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The influence of site physical characteristics on power quality performance

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Abstract

Routine power quality (PQ) monitoring is limited to a statistical sample of sites that are hopefully representative of the overall PQ performance of the network. It would be helpful if the PQ performance of un-monitored sites could be inferred from the results of a PQ survey from a site having similar physical characteristics. This is only possible if it is known which physical characteristics are most influential in determining PQ performance. This paper describes the application of factor analysis techniques to determine the relationship between known site physical characteristics and PQ disturbance levels on the Vector Distribution Network (Auckland, New Zealand).

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The Influence of Site Physical Characteristics on Power Quality Performance

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ABSTRACT

Routine power quality (PQ) monitoring is limited to a statistical sample of sites that are hopefully representative of the overall PQ performance of the network. It would be helpful if the PQ performance of un-monitored sites could be inferred from the results of a PQ survey from a site having similar physical characteristics. This is only possible if it is known which physical characteristics are most influential in determining PQ performance. This paper describes the application of factor analysis techniques to determine the relationship between known site physical characteristics and PQ disturbance levels on the Vector Distribution Network (Auckland, New Zealand).

1. INTRODUCTION

One of the aims of routine monitoring of power quality (PQ) on distribution networks is to establish typical disturbance levels that are present on the network. The constraints of instrumentation cost, data storage capacity and communications infrastructure require that monitoring can only take place at a sample of sites that are hopefully representative of the overall PQ performance of the network.

It would be helpful to the network manager if the results of a PQ survey from a particular site could be used to infer the PQ behaviour at other un-monitored sites having similar physical characteristics. This is only possible if it is known which physical characteristics are most influential in determining the power quality levels at a particular site. It could be expected that other sites having similar physical characteristics will also exhibit similar disturbance levels.

In this paper factor analysis techniques are applied to determine the relationship between known site physical characteristics and PQ disturbance levels on the Vector Distribution Network (Auckland, New Zealand). 12 months of data from 13 zone substations on the network has been analysed in conjunction with data on the physical properties of each site. An overall site PQ index is obtained by combining indices for voltage variation, voltage unbalance and voltage harmonic distortion (THD). The influence of each of these component indices in determining the overall PQ index is analysed. The existence of a relationship between the physical characteristics and component PQ indices and the overall PQ index is investigated.

2. POWER QUALITY DATA ACQUISITION AND ANALYSIS

Vector Ltd is an electricity, gas and telecommunications utility provider in Auckland, New Zealand. Vector has been involved in routine power quality monitoring of the electricity network since 1999. The data on which this paper is based was recorded by 13 PQ monitoring instruments located in 11kV zone substations on the Vector network. The survey covered a 12-month period from July 2003 to June 2004. Three continuously varying disturbances were analysed: voltage, voltage unbalance, and total harmonic voltage distortion (THD).

2.1. PQ INDICES

Continuous PQ monitoring generates large amounts of data that must be condensed and analysed so that levels can be assessed against limits, trends identified, and problem areas prioritised for attention. Indices that effectively characterise PQ levels are used as a data reduction technique.

The PQ indices that have been used in this paper have been developed by the Integral Energy Power Quality and Reliability Centre at the University of Wollongong, Australia. These indices are described fully in [1], but for clarity, the relevant indices will be briefly defined here.

Voltage Index (VI)

Method: 1. Calculate Absolute Voltage Deviation (AVD)

$$AVD = \frac{|V_{float} - V|}{V_{float}} \times 100\% \qquad (1)$$

Where V_{float} is the system target voltage (11 kV for this survey), and V is the actual measured voltage.

2. Find the 95th percentile value of AVD across the 3 phases over the survey period.

Voltage Unbalance Index (VUI)

Find the 95th percentile value of voltage unbalance over the survey period.

Harmonics Index (HI)

Find the 95th percentile value of THD for each phase across the 3 phases over the survey period. The Harmonics Index is the maximum of the 95% values across the 3 phases.

The above indices were calculated for each site in the survey.

