WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

Voltage Reduction Analysis

Webinar Questions

Contents

Glossary

Term	Definition
AVC	Automatic Voltage Control
BSP	Bulk Supply Point
CVR	Conservation Voltage Reduction
DNO	Distribution Network Operator
EHV	Extra High Voltage
ENA	Energy Networks Association
ICT	Information and Communication Technology
LVNT	Low Voltage Network Templates
OC6	Operating Code 6
OLTC	On Load Tap Changer
SFTP	Secure File Transfer Protocol
UoB	University of Bath
WPD	Western Power Distribution

This document summarizes the questions asked at the VRA webinar on the 5th of July 2016 along with some answers. If there are further follow up questions then please consult the project reports on the WPD innovation website or get in contact with the WPD innovation team wpdinnovation@westernpower.co.uk.

1. Data

1.1 Data integrity

What happened to the month of March?

Unfortunately, issues with communication between monitors and servers meant that no data was collected for the month of March 2015. As such no direct comparisons between data before and after the voltage changes could be made for this month. However, within the project the overall pattern in results over the year was modelled using a statistical technique known as lowess. This fits a smooth curve to the data that is available to produce a smoothed set of results for each month, reducing the noise that might be present in the raw results. This produces a (smoothed) estimate for each month, including those for which there were no data, including March. Details of this analysis are given in section 2.2 of the UoB report and are summarised in the figure below.

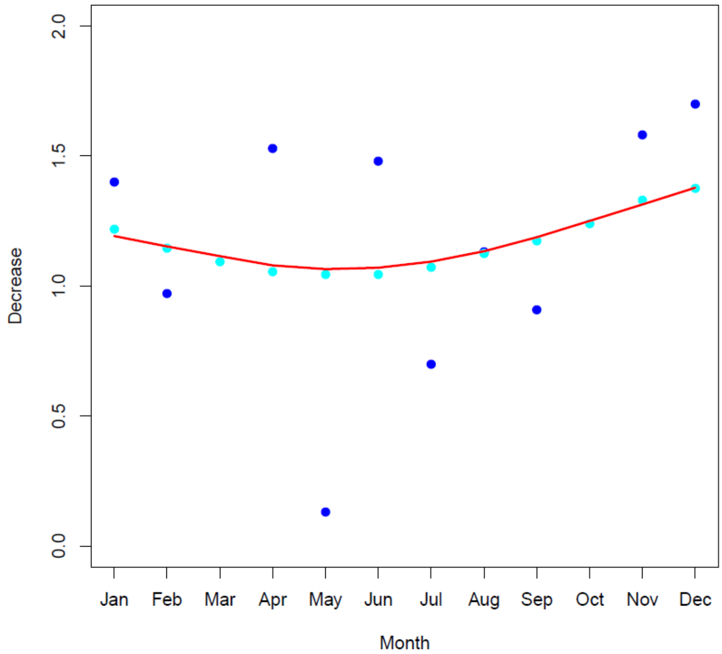


Figure 4.4: Estimates of average demand reduction between 2014 and 2015

1.2 Weather corrections

Can you say a bit more about weather correction please? Are they large relative to the 1%-ish demand reduction? Could they be a source of systematic error?

The project used existing weather corrections from the WPD charging team for south Wales. These were presented as 2 values for each half hour: the measured energy flow and a corrected version. These were then combined to get a correction factor. The corrected values incorporated effects such as temperature, humidity, cloud cover, wind and rain.

Extensive analyses were performed that aimed to assess the extent to which the final results might be sensitive to changes in the weather corrections. This ranged from examining patterns in, and the magnitude of, the weather corrections by week, to formal statistical analysis of the difference between the raw and corrected measurements by month. In post-hoc analyses, the statistical tests for changes in demand were also performed on uncorrected demands. There was no evidence of systematic bias in one direction (caused by the weather corrections) that would have led to the observed reductions in demand.

