

Review of Signal Processing Techniques for Detection of Power Quality Events

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Abstract: The challenging process industry requires true power for its smooth functioning and here comes the importance of good power or power. The term Power Quality (PQ) aims at supplying true power to the process. The scope of the power quality increased with the introduction of newly designed sophisticated devices like computers and microcontrollers. The performances of these devices are extremely sensitive to the various power quality problems. The mainly occurring PQ problems are voltage sag, voltage swell, voltage flickers, harmonics distortions etc. The concept of power quality became increasingly complex and vital with the introduction of recently designed sophisticated and sensitive devices, whose real time performance is extremely subjective to sensitiveness of the supply. Power Quality (PQ) has turned to be a serious issue to electricity consumers at all levels. Power quality is a major concern to electricity consumers today. The sensitivity factor of the power electronic equipment and non-linear loads to the input excitations voltages are widely used in process control as well as individual consumers which lead to the PQ problem. The paper gives a brief review in accordance with relevant literature surveys classifies the various electric power quality disturbances using wavelet transform analysis. The survey includes detection voltage disturbances and categorization of the type of event. The power quality analyzer is designed and used to measure the occurrence and classification of PQ events. Malfunction of the equipment will happens when the power failure occurs. Several signal processing techniques for the detection and classification of these disturbances are studied and discussed here. The detection techniques are mainly based on signal averaging, RMS method, Kalman Filter method, Fourier Transforms, Wavelet Transforms etc. Wavelets and fast Fourier transforms are of major importance in the classification.

Keywords: Power Quality (PQ), Wavelet Transform (WT), Support Vector Machines (SVM)

Introduction

As the power quality problems are undesirable to the electrical system, the accurate and early detection of these is very important. The effectiveness of the correct detection is very much helpful in the proper mitigation of the problems. For the proper mitigation, it is necessary to extract the properties of the signal disturbance. The presence of odd harmonics is the major cause for these disturbances. For the proper functioning

of electrical devices, the amount of harmonics should be reduced to its minimum limits. The supreme quality is demanded for the rapid involvement of sensitive electronic equipments in electrical industries. In the present industrialized world, because of the continuous usage and increase in sources of disturbance, the electric power system is subjected to sudden variations in the output voltage signals. When the current and voltage caused by these harmonics are exceeded the safely limits, results in the damage of electrical equipments. This can be

correctly mitigated only through proper classification of the type of fault present in the live system. The quality of the power is gaining importance due to the great damage caused by Power Quality (PQ) disturbances. The damage caused by power quality problems is clearly noticeable at a greater level in the economic point of view. The first step in improving the power quality is the detection of the sources of PQ and then only mitigation can be applied. Aiming to obtain solutions to detect and to classify disturbances, many methods have been studied in this study. There are many methods based on visual waveform analysis but they cannot be used in real time applications. The signal processing methods (Bollen and Gu, 2006) enabled to develop methods that are more reliable and accurate.

This paper deals with a study and survey concentrated on the various signal processing methods for accurate detection and classification of power quality problems. The efficiency of the classification algorithm is very much important for the accurate design of the mitigation control system. The main types of classifications discussed in this study are RMS method, Short Time Fourier Transform (STFT), Fast Fourier Transform (FFT), Wavelet Transform (WT) and Discrete Wavelet Transform (DWT), (Burrus *et al.*, 1998). Among this the RMS method is the most general type and having the drawback of the inability to distinguish between the fundamental frequency and the harmonics components. The phase angle calculations are also cannot be done in the RMS method.

For the accurate mitigation, there must be a thorough idea about the source of disturbance. This will employ us to choose a proper mitigation method. The classification based on signal processing techniques is regarded to be an accurate one and covers the localization of the fault event, duration and type of events. This method is regarded as reliable technique when the automated control mechanism is incorporated with different soft computing like AI based controllers. This also improves the speed of data processing for real time mitigation and also having tabular based data storage for further references. The power quality disturbance are non stationary and non linear in nature. The classification of these varying signals is done in two ways, namely transformation based and amplitude-frequency based methods.