2.2. SITE PQ INDICES

For the purpose of ranking sites in terms of PQ performance across a network, it is useful to derive an overall site PQ index that combines the indices given above. In order to combine the individual indices to derive a site PQ index, it is necessary to express each of the indices in the same 'unit'. This was achieved by normalising each index with respect to the network average for each index. While normalising the indices with respect to a specified limit value would be more informative for the purpose of establishing compliance with standards, the purpose of this survey was comparison of the sites across the network and establishing a ranking of PQ performance. For this reason, normalisation of indices with respect to the network average value was considered to be more appropriate.

The overall site PQ index was obtained by simply calculating the average value of the normalised indices for voltage, voltage unbalance and THD for the site. It is acknowledged that the use of an arithmetic average of component indices to arrive at an overall site PQ index only gives a rough indication of overall PQ performance. For example, a site may have a very good voltage index and voltage unbalance index, but a poor harmonics index. If averaging of these three values results in an acceptable overall site PQ index, this suggests that the poor harmonics index is compensated by the good voltage performance, which may not be the view of the customer. Alternatively, it could be argued that since the effect of all of these disturbance types is additional power losses, a lower level of one disturbance type means that a higher level of another disturbance may be acceptable.

Fig.1 shows the resulting site PQ indices for the 13 sites surveyed across the Vector network.

Fig.1: Annual site PQ indices across the Vector network.

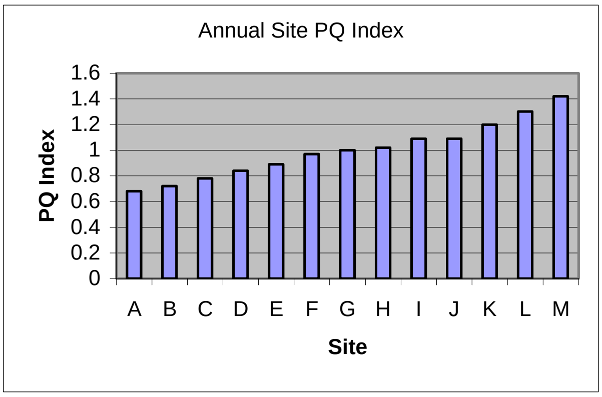


Fig.1 shows that there is a relatively smooth continuum in the site PQ indices i.e. no sites are clear outliers in PQ performance. The worst three sites (i.e. highest PQ index) all have predominantly residential loading. Average PQ levels at the worst site are approximately twice those at the best site (which has predominantly commercial load).

3. PQ FACTOR ANALYSIS

Having obtained an overall site PQ index by combining indices for voltage variation, voltage unbalance and THD, it would be useful to know which of these component factors is most influential in determining the overall site index. Is a higher (worse) PQ index for a site typically due to high levels of voltage variation, voltage unbalance, THD, or a combination of these factors? It is also worthwhile investigating whether any relationship exists between the known physical characteristics of a site and the measured PQ disturbance levels.

3.1. RELATIONSHIP BETWEEN INDIVIDUAL PQ PARAMETERS AND OVERALL PQ INDEX.

Correlation analysis has been used to establish which of the individual component indices is most influential in determining the overall PQ index for a site. The correlation analysis was carried out using the Data Analysis tools in Microsoft Excel. The results of this analysis are shown in Table 1.

Table 1: Correlation coefficients between individual PQ parameters and site overall PQ indices.

	Voltage	Voltage Unbalance	Harmonics	Overall PQ Index
Voltage	1			
Voltage Unbalance	0.0698	1		
Harmonics	0.1770	0.3497	1	
Overall PQ Index	0.6132	0.6540	0.7766	1

As expected, all parameters display a positive correlation with overall site PQ index. The harmonics index HI shows the strongest correlation with overall PQ index, indicating that it is the harmonics levels at a site that is most influential in differentiating between good sites and bad sites. This is indicative of the fact that there is more variation in harmonics levels between sites than there is for voltage or voltage unbalance. It is also worth noting that there is no evidence of any linear relationship between the levels of voltage variation, voltage unbalance and harmonic distortion i.e. having a high level of one disturbance type does not necessarily mean that a site will also have high levels of the other types of disturbances.

3.2. RELATIONSHIP BETWEEN PHYSICAL CHARACTERISTICS OF SITES AND OVERALL PQ INDEX.

As stated earlier, one of the problems with PQ monitoring is that it can only be carried out at a sample of sites. The data obtained from a site will be specific to that site. However, it could perhaps be expected that another site having similar physical characteristics might exhibit similar PQ performance.

