SP ENERGY NETWORKS

Flexible Networks for a Low Carbon Future

Technical Note on Investigation

- Diversity in Secondary Substation Load

February 2015

Flexible Networks for a Low Carbon Future

Technical Note on Investigation of Diversity in Secondary Substation Load

Author: Ian Elders
Date: February 2015

1 Summary of Learning Outcomes

This document reports on a study of the level and patterns of load diversity among secondary substations in the three Flexible Networks test areas.

It is concluded that:

- **The level of diversity depends on the number of secondary substations considered for a given feeder. Short feeders with few substations are generally less diverse**
- **Long urban/rural feeders appear to show more diversity of load, although this is difficult to fully characterise in the light of the limited monitoring of small rural secondary substations**
- **For urban feeders, aggregate peak load is generally in the range 75% to 90% of the sum of the individual peak loads.**
- **For longer urban/rural figures a figure below 70% appears appropriate.**
- **Planners should balance the risks of over-investment and under-investment when selecting a diversity factor to apply in any particular case.**

This deliverable forms part of Work Package 1.4, and fulfils action 27.

2 Motivation

Characterisation of load diversity is an important tool in interpreting secondary substation load measurements in order to estimate demands on the 11kV network. It is unlikely that secondary substation monitoring and data retrieval of the scale and detail that has been deployed as part of the Flexible Networks project can be widely applied. Therefore, the level of information about secondary substation load is limited. Historically, an MDI indicator has been used to measure a single value of peak demand for a year or a significant part of a year. In the future, it is possible that this may be supplemented by a simple statistical description of the load pattern, such as a load duration curve.

It will usually be the case that individual peaks in secondary demand will not coincide with one another. Thus, the sum of the individual peaks for the secondary substations supplied from a feeder (or a section of it) will be higher than the peak of their collective load. Thus, reliance on the sum of MDI measurements will tend to overestimate the peak load on a feeder or a section of it, and correction is required in order to obtain a better estimate of true peak flow. An inaccurate estimate will result in a correspondingly inaccurate view of network capacity headroom, with consequent effects on the planning of network operation and development.

3 Experimental Method

3.1 Objective

The objective of the study is to determine, for the 11kV feeders in the test area, the level and variability of diversity of secondary substation load.

3.2 Experimental Method

No specific interventions were made as part of this activity.

3.3 Data Collection

Real and reactive power data was gathered for all monitored secondary substations in the three test areas for the period from June 2013 to February 2015. These substations were normally supplied from 21 11kV circuits connected to St Andrews Primary (10 circuits), Liverpool Road Primary (2), Whitchurch Primary (3), Yockings Gate Primary (3) and Ruabon Primary (3).

3.4 Analysis Method

The relationship between the peak of the total secondary load and the sum of individual secondary substation peak loads is chosen as a metric of diversity. The ratio of these values is calculated according to equation (1):

$$D_S = \frac{\widehat{\left(\sum S_{\sec}\right)}}{\sum \left(\widehat{S_{\sec}}\right)} \quad (1)$$

In (1), S_{sec} is the load on each secondary substation, and the summation is taken over all monitored secondary substations for an 11kV feeder.

If the secondary substation load peaks are exactly coincident, then the value of D_S will be 1. As the patterns of secondary substation loading become more diverse, the value of D_S will tend to reduce: lower values of D_S indicate larger diversity.

To explore the relationship between the sum of secondary substation peak loads and the peak aggregate load, these two values were calculated for the substations on each 11kV feeder for periods of one day (i.e. the peak daily load), one week and one calendar year (representing an MDI measurement), and the ratio between them calculated and plotted for each period. For shorter periods (one day and one week), the distribution of these ratios was calculated and plotted for each test area in order to compare feeders.

4 Analysis

4.1 Input data

Measurement data was available for a total of 560 days over the study period, corresponding to 79 complete calendar weeks. Not all primary or secondary substation measurements were available throughout this period. The early part of the period covered a time in which, although most secondary substation monitors had been commissioned, the number was still increasing. Intermittent unavailablility of monitors also occurred throughout the period, and it is notable that some extended periods of primary substation monitor unavailability were encountered.

