International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Application of PCA in Power Quality Management

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Accepted 10 May 2014, Available online 01 June 2014, **Vol.4, No.3 (June 2014)**

Abstract

In the present era, where demand of electricity is increasing with every passing day. The quality of electricity supply demanded, wants management of power system parameters. The disturbance in system is measured in terms of certain parameters called indices. These power quality indices are the measurement parameters of power quality disturbances. In this paper, first of all the standard power quality indices are discussed and then principal component analysis is analyzed. A case study of small scale industry is taken and PCA is applied. The software which is used for this analysis is Microsoft Excel. Finally, the conclusion is drawn about the indices which are severly effecting power system. Here, voltage deviation and frequency deviation is mainly affecting the system. After extracting the principal component of indices, mitigating techniques can be implemented accordingly.

Keywords: *Power quality; indices; continuous; event-based; PCA; covariance; eigen value; eigen vector; variance contribution rate; comprehensive evaluation.*

Introduction

Nowadays, there is a great increase in emerging technologies, this increase is affecting power quality parameters considerably. Although these technologies themselves dont compromise with quality of supply. This effect in power quality is measured in terms of certain parameters which can be calculated in terms of the magnitude of distortion and deviation from ideal condition. This deviation is measured and is taken as affecting quality of the supply, which is called power quality. Power quality can be defined as "in normal operating conditions, there are set of parameters which define power quality indices magnitude and range as received at customers end. These indices are in terms of characteristics of voltage (symmetry, frequency, magnitude and waveform) and continuity of supply" (Math H.J; Mamo X). This deviation can be of long time duration or short time duration. Depending on the time of occurrence of these disturbances power quality indices are classified in two types – continuous disturbance and event based disturbance (Ding Ze-jun et al, 2010). As continuous disturbances like – voltage deviation, frequency deviation, voltage harmonics, power harmonics, voltage fluctuation and short time flicker have more severe impact on the power system and it is for longer duration. Whereas, event based disturbances like – sag, swell, overvoltage, overcurrent, have less impact on power system for smaller duration (Singh S. et al, 2014).

Power Quality Indices

Power quality indices are basically used to quantify the quality of power supply by serving as the basis for compairing the negative impacts of different disturbances in the system. The most frequently encountered power quality disturbances comprise of :

1) Harmonics and inter-harmonics
2) Voltage dip (sag), rise (swell)
3) Voltage fluctuations and interruptions
4) Three phase unbalance
5) Voltage imbalance
6) Power frequency variations
7) Oscillatory transients

During normal condition, a power quality event consists of any combination of disturbances listed above. Although for practical application, desired power quality indices should have both comprehensive and instantaneous view for analysis. But here we are concerned with the overall power disturbance and waveform distortion only i.e. comprehensive analysis. Power quality indices can be illustrated as numerical representation of the current and voltage deviation from the ideal behavior. For effectively characterizing behavior of power quality indices Tao Lin and Alexander Domijan define three categories (Lin T. et al, 2005):

a) Power frequency deviation (FDR)
b) Waveform distortion ratio (WDR)
c) Symmetrical components deviation ratio (SDR)

There are many techniques available for measuring these power quality indices, in power system analysis we are not concerned with every parameter mentioned above. In this paper, we will focus on five types of power quality:

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voltage deviation, frequency deviation, three phase unbalance, total harmonics distortion and short time flicker.

PCA

It is an abbreviated form of principal component analysis. This analysis is a result of applied linear algebra. It a method of extracting important information from given ambiguous data sets. It is a way of arranging information in a manner so that their differences and similarities are projected. Here, without much loss of information, large amount of data can be compressed.

While doing experiment, the experimenter comes out with many data sets of different measurement. The dimension of data types is defined by the different types of measurement. Let m be the number of different measurement types, then each data set represent a vector in m-dimensional space.

For example, if there are 40 students in the class, some students are involved in extracurricular activities and some of them are not good in studies. This problem can be concluded in two- dimension sapace. Dimension 'x' for those who are involved in extracurricular activities and dimension 'y' represent those who are not good in studies. And the different measurement is the number of students whose performance detoriated after five tests:

x	3	5	8	18	35
y	15	22	27	38	39

And the plot between the two using line diagram in excel is:

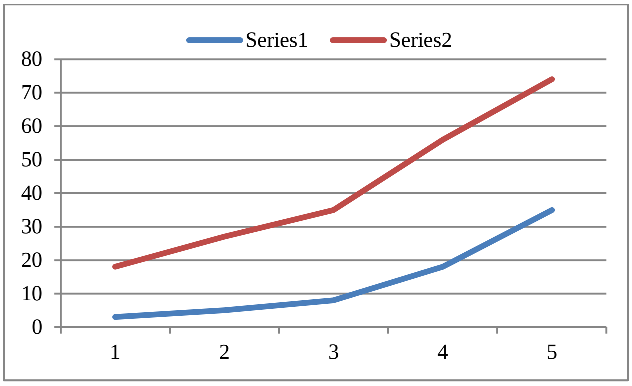

Figure 1 Plot of dimension x and y

Every data sample is a vector which lies in m-dimensional vector space which is spanned by an orthonormal basis, where basis is a set of linearly independent vectors which when put in linear combination forms coordinate system. When this linear combination results in a set of unit length basis vectors then it is called orthonormal basis (Shlens J. , 2003).