The identification and classification of the various types of real time power quality disturbances are done with reference to standards and recommendations of IEEE. The use of Wavelet transforms (Kapoor and Saini, 2011a; 2010a) for power quality (Kapoor and Saini, 2011b; 2010b) classifications is of two types namely, data compression of the fault and wavelet packet transforms. The data compression is made using the signal decomposition and reconstruction of the patterns. It also goes for localization of samples. The

identifications are done based on the comparison of the characteristics of both the actual and measured signals. It is observed that the Wavelet (Kapoor and Saini, 2011a; 2010a) based method is more reliable in defining the characteristics of the fault events.

Power Quality Events

The electrical consumers require completely fit equipments for their smooth functioning. There arises the term power quality which is used to measure the ability of the equipment in terms of fitness. The equipment is said to be fit, if it is able to synchronize the voltage e and current waveforms. It is often difficult to point out an exact cause for the specific problem. Power quality monitoring equipments comes to aid in such situations. Most of the causes of power quality problem can be divided into two categories internal causes and external causes. The ability of the connected load to make these in a synchronized way is very important in the consumer point of view. If equipment fails in meeting the above, results in delivering a poor power. The failure occurs because of the inclusion of sensitive equipments and arc furnaces. This paper deals with the major power quality (Kapoor and Saini, 2011b; 2010b) events, their occurrences, duration, type etc. thorough literature survey is carried out in the field of various power quality events, their classification and detection. The paper studied mainly about voltage sag, voltage swell and harmonics. The problems were created in the test environment using Matlab software. The resultant waveforms were observed and further given to signal processing tool box for its feature extraction and classification. The major power quality events are described are according to IEEE Standard-1159, 1250.

Voltage Sag

Sag is a reduction of AC voltage at a given frequency lasting for 0.5 cycles to a minute, usually caused by system faults or the switching on of loads with heavy startup currents. Voltage sag is a short-duration decrease of the Root Mean Square (RMS) voltage (between 10 to 90%) that lasts from 0.5 sec to several seconds. Sags can cause significant equipment damage over time. It is often referred as a "brownout" and is the result of long-term power consistency problems that create sags in the short term. It can lead to the failure of non-linear loads such as computer power supplies causing a complete shutdown.

Voltage Swell

The opposite of sag is a swell, caused by an increase in AC voltage lasting 0.5 cycles to one minute. A voltage swell occur temporarily, on the phase without fault of a three phase circuit due to single line to ground fault. They can also occur on addition of a large capacitor bank.

Similar to under voltages, over voltages are the result of long term problems that create temporary power swells. Overvoltage conditions can create high current draw and cause equipment to overheat and become stressed.

Harmonics

A harmonic is a sinusoidal component of a periodic wave or signal having a frequency that is an integer multiple of fundamental frequency. The term harmonic refers to the decomposition of a non sinusoidal but periodic signal into a sum of sinusoidal components.

Power Quality Signal Processing Methods

The use of signal processing for power quality (Kapoor and Saini, 2011b; 2010b) applications is not a new idea, as several researchers have used signal processing for more than a couple of decades. In the past few years, however, there has been a renewed interest in exploiting signal processing techniques for power quality measurements and analysis. The Table 1 discusses the various power quality events and their respective IEEE/IEC standards. The disturbance capturing techniques are usually based on detecting the power quality events when a certain threshold level is exceeded.

The RMS Method

RMS is the most common and easy method of signal classification. The normal signal variations are classified by the RMS values. This method is somehow acceptable for looking at simple fault events. But for a complex system having different faults occurring at a time, this method is not reliable. The main disadvantage is its dependence on the lesser size of the signals and also it fails to distinguish between fundamental frequency and harmonics.

Fast Fourier Transform (FFT)

Fourier Transform is used to convert a time domain signals into its corresponding frequency components. This is effective for periodical signals to obtain its magnitudes and phases. The Discrete Fourier Transform (DFT) is an advanced technique of Fourier transform analysis. FFT is considered as a faster version of DFT, the sampling is done in a windowed manner. But FFT is not emerged as an efficient method in the analysis of

extracting the information of the non stationary as well as non linear signals. The Discrete Fourier Transform (DFT) is then considered as a reliable tool for signal decomposition analysis. The introduction of FFT can reduce the overall computation time and thereby able to choose an efficient mitigation algorithm.