4.2 Diversity of Secondary Substation Load

As noted above, the ratio of the peak of the aggregate monitored secondary load on each feeder to the sum of the individual peak loads was calculated and plotted for aggregation periods between one day and one year. Figure 1 and Figure 1 show examples of daily tabulation.

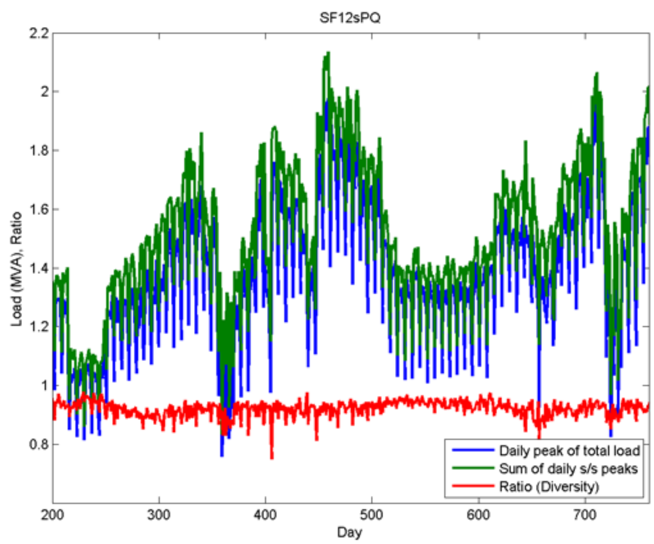

Figure 1: Load diversity for monitored substations on St Andrews feeder 12

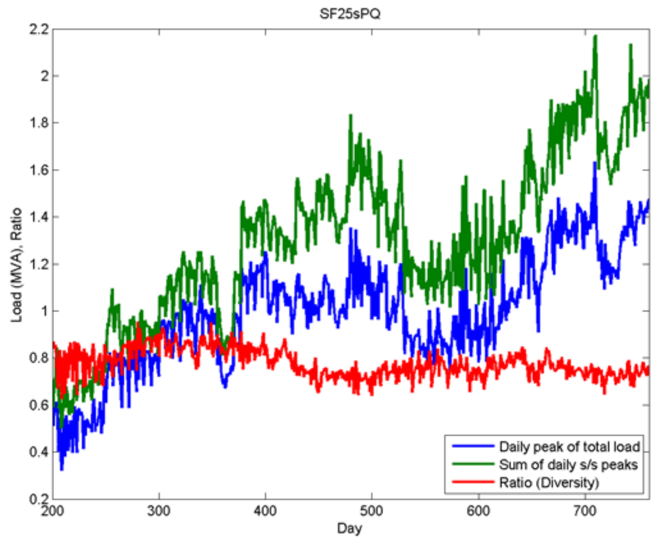

Figure 2: Load diversity for monitored substations on St Andrews feeder 25

Figure 1 shows a relatively short urban feeder, with relatively few monitored substations. Diversity is relatively low, with D_S typically around 0.9. Figure 1 shows a longer feeder extending beyond the St Andrews built-up area, with a larger number of monitored substations (most of which are, however, within St Andrews). It can be seen that load is more diverse, with D_S around 0.8.

