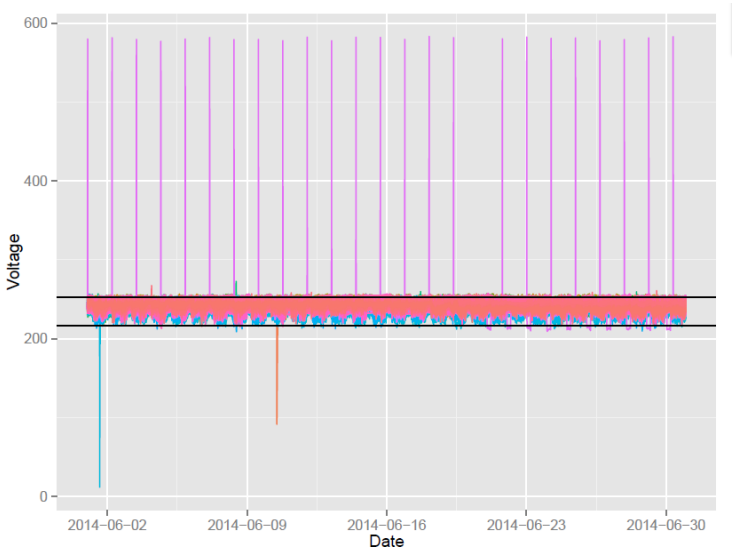

Figure A.19: Voltage data measured at 1792 feeder ends. Measurements are for each ten minute periods in June 2014. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

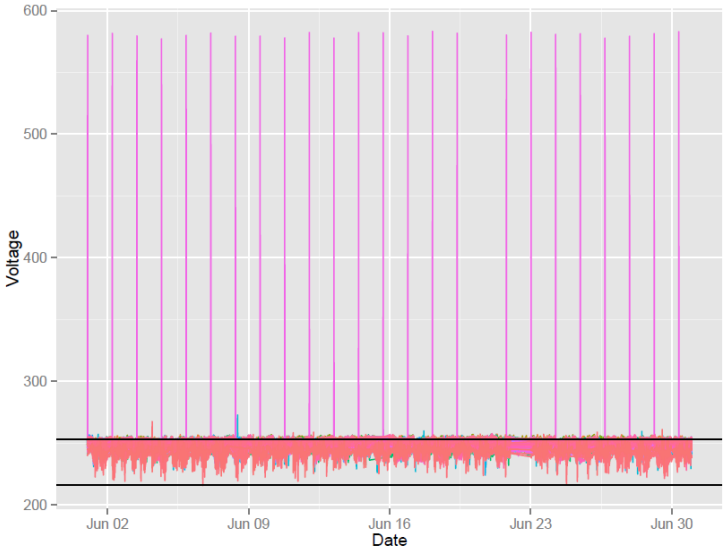

Figure A.20: 10-minute voltage data plotted for each feeder end where at least one 10-minute period exceeds the statutory limit.

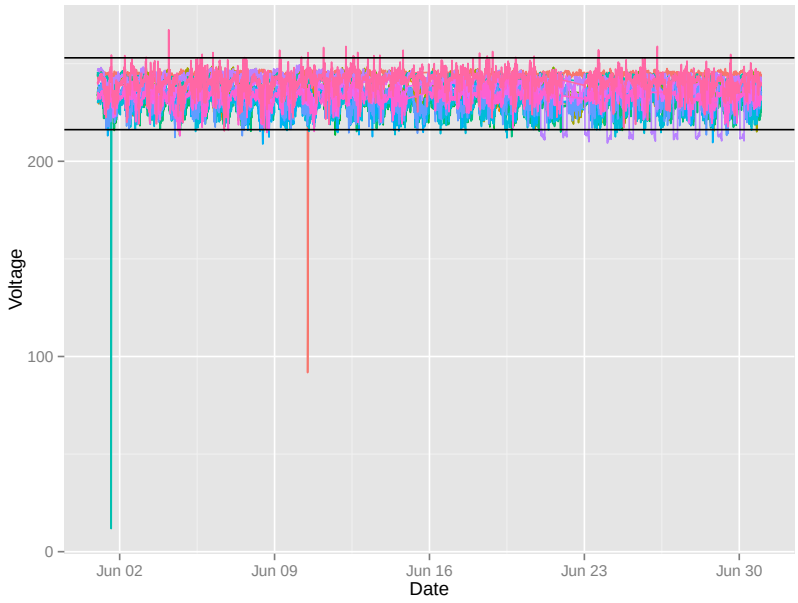

Figure A.21: 10-minute voltage data plotted for each feeder end where at least one 10-minute period falls beneath the statutory limit.