Short Time Fourier Transform

It is commonly known as the sliding window version of FFT, having rather good results in terms of frequency compared with other classification techniques. It also shows poor results for time varying and non linear signals. It can divide lengthy time varying signals into corresponding shorter segments so that the computation complexity is reduced.

Wavelet Transform (WT)

While compared to the above mentioned techniques, the Wavelet transforms (Kapoor and Saini, 2011a; 2010a) are very fast and reliable technique for feature extraction of non stationary signals like voltage sag and swells. The Wavelet can have the ability to extract the features within a short interval of time. This can be achieved for both high frequency and low frequency components of the waveform. The method of analysis of different frequencies is generally adapted and is known as Multi Resolution Analysis (MRA). It has a drawback of poor frequency response at high frequency components. The energy analysis is done for all levels. The Wavelet energy is the sum of squares of the total level of Wavelet coefficients. This energy level is varying for different scales of transformations. This energy analysis is very helpful in classifying the distorted signals.

The energy coefficients of the distorted signals will be given for detailed analysis. The Daubenchies “db4” type of Wavelets is selected for signal decomposition for classification purposes. Here the shifting and scaling operations are performed on the mother Wavelet and obtaining the resultant (daughter) Wavelet. It can be a representation of both frequency and time domains. This feature differs Wavelets form Fourier Transform representations as FT gives a representation only in terms of frequency. The WT analysis is done in three types namely, Continuous Wavelet Transforms) CWT, Wavelet series and Discrete Wavelet Transforms (DWT).

Table 1. Power quality events and their standards

Events	Standards
Classification of power quality	IEC61000-2-1:1990, IEC 61000-2-5:1995
Monitoring of power quality	IEEE 1159:1995
Transients	IEC 816:1984 IEC 61000-2-1:1990 IEEE C62:41:1991, IEEE 1159:1995
Voltage sag/swell and interruptions	IEC 61009-2-1:1990, IEEE 519:1992
Harmonics	IEC 61000-2-1:1990; IEEE 519:1992
Voltage flicker	IEC 61000-4-15:1997

Discrete Wavelet Transforms (DWT)

In numerical analysis and functional analysis, a Discrete Wavelet Transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution: It captures both frequency and location information (location in time). Other forms of discrete wavelet transform include the non- or undecimated wavelet transform (where down sampling is omitted), the Newland transform (where an orthonormal basis of wavelets is formed from appropriately constructed top-hat filters in frequency space). Wavelet packet transforms are also related to the discrete wavelet transform. Complex wavelet transform is another form. To extend the frequency resolution, decomposition of signal is done repeatedly and signal can be realized into two lower frequency ranges. This process is known as multi resolution analysis.

Table 2 gives an overview and comparison of commonly used wavelets. Among these wavelets, Daubechies wavelet is suitable for power quality (Kapoor and Saini, 2011b; 2010b) analysis. In commonly used wavelets daubechies wavelet is one of the most widely used mother wavelets.

As per IEEE standards, Daubechies wavelet transform is very accurate for analyzing Power Quality (Kapoor and Saini, 2011b; 2010b) Disturbances among all the wavelet families, for transient faults. The names of the Daubechies family wavelets are written as Db_N , where N is the order and db the “surname” of the

wavelet. Matlab has an efficient wavelet tool box where the signal classification is done in an easier way.

The wavelet transform is more suitable because of its capability of coefficient detection in short time interval and the ability to select short band pass spectrum and also to save the information in time-frequency domain, without energy aliasing. The statistical parameters of wavelet coefficients like mean, median, SD, absolute value etc. can easily represent Daubechies (db), the mother wavelet function (Bollen, 2000; Caicedo *et al.*, 2011; IEEEIAS, 1997). These feature extraction techniques will help to reduce the dimension of sampled signal and thereby reducing the computation time and increasing accuracy is demanded.

Simulation for Power Quality Disturbance Generation

The test environment is created in Matlab’s Simulink. The various power quality disturbances like voltage sag and swell, voltage harmonics etc. are observed in the work space. The Fig. 1 shows the two level wavelet packet decomposition schematics. The signal processing analysis was done on these disturbances. The Daubechies (Db) family of wavelets are studied in Fig. 2. The complete signal is analyzed using Matlab signal processing tool box. The test system is constructed in Matlab Simulink tool and is observed for various disturbances like voltage sag and swell. The simulation diagram and waveform results are given in Fig. 3 and 4 respectively.