1.3 P values

What parameters did you use to calculate the p-values – was there a standard deviation calculated, if so how?

The p-values were calculated using a paired analysis. Instead of testing the overall change in average demand for a group of substations, changes in demand on a substation by substation basis were examined and the results pooled to obtain an overall estimate. The groups of substations (before and after the change in voltage settings) do not comprise independent samples and it is important to account for the characteristics of individual substations that might affect the magnitude of potential changes. These effects would be lost if the data were aggregated and a simple test between two groups (before and after the change in voltage settings) performed. For a particular month, the base analysis comprised of performing a paired t-test with the standard error (standard deviation of the sample means) required for the test calculated using the set of differences (after – before) for each substation.

More sophisticated analysis using random effects models was also performed. These formulate the comparisons within a regression model framework, with allowance for the fact there are repeated measures, i.e. patterns in measurements from the same substation may be more similar that those from other substations. This facilitated comparisons (before and after the change) to be made on a daily basis and for other information to be incorporated.

Although the p-value analysis does show statistical significance, it doesn't necessarily show that the voltage reduction was the cause – given that national demand has been decreasing that could have caused the observed decrease (theoretically). If that were taken as an assumption, is it possible that the unchanged voltage substations might be the ones with the statistically significant deviation (higher demand than expected)?

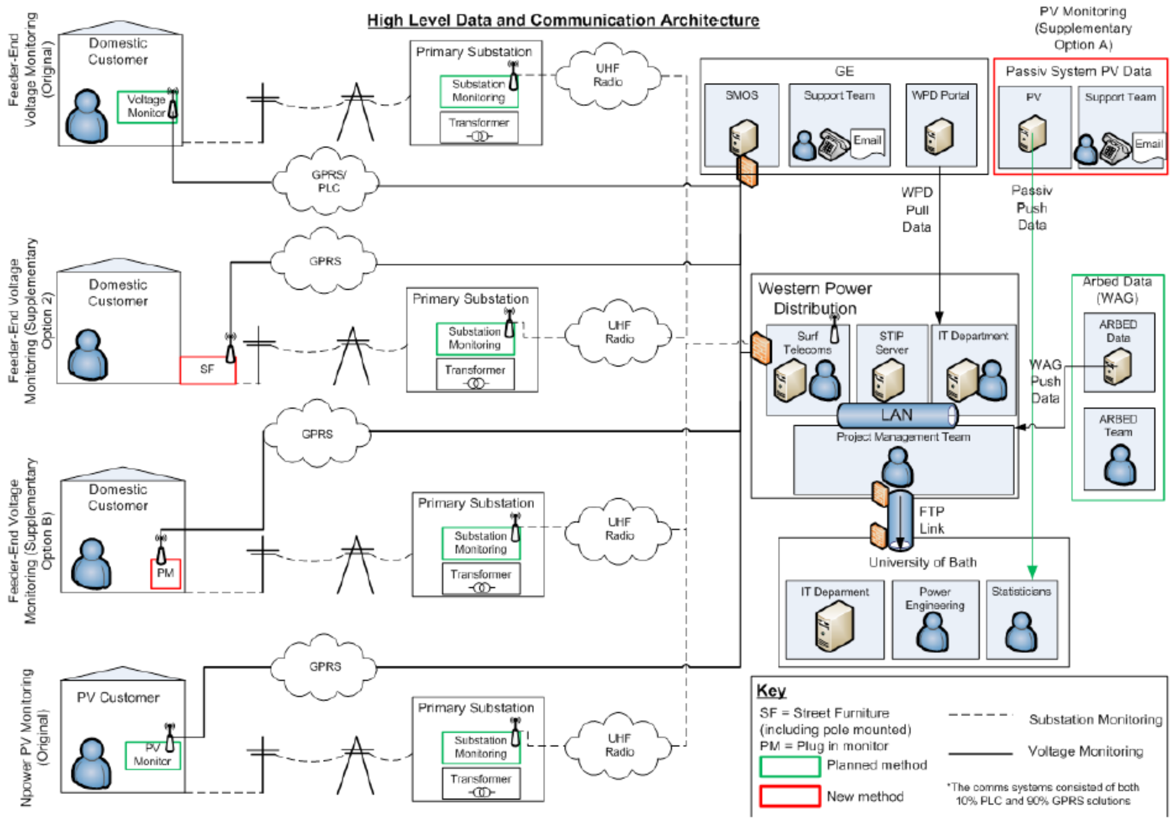
As this is an observational analysis, rather than a designed experiment in which all possible factors are controlled (for example a clinical trial), there will always be the possibility that it is other factors, that are not controlled for in the analysis, that are driving the results. The statistical testing will indicate when there is a (statistically) significant association, but cannot prove causation. Within the statistical analysis, the testing for changes in demand was performed separately for the substations with the change and then for those without. It should be noted that for both groups, the differences found in this testing are relative to the baseline year of 2014, not the other group of substations. A statistically significant reduction in demand was found for substations with the voltage change. No such reduction was found for the substations without the change.