Of the 1792 feeder end monitors considered here, 132 had at least one ten minute period above 253V and 15 below 216.2V for during June. Figure A.20 shows the voltage profiles for those 132 where at least one 10-minute period exceeded the statutory limit and Figure **??** for the 15 where at least one 10-minute period was lower than the statutory limit.

Figure A.22 shows the percentage of ten minute periods exceeding the 253V for each day in June 2014, with and average of 0.5052% over the month.Figure A.23 shows the percentage of ten minute periods below the 216.2V for each day in June 2014, with and average of 0.0050% over the month.

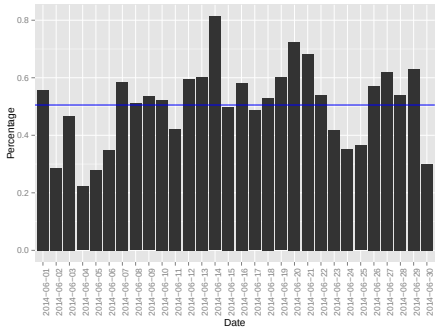

Figure A.22: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in June 2014 of all substations. The blue horizontal line represents the monthly average of exceedances.

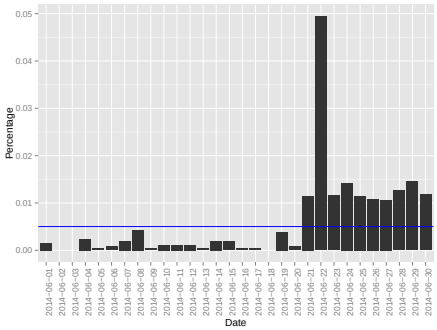

Figure A.23: Black bars represent the percentage of 10-minute periods below the statutory limit per day in June 2014 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

Figures A.24, A.25, A.26 and A.26 show a breakdown of the occurrences of these, showing that in both cases the points outside the limits arise from a small number of feeder end monitors.

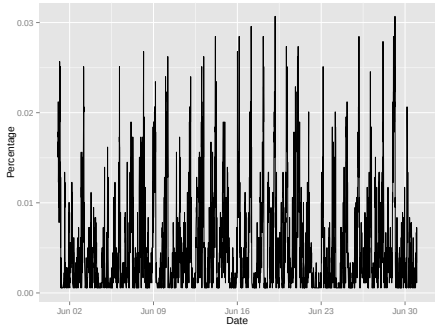

Figure A.24: Percentage of voltage monitors exceeding the statutory limit in each 10-minute period.

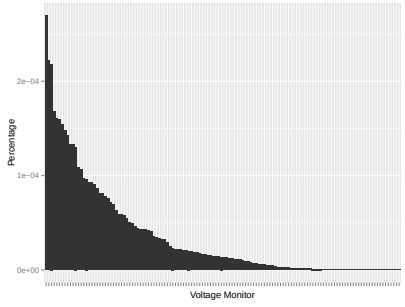

Figure A.25: Percentage of 10-minute periods that each voltage monitors exceed the statutory limit in June 2014.

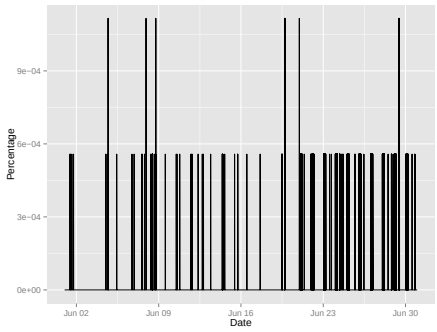

Figure A.26: Percentage of voltage monitors below the statutory limit in each 10-minute period.

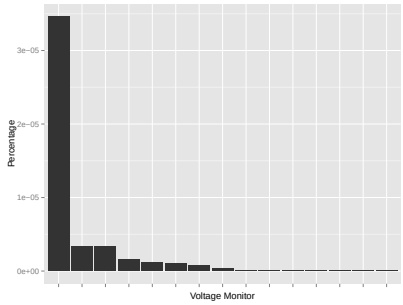

Figure A.27: Percentage of 10-minute periods that each voltage monitors falls beneath the statutory limit in June 2014.

A.1.2 June 2013

For June 2013, 2785 voltage monitors had 10-minute voltage data available for analysis. Of these 2785 monitors, 1835 had working voltage monitors associated with substations suitable for analysis. Figure A.28 shows voltage data from these 1835 feeder end monitors for every ten minute period in June.