Table 2. commonly used wavelets

	Haar	Daubechies	Symmlets	Coflets	Meyer	Gaussian	Mexican Hat	Morlet
Dwt	Yes	Yes	Yes	Yes	Yes (IIR)	No	No	No
Cwt	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Φ Compact Supported	Yes	Yes	Yes	Yes	No	No	No	No
Support Width	1	2N-1	2N-1	6N-1	∞	∞	∞	∞
Filter Length	2	2N	2N	6N	IIR	IIR	IIR	IIR
Orthogonal	Yes	Yes	Yes	Yes	Yes	No	No	No
Scaling Function Φ	Exist	Exist	Exist	Exist	Exist	N/A	N/A	N/A
Reconstruction	Yes	Yes	Yes	Yes	No	No	No	No
Fast Algorithm	Yes	Yes	Yes	Yes	No	No	No	No

Table 3. Signal statistics at different decomposition levels

Event	Decomp. Level	Mean	Maximum value	Minimum value	Range	SD	Abs dev-median	Abs dev- mean	L1 normal	L2 normal	Maximum normal
Sag	Original	-212.7	220	-220	440	141.9	122.3	123.2	1.2E+07	4.5E+04	220
	Level 1	-0.189	0.195	-0.195	0.391	0.126	0.108	0.109	4576	28.19	0.1955
	Level 2	-0.534	0.552	-0.552	1.106	0.356	0.307	0.309	7744	56.39	0.5529
	Level 3	-1.512	1.564	-1.564	3.128	1.009	0.873	0.876	1.1E+04	112.8	1.564
	Level 4	-4.276	4.423	-4.423	8.847	2.853	2.649	2.478	1.5E+07	225.5	4.423
Swell	Level 5	-12.09	12.51	-12.51	25.02	8.069	6.980	7.007	2.1E+04	451.1	12.51
	Original	-222.9	352	-352	704	178.2	166.5	156.9	1.5E+07	5.6E+04	352
	Level 1	-0.198	0.312	-0.312	0.625	0.158	0.148	0.139	6969	35.4	0.3128
	Level 2	-0.560	0.884	-0.884	1.769	0.447	0.418	0.394	9856	70.81	0.8847
	Level 3	1.585	2.502	-2.502	5.004	1.267	1.181	1.115	1.4E+04	141.6	2.502
	Level 4	-4.482	7.077	-7.077	14.15	3.583	3.339	3.153	1.9E+04	283.2	7.077
	Level 5	-12.68	20.02	-20.02	40.03	10.13	9.444	8.917	2.7E+04	5.66.4	20.02