Additionally, as part of the more sophisticated random effects analysis, data from the two sets of substations were analysed simultaneously. Again, there was no evidence of a statistically significant increase in the demands from the substations that did not have the change in voltage settings.

1.4 Data storage

What system did you use to store the data, and what tools were used for the analysis?

The following diagram highlights the ICT and communications architecture for the LVNT project. The VRA project used the same equipment minus the Passiv system and the Arbed data



Automated data transfers from WPD to the UoB were made by secure file transfer (SFTP) on a weekly basis. This was incorporated into a database that was designed to facilitate the statistical analysis. All statistical analysis was performing using R, a language and environment for statistical computing (https://www.r-project.org/about.html).

2. Demand Reduction

2.1 Voltage reduction ratio

Other innovation projects have shown that a good rule of thumb was that you could expect 1% energy reduction for a 1% voltage reduction (i.e. no change in current). It was also found that this rule of thumb could vary (up or down), dependent on time of day, time of year and location. Did you have similar observations from your project?

The project found that the drop in settings from 11.4kV (±200V) to 11.3kV (±165V) gave on average a 1.16% drop in energy. The difference between the 2 nominal set points is 0.88% which would give a slightly larger than 1 to 1 ratio. However the drop is actually between 2 bandwidths rather than 2 fixed values and so it is difficult to get a definite ratio.

Investigating the changing effect of the reduction was a major part of the project. This highlighted the effect of seasonal variations, with stronger responses in the winter than summer. Investigations into the effect of the time of day, or the substation type provided non-significant results.

Have you directly correlated the measured voltage changes with the demand changes to get a specific Watt/Volt effect?

This project investigated the effects on demand and voltage separately; as such no specific Watt/Volt ratios were calculated. In addition the data available for the different analysis, as well as the sense checking, was not identical.

2.2 Load composition

Your 0.88% VR and 1.16% energy reduction implies a CVR Factor of 1.32 which is quite high compared with other studies. Can you explain what consumer devices are contributing to this?

As mentioned above, the drop was between 2 ranges rather than 2 absolute values; as such a single CVR factor should be treated with some caution. This also represents the average response. As shown in the project, the CVR will change with the season.

It is also acknowledged that the response of demand to a voltage change is highly dependent on the makeup of the load. However this project looked purely at the overall effect on a wide area rather than detailed load make up. As such WPD cannot comment on the detailed cause behind the measured effect. Attempts to distinguish the responses of substations by network template or substation type were investigated but gave non-significant results

Do the team see this voltage response changing as demand composition changes with more penetration of power electronic loads and less resistive lighting?

As mentioned above, the make-up of the load was not assessed as part of this project. As such it is difficult to comment on any changes. The reaction of a network to a voltage change is dependent on the load and so any changes in its composition will affect the response to the voltage reduction.