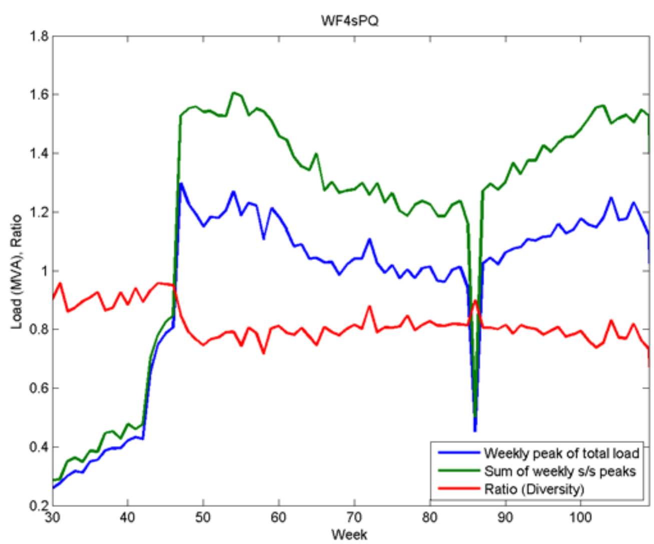

Figure 3: Weekly load diversity for monitored substations on Whitchurch feeder 4

Weekly tabulation of Whitchurch feeder 4 (shows the effect of increasing the number of monitored substations on the calculated diversity of load. As additional secondary substation monitors are commissioned, the two peak load lines develop significant separation, suggesting that the newly monitored load tends to peak at a time when the already-monitored load is low, and vice-versa.

To better understand and compare the overall level of diversity in individual feeders, the distribution of the diversity measure D_S was calculated and plotted for each feeder. Figure 4 to Figure 6 show the distributions for daily values of D_S for each test area:

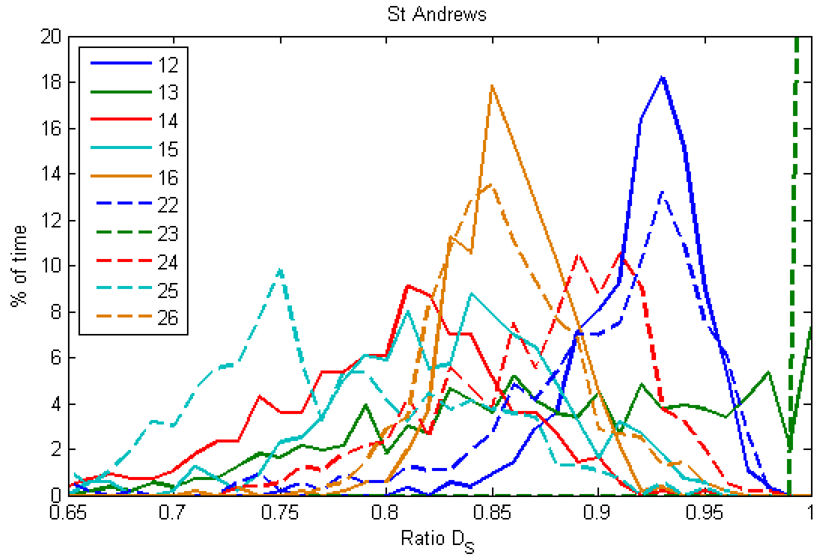

Figure 4: Distribution of monitored secondary load diversity for St Andrews feeders

It can be seen from Figure 4 that the level and spread of load diversity varies between St Andrews feeders. Some, such as feeders 12, 16, 22 and 26 have a reasonably constant diversity, with most values lying over a span of about 0.1, with the most common value present for 12-18% of the time. These feeders are relatively short, urban feeders with a small number of monitored substations. Longer feeders with more monitored substations (such as 14, 24 and 25, which interconnect to adjacent primary substations) have a more broadly spread characteristic. This means that the diversity of the load varies more from day to day. It is likely that this results from the larger number of monitored substations, as well as a more diverse range of loads resulting from their mixed urban and rural character. Feeder 23 is notable since, for the great majority of the time, there is little or no diversity in the load. This feeder (which is also of mixed urban/rural character) has very few monitored substations, which are dominated by a single HV customer. Where the load on a feeder is dominated by a single secondary substation or HV customer, then it is to be expected that no diversity will exist.

