9.3.2 Source of Eskom-Z exceedances

The normalised cross correlation and variance were used to determine the cause of the unbalance at the Eskom-Z 11 kV and 22 kV busbars. The data used was from 21–24 December 2017. The entities that could contribute to the voltage unbalance were the load on the Eskom network, Transnet traction load and the IPP-N wind farm. The correlation between the Eskom-Z 11 kV busbar, 22 kV busbar voltage unbalance and the traction load is shown in Figure 23, which shows that there is a correlation of 0.123 between the Eskom-Z 11 kV voltage unbalance and the traction load at zero sample time shifts. There is a -0.00777 correlation between the Eskom-Z 22 kV busbar and the traction load at zero sample time shifts. These correlation values are quite small and close to zero. In this case, the correlation method fails to identify the source of voltage unbalance. This calls for an alternative method for identifying the source of voltage unbalance exceedances. The variance was used as an alternative tool to determine the source of voltage unbalance exceedances.

Table 6 shows the Eskom-Z S/S voltage unbalance correlation with other entities in the network. The correlation values are low. The correlation method failed to identify the source of voltage unbalance exceedances. The variance will be used to determine the source of the exceedances.

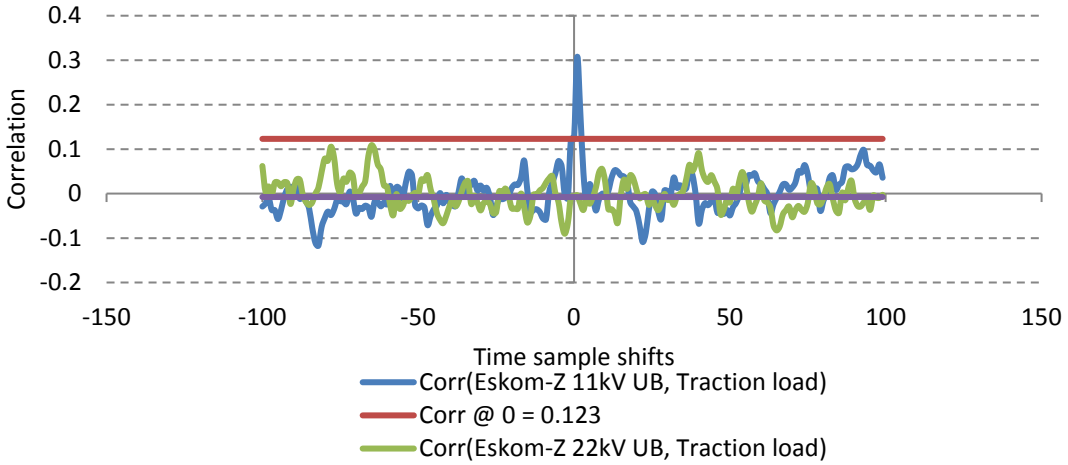

Figure 24: The correlation between the Eskom-Z voltage unbalance and the total traction load, where UB is voltage unbalance.

Table 6: Correlation between Eskom-Z with other entities

Data 1	*Data 2*	*Correlation (Data 1, Data 2) @ 0*
Eskom-Z 11 kV voltage unbalance	Eskom-Z load	-0.04162
Eskom-Z 11 kV voltage unbalance	Eskom-Z 22 kV voltage unbalance	-0.02666
Eskom-Z 22 kV voltage unbalance	Eskom-Z total load	0.00491
Eskom-Z 11 kV voltage unbalance	Eskom-P 132 kV voltage unbalance	0.59776
Eskom-Z 11 kV voltage unbalance	IPP-N active power	0.00288
Eskom-Z 22 kV voltage unbalance	Eskom-P 132 kV voltage unbalance	-0.01164
Eskom-Z 22 kV voltage unbalance	IPP-N active power	0.01794

9.3.3 Determination of unbalance exceedances using the variance

The variance of data X can be calculated using Equation 5. It should be noted that the moving average was used to determine source of voltage unbalance in this case but generally a standing average is used. The variance was used to measure the degree of dispersion of data. For the purpose of data comparison, the variance was calculated using normalised data with respect to the maximum. Normalization was conducted on the data recorded from 21–24 December 2017. It was ensured that the accuracy between the normalised data average and its corresponding moving average was two decimal places. Table 7 was constructed to record the various variances.

$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{x_{mov}})^2}{n} \quad (5)$$

where

- σ^2 is the variance of data X;
- i is the sample number in data X;
- n is the number of samples of the data X;
- x_i is the i[th] sample in data X; and
- $\overline{x_{mov}}$ is the moving average of data X.

It can be seen from Table 7 that the source of the voltage unbalance limit exceedance on the 11 kV and 22 kV busbars at Eskom-Z S/S was the traction station load. The variance of the traction load was 2.5%. The Eskom-Z S/S 11 and 22 kV busbar voltage unbalance variances were 1.52% and 1.41% respectively. The traction load variance was the highest variance for the source of unbalance and corresponds with the high variances on of the Eskom-Z 11 and 22 kV busbar voltage unbalance.

Table 7: The variance of the load and sources on sites near Eskom-Z S/S

Data 1	$\%\boldsymbol{\sigma^2}$
Eskom-P 132 kV voltage unbalance	0.4400
Eskom-Z 11 kV and 22 kV load	0.0046
Total traction load	2.5000
IPP-N active power	0.0791
Eskom-Z 11 kV voltage unbalance	1.5200
Eskom-Z 22 kV voltage unbalance	1.4100

The voltage regulation data on the 22 kV and 11 kV busbar showed a high variance on the red phase, as can be seen in Table 8. This means that the red phase is the phase most used by the traction stations.

Table 8: The variance of the 11 and 22 kV phase voltages at Eskom-Z S/S busbars

Data	$\%\boldsymbol{\sigma^2}$
Eskom-Z 11 kV red phase	14.46
Eskom-Z 11 kV white phase	3.76
Eskom-Z 11 kV blue phase	8.52
Eskom-Z22 kV red phase	11.32
Eskom-Z 22 kV white phase	4.80
Eskom-Z 22 kV blue phase	4.14

9.3.4 Eskom-Z data availability

It should be noted that the conclusions drawn from the data depends on data availability, so the data availability on data that was used is discussed in this section. Table 9 shows the data used and the corresponding data availability based on the observed period. The observation period is eight days, from 21–28 December 2017. There are thus 1 152 samples expected per data observed, since there are 144 samples per day. Data availability is thus the number of samples in the data acquired divided by the total expected samples during the period. Data availability can be expressed in percentage format.

Table 9: Data availability of the observed data.

Data	*Availability [%]*		
	Load	*Supply*	*Voltage unbalance*
Eskom-P 132 kV voltage unbalance	-	-	100
Eskom-Z S/S load	80.64	-	-
Total traction load	80.37	-	-
IPP-N active power	-	99.65	-
Eskom-Z 11 kV voltage unbalance	-	-	100
Eskom-Z 22 kV voltage unbalance	-	-	100

10. Conclusions

The normalised cross correlation can be used to determine the source of voltage unbalance. When the cross correlation does not work, alternative methods must be used. The variance was used to replace the correlation method in one of the case studies. The grid code does not specify how the voltage unbalance caused by various entities should be handled. The normalised cross correlation method must be used to govern the entities contributing to voltage unbalance of the grid. The normalized cross correlation should be used in the grid code to govern voltage unbalance related issues. The normalized cross correlation value for wind farms should be less than or equal to zero.

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