2.3 Results

December average volts showed -0.8% (i.e. small rise). Yet there was a still demand reduction. Can you clarify the December voltage and demand reduction statistically verified figures?

The data that was available for the statistical analysis of changes in demand and voltage and level of sense checking that was performed were not identical. Increased sense checking and data cleaning for demand (the primary analysis) meant that additional substations would have been included within the voltage comparison for December and these are likely to have driven the non-significant increase that was observed.

2.4 Savings

Is the £14.9 million purely customer savings as a result of energy efficiency or does this include reduced DUOS costs due to deferred reinforcement?

The savings calculated is purely the value of the estimated reduced energy across South Wales. It applies the 1.16% reduction to the total energy delivered by the 11kV and LV networks in South Wales. These were then multiplied by average Domestic and Industrial values for energy.

Are the savings in money terms only based on the cost per kWh? Will Taxes, VAT, Levies, DUOS and TUOS all increase as volume of units decrease as these are an allocation of fixed charges?

Our estimate is a simple view of the short term gain to customers looking directly at the drop in kWh and the associated direct value.

It is true that certain elements of a bill have fixed revenues to recover and as such would increase in a per unit basis. However it should also be noted that the reduction in maximum demand caused by the voltage reduction would reduce the need for reinforcement, reducing overall DUOS costs.

2.5 Losses

What is the change in network losses due to voltage reduction?

The project did not directly measure losses and as such cannot provide any measurements to show an increase or decrease in network losses.

However, taking a theoretical look at the effect on losses, due to the strong response of the demand reduction, it was shown that network losses dropped as an absolute number but increased as a percentage. Any increased losses from running at lower voltage were offset by the reduction in total energy flowing.

2.6 Reactive power

Why did the reactive power reduce by ≈8% compared to the average demand reduction of just 1.16%?

This "larger" decrease is purely the effects of displaying things in percentages. The drops in real and reactive power were very similar in magnitude; however the base level of reactive demand is lower. Table 5 from the learning report, shows the differences in both Magnitude and Percentage.

Table 5: Effects on reactive power per month

Month	Mean 2014 (kVAr)	Mean 2015 (kVAr)	Mean Difference (kVAr)	Percentage difference	p-value
January	14.96	13.67	1.29	8.62	0.00
February	13.80	12.63	1.16	8.44	0.00
April	10.05	9.48	0.56	5.60	0.04
May	10.66	9.77	0.89	8.35	0.00
June	12.61	11.45	1.16	9.20	0.00
July	13.52	12.36	1.16	8.59	0.00
August	11.70	10.89	0.81	6.95	0.00
September	12.35	11.18	1.17	9.48	0.00
October	13.26	12.39	0.86	6.52	0.00
November	12.83	12.06	0.77	6.02	0.00
December	12.73	12.23	0.49	3.89	0.00

What was the system power factor before and after voltage reduction?

The value of the average power factor for January 2014 was approx. 0.988, this changed to approx. 0.989 in January 2015.

It should be noted that this value describes the ratio of the average values rather than the average value of the ratios. The latter was not explicitly looked at as part of the project.

You mention that for a 1% voltage reduction you see with some confidence an 8% reduction in reactive power. This clearly could when aggregated at times of minimum demand become problematic in the containment of high voltage at the GSP interface. Have you considered operating with different voltage targets at differing times of the day? Clearly the scale of the benefit is equally less at times of low demand from reduced MW load, and as such in whole system terms such a strategy could be expected to be more economic?

Variable voltage targets could allow for DNO's to maximise the benefits of voltage reductions whilst reducing any negative impacts. However such systems would require significant upgrades to current systems. Active voltage control on the 33kV network is being trialled as part of the Equilibrium NIC project.

2.7 Impact on assets

Would a voltage reduction impact either positively or negatively on network assets e.g. on their condition, economic life?

The impact of the voltage reduction should have minimal effect on asset condition and life.