Key physical characteristics of the 13 monitored sites on the Vector network were obtained and analysed in conjunction with measured PQ performance. The aim was to determine whether any relationship exists between any of the physical characteristics and the PQ performance of the sites. For each site, the physical characteristics considered were:

1. Fault level (prospective fault level) (MVA).
2. Annual maximum demand (half hour average) (MVA).
3. Maximum demand/fault level (often referred to as ‘load ratio or ‘electrical short circuit ratio’).
4. Predominant load type (commercial, industrial, residential).
5. Total feeder length (km).
6. Proportion of overhead lines to underground.

The process of analysing the relationship between each of these characteristics and the overall PQ index for each site was:

1. Carry out correlation analysis of each of the physical characteristics against the overall site PQ indices to determine if a linear relationship exists between them.
2. Carry out multi-variable linear regression (MVLR) analysis on the physical characteristics and the site PQ indices to determine if any statistically significant relationship exists.

Initial correlation analysis indicated that load category was clearly the most influential factor in determining the overall PQ index of a site, and that of the three load categories, residential showed the strongest correlation with overall PQ index.

Initial results of the MVLR indicated that length of feeder and percentage of overhead lines had no significant influence on overall PQ index. The process was repeated using the remaining physical parameters. The results are shown in Table 2.

Table 2: Results of MVLR – site physical parameters and PQ index.

Variable	**Coefficient**	**P Value**
Constant	-3.98	0.058
Load type	0.45	0.00017
Fault level (MVA)	0.021	0.070
Max. Demand (MVA)	-0.146	0.043
Max demand/fault level	28.099	0.032
Average load current	0.00025	0.096
Significance F	0.0023	
Adjusted R	0.825	

A P-value greater than 0.12 indicates that there is no evidence that the corresponding variable makes any significant difference to the dependent variable (site PQ index) [2]. The P-value is the probability that, if the null hypothesis were true (that the given site physical parameter has no influence on site PQ index), sampling variation would produce an estimate that is further away from the hypothesised value of the data estimate. The P-value measures the strength of the evidence against the null hypothesis. The smaller the P-value, the stronger the evidence against the null hypothesis.

The P-values for all parameters is less than 0.12, which indicates that they all have a significant influence in determining the overall PQ index for a site. Based on the P-values, load type shows the strongest evidence of influence on overall site PQ index, followed by maximum demand/fault level. The Significance F statistic indicates that there is strong evidence that at least one of the variables is required in the model. The Adjusted R statistic indicates that 82.5% of the variation in overall site PQ index can be explained by the variation in the individual physical parameters.

Given the very strong evidence of the influence of the load type on overall site PQ index, the analysis was repeated with just load type as an input and site PQ index as an output. The results of this analysis are given in Table 3.

Table 3: Results of linear regression analysis between site load category and site PQ index.

Variable	Coefficient	P-Value
Constant	0.4390	0.0092
Load type	0.284	0.00062
Significance F	0.000617	
Adjusted R	0.641	

The P-value for load type again indicates the strong evidence of its influence on overall site PQ index. The Adjusted R value in Table 3 indicates that 64.1% of the variation in overall site PQ index can be explained by load type.

To determine the effect of each of the three load categories on the overall site PQ index, the MVLR analysis was repeated using only the load categories as input data. For the purpose of this analysis, the various load categories were binary coded. Assigning a value of 1 for a particular load category for a site means that the value for the other two load categories for that site must be zero. Using this method, it is possible to obtain coefficients and P-values for each of the load categories. Note that for the purposes of this analysis, the constant term in the regression model has been set to zero.

The results of the analysis are given in Table 4.

Table 4: Results of MVLR – site load type and PQ index.

Variable	Coefficient	P-Value
Commercial	0.761	9.39×10^{-6}
Residential	1.310	$8.95 \times 10^{--9}$
Industrial	0.945	1.77×10^{-9}
Significance F	4.609×10^{-9}	
Adjusted R	0.885	

The P-values for each of the variables show that there is strong evidence for rejecting the null hypothesis that each of the variables has no effect on the overall site PQ value. The Significance F statistic indicates that there is very strong evidence that at least one of the variables is required in the model. The adjusted R statistic indicates that 88.5% of the variation in the site PQ index can be explained by the variation in the load category. The values of the coefficients indicate that commercial sites will have the lowest (best) PQ index, followed by industrial sites, with residential sites having the worst PQ index.