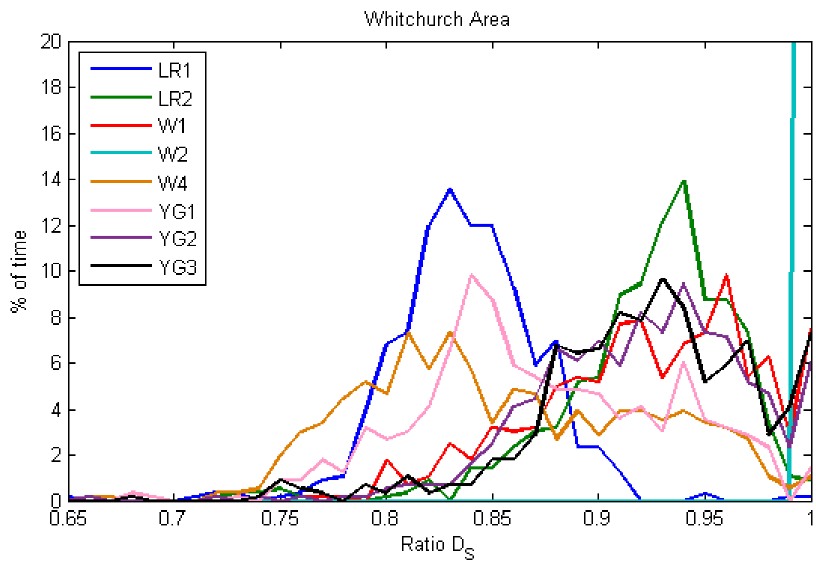

Figure 5: Distribution of monitored secondary load diversity for Whitchurch feeders

Figure 5 shows the distribution of secondary load diversity in the Whitchurch test area. 'LR' indicates Liverpool Road feeders, while 'W' and 'YG' show, respectively Whitchurch Primary and Yockings Gate feeders. Whitchurch feeder 2 has, for the great majority of the study period, a single monitored secondary substation. The overall level of diversity appears lower than at St Andrews, with a greater concentration of the distribution above 0.9. Liverpool Road feeder 1 shows the greatest consistent level of diversity, which may result from the fact that this feeder has the largest number of monitored secondary substations. Whitchurch feeder 4 also has a relatively large number of secondary substation monitors; however, some of these were, as mentioned above, commissioned part-way through the study period. This may account for the relatively wide spread of the diversity distribution.

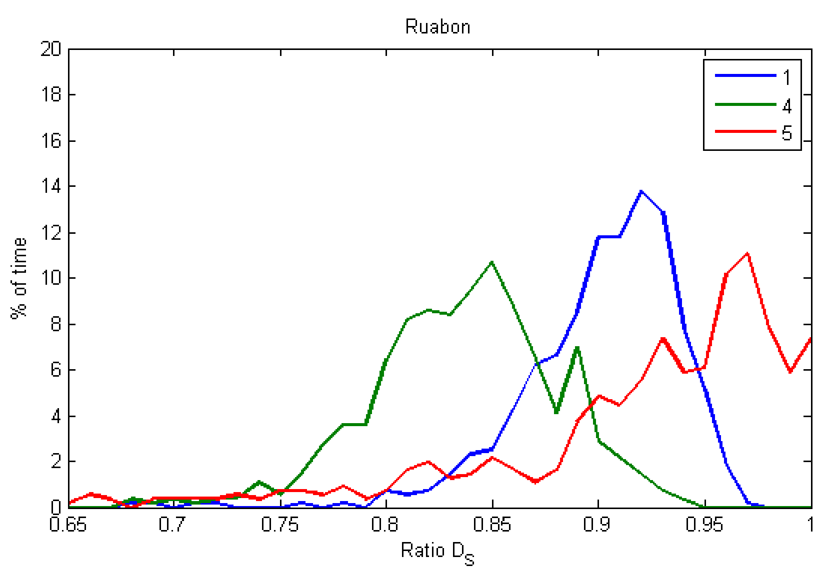

Figure 6: Distribution of monitored secondary load diversity for Ruabon feeders

Figure 6 shows the distribution of diversity for Ruabon feeders. Feeder 5 has few monitored substations, and is thus least diverse in general. However, it has a relatively broad range of day-to-day diversity, which may reflect different patterns of behaviour among the three monitored substations. Feeders 1 and 4 have similar numbers of secondary substations but show differing levels of diversity and of day-to-day variation.

Annual diversity was calculated as a single value for each feeder for calendar year 2014, and is shown in Figure 7.