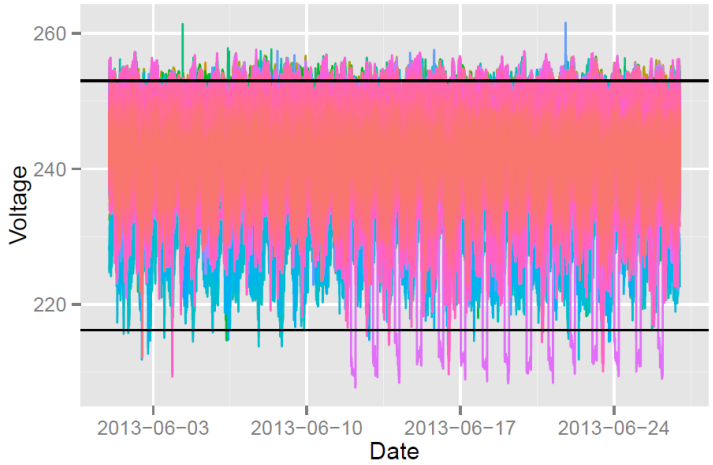

Figure A.28: Voltage data measured at 1835 feeder ends. Measurements are for each ten minute periods in June 2013. The back horizontal lines indicate the statutory limits of 230V +10%, -6% .

Of the 1835 feeder end monitors considered here, 120 had a measurement above 253V and 14 below 216.2V for (at least one) ten minute period during

June. Figure **??** shows the voltage profiles for those 120 where at least one 10-minute period exceeded the statutory limit and Figure **??** for the 14 where at least one 10-minute period was lower than the statutory limit.

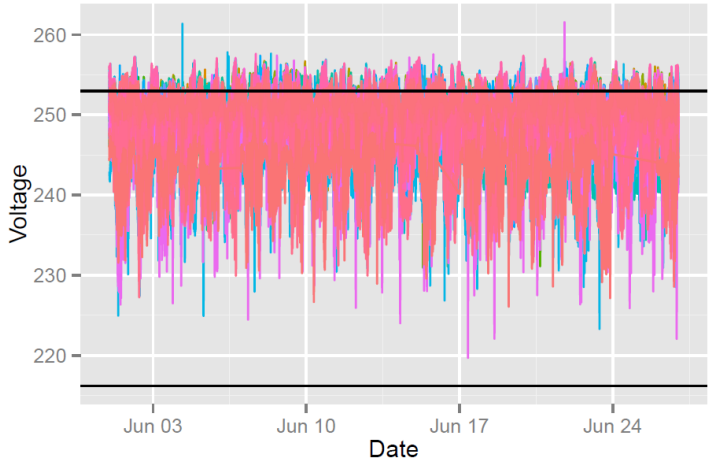

Figure A.29: 10-minute voltage data plotted for each feeder end where at least one 10-minute period exceeds the statutory limit.

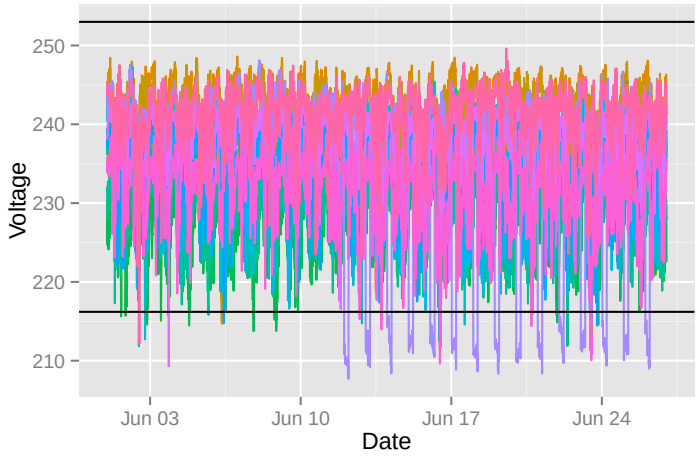

Figure A.30: 10-minute voltage data plotted for each feeder end where at least one 10-minute period falls beneath the statutory limit.

Figure A.31 shows the percentage of ten minute periods exceeding the 253V for each day in June 2013, with and average of 0.3712% over the month. Figure

A.32 shows the percentage of ten minute periods below the 216.2V for each day in June 2013, with and average of 0.0079% over the month.

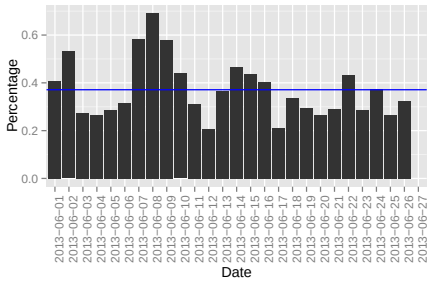

Figure A.31: Black bars represent the percentage of 10-minute periods exceeding the statutory limit per day in June 2013 of all substations. The blue horizontal line represents the monthly average of exceedances.