The project showed that the maximum demand dropped as a result of the voltage drop. As the response was slightly higher than a 1 to 1 ratio then the maximum current will also have dropped.

However it should be noted that the magnitude of the drop is minimal, and smaller than the natural variation in substation load. As such it is expected that the changes will have minimal effect on asset life.

Presuming that the voltage reduction was achieved by an OLTC, then how many tap changes per day would have been typical and how did this change under the new voltage strategy?

The number of tap changes was not actively logged as part of the project. However there have been no reports of increased tapping.

The average number of tap changes per day this varies by site and by time of the year. This can range from a few taps a day to approx. 20.

2.8 Impact on customers

Were there any identified impacts on Generation outputs? Did you see a reduction in generators outputs etc...? Did any generators disconnect during the test?

No impacts on generators were noted during this trial. The change in voltage was small and the number of total voltage excursions reduced.

Would other end users experience any impacts of a lower voltage? E.g. on domestic consumer appliances.

No impacts on customer appliances were reported during this trial. As mentioned above, the change in settings caused a very small drop in voltage and the number of voltage excursions reduced.

Does this exercise need to be judged against Customer perspectives? An example would be electricity being used for heating, if the voltage is reduced then a Customer will see a reduction in heat output from appliances and hence, could reasonably be expected to use said appliances for a longer period of time to gain the same amount of heat? Surely the same could also be said of industrial processes to a degree?

Reducing the voltage will affect the operation of different loads to different degrees. In the example mentioned, to provide the same heating, the appliance would be on longer. For resistive loads with controls like this there will be a reduction in maximum demand, but no reduction in consumption. However overall the study has shown a reduction in consumption across South Wales, this implies a high penetration of resistive loads with no feedback control.

As for the effects on customers, it should be noted that when operating a distribution network, the voltage supplied is not constant, but varies within the statutory limits depending on system loading, running conditions, generation…. Whilst the average voltage will be lower following the change, the effect on equipment will be minimal compared to the natural voltage variations. These are designed to stay within statutory limits but not to remain constant.

2.9 Wider industry

Have you had engagement with other DNOs on this?

The findings of this project have been shared with the other DNO's through the relevant ENA working groups

2.10 Future designs

You mentioned that dropping the voltage increases the number of under-voltages but this is offset by reductions in overvoltage. This implies that perhaps the voltage could be dropped further to be optimal? Of course there will be certain feeders that are not possible but in general this seems like it would be favourable.

This is something that we have investigated. If you were looking to minimise the number of total excursion in the month of January then the voltage could be dropped a further 1.2% (from the current position).

However the number of excursions is not the only factor in the setting of network voltages. DNO's also need to consider the operability of networks. By having higher voltages, it is easier to back-feed the network under outage conditions. The amount of time a network is in abnormal running is minimal, however it is critical to allow for this option if we want to be able to restore supplies as quickly as possible.

With potential changes in loads, with more and more constant power loads (such as LEDs) the savings will reduce. Is it therefore economic to invest in the network for the diminishing return?

As acknowledged earlier, changes in load will change the response of the network to reduced voltage.

However the costs of implanting a change in voltage settings are relatively low, especially when timed with existing AVC maintenance. Also as the response to the changes are so strong the cost of implementation is very quickly offset.

If voltage was reduced permanently would there be costs to implement and maintain this compared to retaining the status quo? If so, how much?

There would be costs of implementing the changes; however on most networks this would be minimal. This would involve changing the settings at the next maintenance visit. However there will be networks where dropping the 11kV voltage will cause issues at individual distribution substations. Where this occurs, a short outage would be needed to manually tap the local distribution transformer back up.

2.11 Other

What are the distribution transformer tap positions in South Wales? Are they standard or do you have tapping zones on longer feeders?

Most distribution transformers are set to tap 1 in South Wales (+5%) with no different tapping zones. Due to historic network design this is not the case across the WPD network.