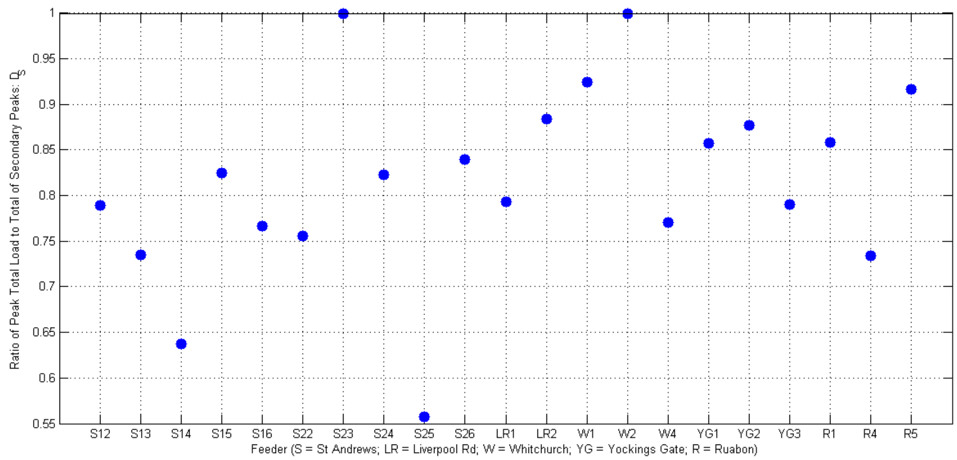

Figure 7: Annual diversity of secondary substation load

In general, the peak aggregate secondary substation load is between 90% and 75% of the sum of the individual peak substation loads. Outliers fall into three categories:

- As previously discussed, St Andrews feeder 23 and Whitchurch feeder each had one secondary substation monitor for which data was available at the system peak. There is thus no diversity (D_S = 1).
- Whitchurch feeder 1 and Ruabon feeder 5 are short feeders with few monitored secondary substations
- St Andrews feeder 14 and St Andrews feeder 25 are long, mixed urban/rural feeders with a relatively large number of monitored secondary substations, some of which are outside the urban area. St Andrews feeder 24 has similar characteristics, but with fewer monitored substations, and few of these are outside St Andrews town.

In summary, it appears, perhaps unsurprisingly, that the load on short feeders with few secondary substations is less diverse than on long feeders. For urban feeders, it seems that a factor of around 80-90% can be applied to individual substation peak demands to arrive at the aggregate peak demand. For long urban/rural feeders, there appears to be evidence that a lower factor applies, but it must be noted that relatively little of the rural load is monitored at secondary substation level in this project.

Given the range of diversity values observed, and the uncertainties resulting from the limited number of monitored secondary substations observed, these results should be applied with care. Assumption of too much diversity (D_S is too small) would result in the peak feeder load being larger than expected in relation to the sum of substation peak loads reported by MDIs. This could lead to a risk of overloading of network assets. At the other extreme, discounting diversity entirely, or assuming too little diversity would result in unnecessarily undertaking or bringing forward investment in reinforcement, when in fact there is sufficient network capacity to meet current and future demand. The relative importance of these risks will vary from case to case depending on the characteristics of the section of network involved. Planners should make use of local knowledge of the network and of the nature and distribution of loads when balancing these risks.

5 Conclusions

Without monitoring all of the secondary transformers on a selection of feeders, it is impossible to give a completely definitive factor to correct from the sum of individual peaks to an aggregate feeder (or feeder section) peak load. However, it seems apparent that a value of 75% to 90% may be suitable for aggregating load on urban feeders. For longer feeders serving a combination of urban and rural load, it appears that a value below 70% may be appropriate; however there is limited evidence to support a more specific proposal.

The special case of feeders whose load is dominated by a single secondary substation or HV customer should be noted. No diversity would be expected in such cases.

It should be noted that the level of rural load monitoring undertaken in this project is not sufficient to propose an aggregation factor for entirely rural load, which would be valuable in forecasting the consequences of transferring feeder sections between adjacent primary substations.

Planners should be aware of the risks of under- and over-investment when selecting an appropriate diversity factor to apply to a particular HV feeder.