Based on this analysis, the model for predicting the value of the PQ index for a site is:

$$\begin{aligned} \mathit{Forecast\ PQValue} &= 0.761(\mathit{commercial}) + 0.945(\mathit{industrial}) \\ &\quad + 1.31(\mathit{residential}) + e_r \end{aligned} \tag{2}$$

3.3. SUMMARY OF RESULTS OF RELATIONSHIP BETWEEN SITE PHYSICAL CHARACTERISTICS AND OVERALL PQ INDEX.

- In terms of the physical parameters of a site on the MV network, the overall PQ index of a site is mostly dependent upon the load type and the load ratio (maximum demand/fault level). The average value of load current also has a significant influence. Of the three categories of load, commercial load sites have the best PQ index, followed by industrial. Residential load sites have the worst PQ index.
- The calculations on which these conclusions are based only involve a small number of sites (13 sites). Surveying over a larger number of sites would provide results that are more representative of the overall system.
- The Adjusted R value in Table 2 indicates that 82.5% of the variation in the value of site PQ index can be explained by the load category. This begs the question: what factors explain the remaining 17.5% of variation? All that can be said from this analysis is that the load category and load ratio have a very strong influence on the PQ performance of a site, but that there are other factors (possibly not considered in this analysis) involved.

3.4. RELATIONSHIP BETWEEN PHYSICAL CHARACTERISTICS OF SITES AND INDIVIDUAL COMPONENT PQ INDICES.

Having investigated the relationship between site physical characteristics and the overall site PQ index, it is also worthwhile looking at the effect of the physical characteristics on the component PQ indices (voltage index, voltage unbalance index and harmonics index). The process of analysing this relationship is the same as that used in the previous section i.e.

Step 1: Carry out correlation analysis of each of the physical characteristics against the particular component index to determine if a linear relationship exists.

Step 2: Carry out MVLR analysis on these physical characteristics and the particular component index to determine if any statistically significant relationship exists.

3.4.1. VOLTAGE INDEX

Site load category was the only physical characteristic that showed any significant correlation with site voltage index. MVLR analysis did not indicate any clear relationship between any of the physical characteristics and site voltage index.

3.4.2. VOLTAGE UNBALANCE INDEX

As with the voltage index, there was no significant correlation between site physical characteristics and the voltage unbalance index. Results from the MVLR analysis indicated that load type is the most influential in determining site voltage unbalance index (P-value = 0.048). This is most likely due to higher voltage unbalance indices for residential sites where it is much harder to balance the predominantly single-phase loads across the three phases.

3.4.3. HARMONICS INDEX

Correlation analysis indicated no evidence of a linear relationship between any one of the site physical characteristics and the site harmonics index. MVLR analysis indicated that load type and average load current have significant influence on the site harmonics index, with average load current showing the strongest evidence of influence.

The MVLR analysis was repeated, this time using only the three load categories (commercial, industrial and residential) as the inputs. Results are given in Table 5.

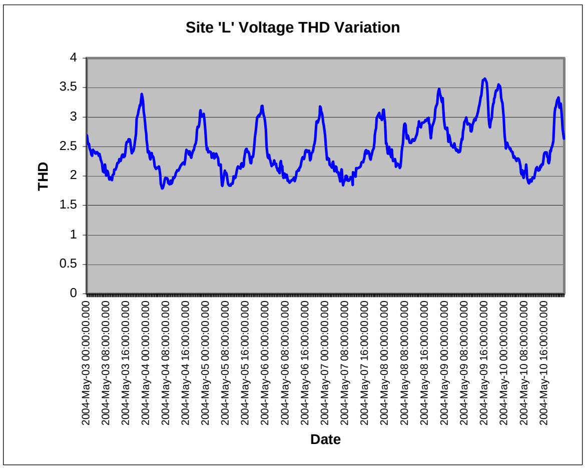
Table 5: Results of MVLR considering site load type and site harmonics index.