You mentioned that there were few excursions of a 10 minute mean voltage relative to the statutory limits. Is this correct as the statutory limits are not defined as 10 minute averages? The instantaneous voltages would presumably be a lot more spikey.

Using instantaneous voltages would definitely give much more spikey responses for both current and voltage.

The relationship with statutory limits is interesting. Currently DNO's measure compliance with the limits with equipment and processes following the EN 50160 standard. This uses 10 minute averages. There is currently an ENA working group looking clarify the process through a new engineering recommendation.

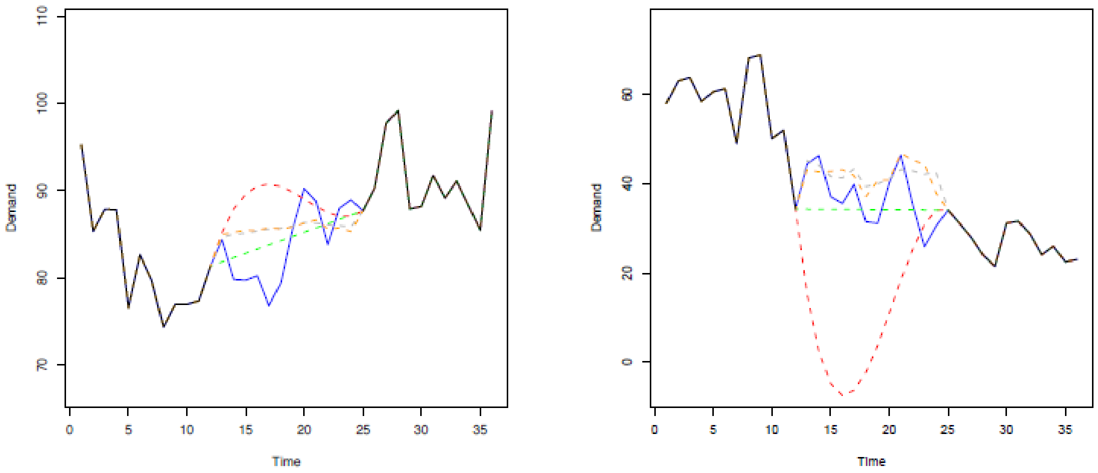
Will the reductions affect OC6 requirements?

The small changes in voltage will have minimal impact on OC6 requirements. The distribution of voltages still remains at the top end of the spectrum.

3. Juniper

Can you please clarify the Juniper results? The working behind the value quoted of a 0.6% reduction in load is not clear.

As described in the report, the aim was to compare observed demands with what might be expected if the Juniper trial had not taken place. Due to the observed variability in demands, it was not really appropriate to simply compare demands before, after and during the period of the trial, and so a model was developed to provide predictions for demands at the time of the trial. Several methods were used, all of which led to similar results. These included linear interpolation between the periods before and after the trial, smoothing splines and models based on historical data. The figure below shows an example of the different methods.



The CVR Factor in Operation Juniper appears to be 0.5, much lower than the main VRA results. Can you explain why the two different trials give markedly different results?

As described in the report the actual voltage drop seen at substations was only approximately 0.8%, as such the 0.6% reduction in demand actually corresponds to a 0.75 CVR factor. This is still lower than the longer term results. Anecdotally we would suggest this is down to the timing of the Juniper trial.

Why is 3% OC6 reduction only leading to 0.8% voltage reduction? – I think I heard you say this and it goes some way to explain the small 0.6% demand reduction

As described in the report, there were several issues with the physical operation of operation juniper. These are highlighted below:

- Operational faults on certain tap changers. WPD has since worked to rectify these issues
- 2 Networks in South Wales are fed at EHV rather than 132kV. The OC6 call in South Wales is operated at BSP level and hence did not affect those networks
- At certain sites the reduction of voltages at the BSP was not reflected at primary level. This may be due to embedded generation.