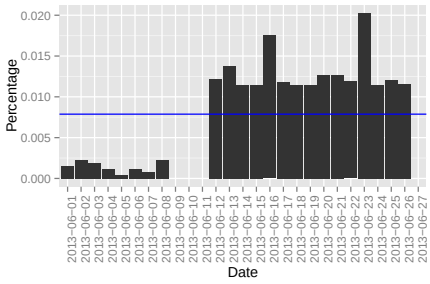

Figure A.32: Black bars represent the percentage of 10-minute periods below the statutory limit per day in June 2013 of all substations. The blue horizontal line represents the monthly average of periods below the statutory limit.

Figures A.33, A.34, A.35 and **??** show a breakdown of the occurrences of these, showing that in both cases the points outside the limits arise from a small number of feeder end monitors.

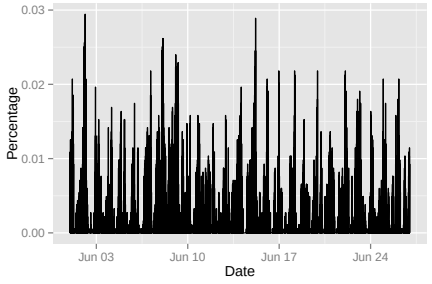

Figure A.33: Percentage of voltage monitors exceeding the statutory limit in each 10-minute period.

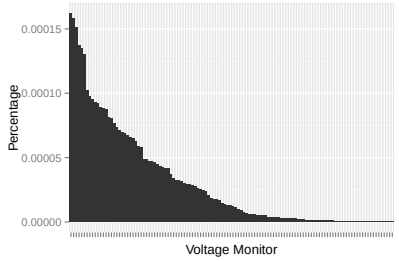

Figure A.34: Percentage of 10-minute periods that each voltage monitors exceed the statutory limit in June 2013.

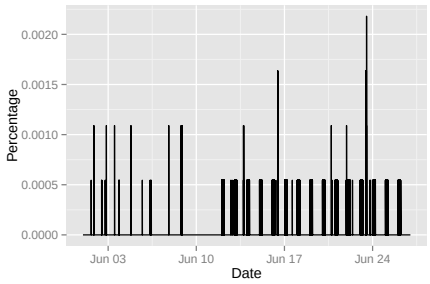

Figure A.35: Percentage of voltage monitors below the statutory limit in each 10-minute period.

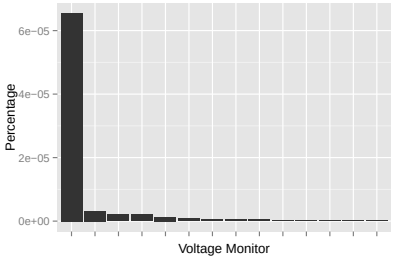

Figure A.36: Percentage of 10-minute periods that each voltage monitors falls beneath the statutory limit in June 2013.

A.2 Intersection of excursions

A.2.1 June 2014

As previously mentioned, 28 substations and 12 voltage monitors exceeded the statutory limit of 253V in June 2014, with an average percentage of ten minute periods over the month of 0.8377% and 0.5052%, respectively. Of these, 21 substations were associated with at least one voltage monitor. In total there were 100 voltage monitors providing data with at least one 10-minute excursion associated to these substations. Within June 2014, a substation excursions occurred simultaneously with its associated voltage monitor(s) excursion(s) 57.62% of the time. The remaining 42.38% of the time, a substation excursions occurred without a subsequent excursion from its associated voltage monitor(s).

Of the 13 substations and 15 voltage monitors falling below the statutory limit of 216.2V in June 2014, the average percentage of ten minute periods excursions was 0.0011% and 0.0050%, respectively. Within this period, one substations had one voltage monitor associated to it. For this substation, an excursions occurred simultaneously with its associated voltage monitor excursion 50% of the time. The remaining 50% of the time, the substation excursions occurred without a subsequent excursion from its associated voltage monitor.

A.2.2 June 2013

As previously mentioned, 27 substations and 120 voltage monitors exceeded the statutory limit of 253V in June 2013, with an average percentage of ten minute periods over the month of 0.2836% and 0.3712%, respectively. Of these, 27 substations were associated with at least one voltage monitor. In total there were

129 voltage monitors providing data with at least one 10-minute excursion associated to these substations. Within June 2013, a substation excursions occurred simultaneously with its associated voltage monitor(s) excursion(s) 53.09% of the time. The remaining 46.91% of the time, a substation excursions occurred without a subsequent excursion from its associated voltage monitor(s).

Of the 12 substations and 14 voltage monitors falling below the statutory limit of 216.2V in June 2013, the average percentage of ten minute periods excursions was 0.0078% and 0.0079%, respectively. Within this period, one substations had one voltage monitor associated to it. For this substation, 100% of the time, the substation excursions occurred without a subsequent excursion from its associated voltage monitor.