Variable	**Coefficient**	**P-Value**
Commercial	1.6245	0.025
Residential	3.007	0.0001
Industrial	2.533	9.164×10^{-6}
Significance F	2.21×10^{-5}	
Adjusted R	0.800	

Industrial load type shows the strongest evidence of a relationship with Harmonics Index. The Adjusted R value indicates that variation in load type explains 80% of the variation in site Harmonics Index. Based on the coefficients in Table 5, commercial sites would be expected to have the lowest harmonics index, followed by industrial sites. Residential sites would have the highest expected harmonics index.

This initially seems a surprising result. It might be expected that industrial sites that typically have a significant proportion of distorting loads (variable speed drives, dc supplies, computers etc) would have higher harmonics indices than residential sites. However, voltage THD on residential feeders tends to be highest during times of low linear loading, typically at night and during the early morning hours.[3] The peak values of voltage THD recorded during these times at residential sites are often higher than the peak voltage THD values recorded at industrial sites. Fig.2 shows the typical daily cycle of voltage THD levels at a site having predominantly residential load. The peaks in voltage THD levels occur between 10:00 pm and 11:15 pm.

Fig.2: Daily voltage THD variation at a predominantly residential monitoring site.



While load category has the most influence on harmonics index of all of the site physical characteristics considered, a significant amount of the variation in the harmonics index is also explained by factors such as maximum demand, fault level, and value of average load current at the site.

3.4.4. SUMMARY OF ANALYSIS OF RELATIONSHIP BETWEEEN SITE PHYSICAL CHARACTERISTICS AND COMPONENT PQ INDICES

- Load category (commercial, industrial, residential) was the only site physical characteristic found to have any significant influence in determining the voltage index of a site.
- Site load category is the only physical characteristic found to have any significant influence in determining the voltage unbalance index for a site. Of the three load categories, commercial sites would be expected to have the best voltage unbalance index, followed by industrial, with residential having the worst expected voltage unbalance indices.
- Correlation analysis of site harmonics indices showed no linear relationship between any one of the physical characteristics and the harmonics index. The results of the MVLR indicated that load category and average load current are the main physical characteristics that influence the site harmonics index.

4. CONCLUSIONS

Indices for voltage variation, voltage unbalance and voltage harmonic distortion have been calculated using PQ monitor data from 13 MV sites on the Vector network. These component indices have been used to derive an overall site PQ index that can be used to rank sites across a network in terms of PQ performance.

Factor analysis techniques have been applied to the PQ data. The aim of the factor analysis was to answer two questions:

- Of the three continuous PQ disturbance types included in this study (voltage variation, voltage unbalance, voltage harmonic distortion), which one has the most influence in determining the overall PQ performance of a site?
- Which of the known physical characteristics of a site has the most influence in determining the overall PQ performance of a site?

Correlation and multi-variable linear regression techniques have been applied to attempt to answer these two questions.

It was found that harmonic distortion levels show the strongest correlation with overall PQ index of sites. Where a site had a higher (worse) overall PQ index, it was mainly due to that site having a high harmonics index. There is no evidence of correlation between the component indices for voltage, voltage unbalance and harmonics, indicating that if a site has high levels of one type of disturbance, it will not necessarily have high levels of the other disturbance types.

With regard to the physical characteristics of a site, load type and load ratio were found to be the most influential factors in determining the overall PQ index of a site. Of the three load categories (commercial, industrial and residential), commercial typically has the lowest (best) PQ index followed by industrial, with residential sites being worst. It must be noted that these conclusions are based on a small sample of sites, some of which have incomplete data. Expanding the survey to a larger number of sites and analysing data over a longer time period could change the results of this analysis.

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REFERENCES

[1] Gosbell V, Perera S, Barr R, Baitch A, “Primary and Secondary Indices for Power Quality (PQ) Survey Reporting”, Proc. ICHQP 2004, September 2004, Lake Placid USA, Paper 93.

[2] Wild C, Seber G, Chance Encounters – A first course in data analysis and inference. University of Auckland. John Wiley & Sons, Inc., 2000.

[3] Sabin D, Brooks D, Sundaram A, “Indices for Assessing Harmonic Distortion from Power Quality Measurements: Definitions and Benchmark Data”, IEEE Transactions on Power Delivery, 1999 (on-line version http://ccu2.org/harmind.pdf)