For finding PCA, the first step is deduction of mean to remove noise. As PCA refers to linearity, these measurement should lie in a single line and deviation from this line is taken as noise. For satisfying linearity, data adjusted plot is obtained by subtracting individual data from mean:

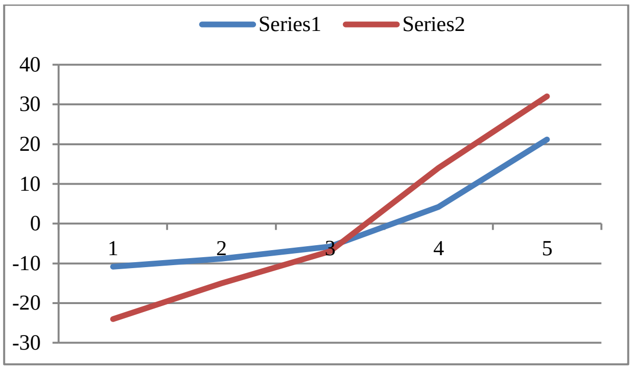

Figure 2 Plot of standardized data

Here mean for x-axis is 13.8 and mean for y-axis is 28.2 Redundancy refers to those similar measurement which are obtained because of some error. This can be removed by finding variance. Variance is the account of variation between the different measurements obtained or the spread of data in a given data set. Generally, standardization of raw matrix is done by subtracting individual raw data from mean and dividing the resultant from their variance. In this case, variance is 13.1795 for x-axis and 10.329 for y-axis. This is done to obtain a data set whose mean is zero. Third step is to find covariance between the two dimension to find the relationship between the two dimension. After obtaining covariance between x and y, a relationship between the two dimension is established which speaks about the whether the involvement of student in extracurricular activities affecting their studies. The covariance matrix is basically a square symmetric matrix like:

0.79978	0.696156
0.696156	0.799192

The eigen vectors of this symmetric matrix will always be orthonormal. The corresponding eigen value and eigen vectors are:

eigen value		eigen vector	
1.4956	0	0.7073	-0.707
0	0.1033	-0.707	0.7073

The dimension having greatest magnitude of eigen value is the "first principal component" compared to other components in a given dimension. The dimension having second greatest magnitude of eigen value is the "second principal component". Hence, in cumulative variance contribution rate:

$$V = (\sum_{k=1}^{m} \lambda_k)/(\sum_{j=1}^{5} \lambda_j).$$

If V $\geq$ 85% is satisfied then whole system can be represented by the number of principal components involved.

Here, (1.4956)/(1.4956+0.1033) = 0.935 which is greater than 0.85

This results in reduction of amount of calculation to be done. It makes the analysis simple, without much loss of accuracy. Hence, this statistical tool is used in many areas like face recognition, image processing, rock analysis (Luo X. et al, 2010) and power quality analysis (Zhou H. et al, 2011).

Application of PCA in power quality analysis has grabbed attention because in today's era there are different types of demand of customers. For example, in classroom flickering of tube light is the most unwanted feature whereas small amount of voltage deviation is manageable. In industries, voltage deviation and harmonics is major area of concern. In operation theaters, continuity of supply is a major issue. Above examples give us an idea about the variation of demand from customer end. In these cases, PCA helps in finding out the principal component affecting the system and what should be controlled in an area concerned (Smith I. , 2002).

Case Study

This data is collected from small scale industry, where induction machine was supplying the demand at customer's end. The five standard power quality indices are obtained at ten different conditions.

Table 1 Raw data

	Voltage deviation	Frequency deviation	Three phase unbalance	Total harmonic distortion	Short time flicker
A	0.3	0	0.3	3.52	0.12
B	0.5	1.7	0.4	1.7	0.5
C	2.7	0.19	53.3	1.8	0.56
D	3.4	0.25	53.7	1.1	0.66
E	0.4	0.45	30.6	1.1	0.35
F	6.3	0.55	32.1	1.7	0.12
G	0.6	0.78	38.8	1.7	0.1
H	6.2	0.1	23.7	1.2	0.3
I	2.5	0.23	33.9	1.2	0.33
J	1.5	0.27	36.7	1.2	0.4

As PCA is a statistical tool which is concerned about linearity, this raw data can be linearized by converting it into standard form of mean zero.

Step 1: *Calculate standardized matrix*

standardised data				
-0.36555	-0.56567	-0.36555	1.782395	-0.48562
-0.67971	1.09345	-0.82748	1.09345	-0.67971
-0.38718	-0.49504	1.787206	-0.42585	-0.47914
-0.35927	-0.49364	1.786431	-0.45738	-0.47615
-0.46013	-0.4564	1.788393	-0.40801	-0.46385
-0.13623	-0.55873	1.759513	-0.47423	-0.59033
-0.45842	-0.44784	1.787818	-0.39374	-0.48782
-0.00996	-0.61752	1.733039	-0.50796	-0.5976
-0.34882	-0.50311	1.785427	-0.43718	-0.49631
-0.406	-0.48266	1.787913	-0.4247	-0.47456

Figure 3 Standardized data in ms excel

This is done by first obtaining mean , variance and then standardizing it element wise by,

$Z_{ij} = (x_{ij} – \mu)/\sigma$

Where μ is obtained by the average command and σ is obtained by stdev command in Ms Excel.

Step 2: Calculate correlation of this standardized matrix

The relation between different dimensions is obtained and matrix obtained after calculating correlation is a symmetric square matrix.

correlation				
1	-0.68445	0.495921	-0.40668	-0.03144
-0.68445	1	-0.71348	0.47286	-0.69596
0.495921	-0.71348	1	-0.95061	0.505968
-0.40668	0.47286	-0.95061	1	-0.27325
-0.03144	-0.69596	0.505968	-0.27325	1

Figure 4 Correlation matrix in ms excel

Step 3 : obtain eigen value and eigen vector

The matrix obtained after standardization is a symmetric square matrix and corresponding eigen values are

eigenvector					eigenvalue
0.3651	-0.605	-0.4952	-0.4885	-0.1296	3.1528
-0.5043	-0.1244	0.4763	-0.6089	-0.3641	1.0504
0.5341	-0.0324	0.3542	0.2705	-0.7177	0.7878
					0.009
					0

Figure 5. Eigen value and eigen vecctor

Arranging these eigen values in

3.1528 > 1.0504 > 0.7878 > 0.009 > 0

And eigen vectors of only those eigen values are taken which satisfy the condition of cumulative variance contribution rate:

variance c	cumulative variance
0.63056	0.63056
0.21008	0.84064
0.15756	0.9982
0.0018	1

Figure 6 Obtained variance and cumulative variance

Calculation of principal components is done using mmul in Ms Excel:

$Z_k = \sum_{j=1}^{5} u_{kj} x_{ij}$

$Z_1 = (0.3651*x_{i1}) –(0.605* x_{i2})-(0.4952* x_{i3})-(0.4885*x_{i4})-(0.1296*x_{i5})$ (1)

$Z_2 = (-0.5043*x_{i1})–(0.124*x_{i2})+(0.4763* x_{i3})-(0.6089*x_{i4})-(0.3641*x_{i5})$ (2)

$Z_3 = (0.5341*x_{i1})–(0.0324*x_{i2})+(0.3542* x_{i3})+(0.2705*x_{i4})-(0.7177*x_{i5})$ (3)

where x_j is raw matrix and u_{kj} represent eigen vector. Taking variance contribution rate of each principal component as its weight. Comprehensive index value Z is

$Z_T = \sum_{k=1}^{m}(\lambda_k/\sum_{j=1}^{5}\lambda_j)* (\sum_{j=1}^{5}u_{kj}x_j)$.
$Z_T = (0.63506*Z_1) + (0.84064*Z_2) + (0.9982*Z_3)$

Table 2 Result

Z_1	Z_2	Z_3	Z_T
-1.7741	-2.195	1.1325	-1.84
-1.9393	-1.49	0.4547	-2.03
-26.475	22.7016	20.3998	22.633
-26.125	22.9215	20.6522	23.292
-15.862	13.5199	11.0839	12.398
-14.774	10.9649	15.0906	14.897
-20.31	17.0093	14.4262	15.8
-10.158	7.3093	11.812	11.484
-16.64	14.0064	13.4229	14.604
-18.427	15.8139	13.8291	15.394

Equations (1), (2) and (3) represent first, second and third principal component respectively. Here, first principal component is most important and -0.605 and 0.3651 is of highest magnitude so effect of frequency deviation and voltage deviation is severe. According to second principal component -0.5043 is of higher magnitude and ultimately voltage deviation is mainly affecting the quality of supply.

Conclusion

PCA is simple statistical tool which helps in reducing dimension. It has application in several fields. In power system analysis done above, voltage deviation and frequency deviation are major area of concern. Hence, proper method focusing on these power quality indices should be initiated.

References

Math H.J. Bollen, Understanding Power Quality Problems, *IEEE press*.

Mamo X., Javerzac J.L., Power Q uality Indicators, *IEEE conference*.

Ding Ze-jun, Zhu Yong-qiang, Xu Yu (2010), Comprehensive evaluation of Power Quality based on meaningful classification, *IEEE conference*; China.

Singh Surbhi, Tilak thakur (2014) , Comprehensive analysis of power quality indices, *IJSAE journal*.

Lin Tao, Domijan A (2005)., On Power Quality indices and Real Time Measurement, *IEEE* , volume 20, pp.2552-2562

Shlens jon (2003), A tutorial on principal component analysis, version 1.

Luo Xing-wen, YAO Hai-lin (2010) A model for comprehensively evaluating rock quality base on principal component analysis and its application, *CNKI conference*; China, pp.452-456.

Zhou Hui, Yang Honggeng (2011) ,Application of weighted principal component analysis in comprehensive evaluation for Power Quality, *IEEE press*; China, pp.369-372.

Smith I Lindsay(2002), A tutorial on principal componenet analysis.