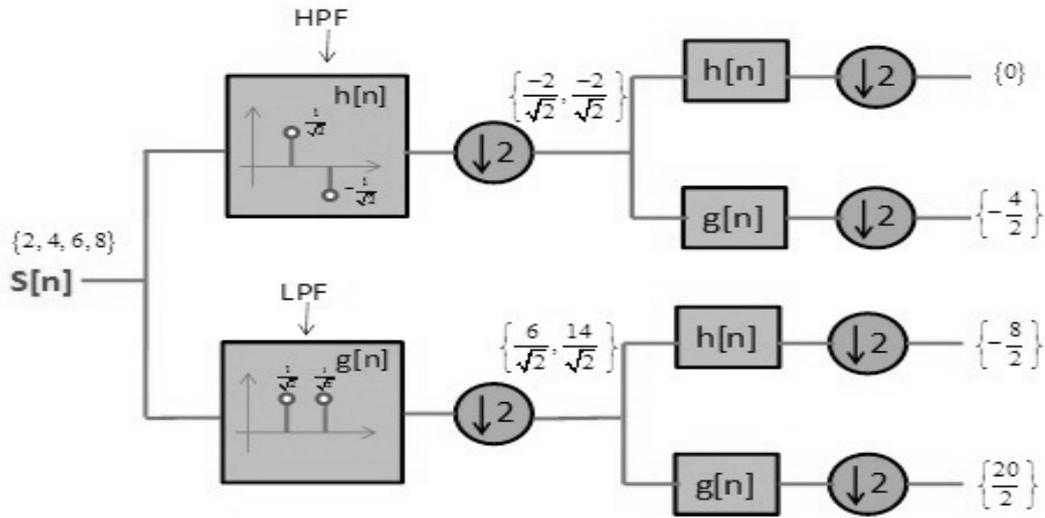


Fig 1. Two level wavelet packet decomposition

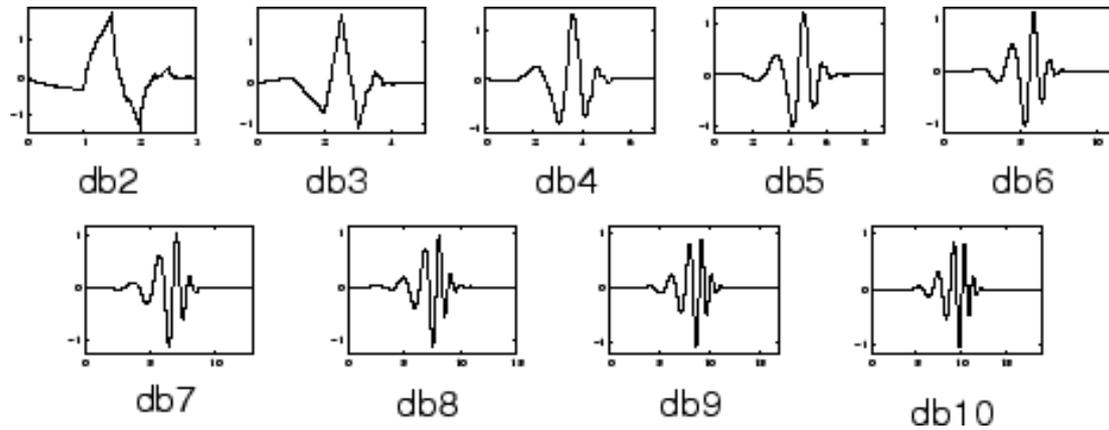


Fig 2. Daubechies family wavelets

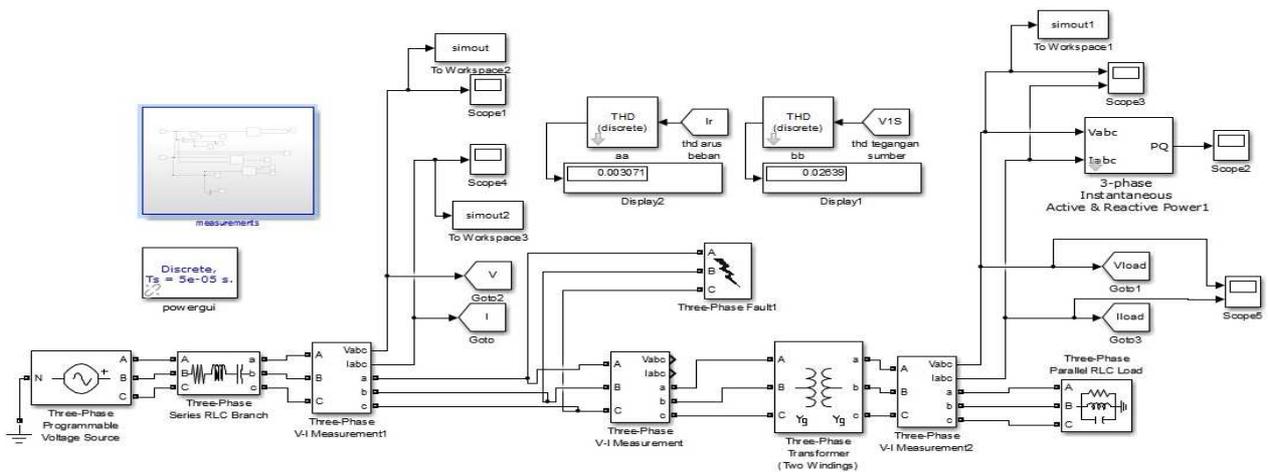


Fig. 3. Simulink diagram for disturbance generation

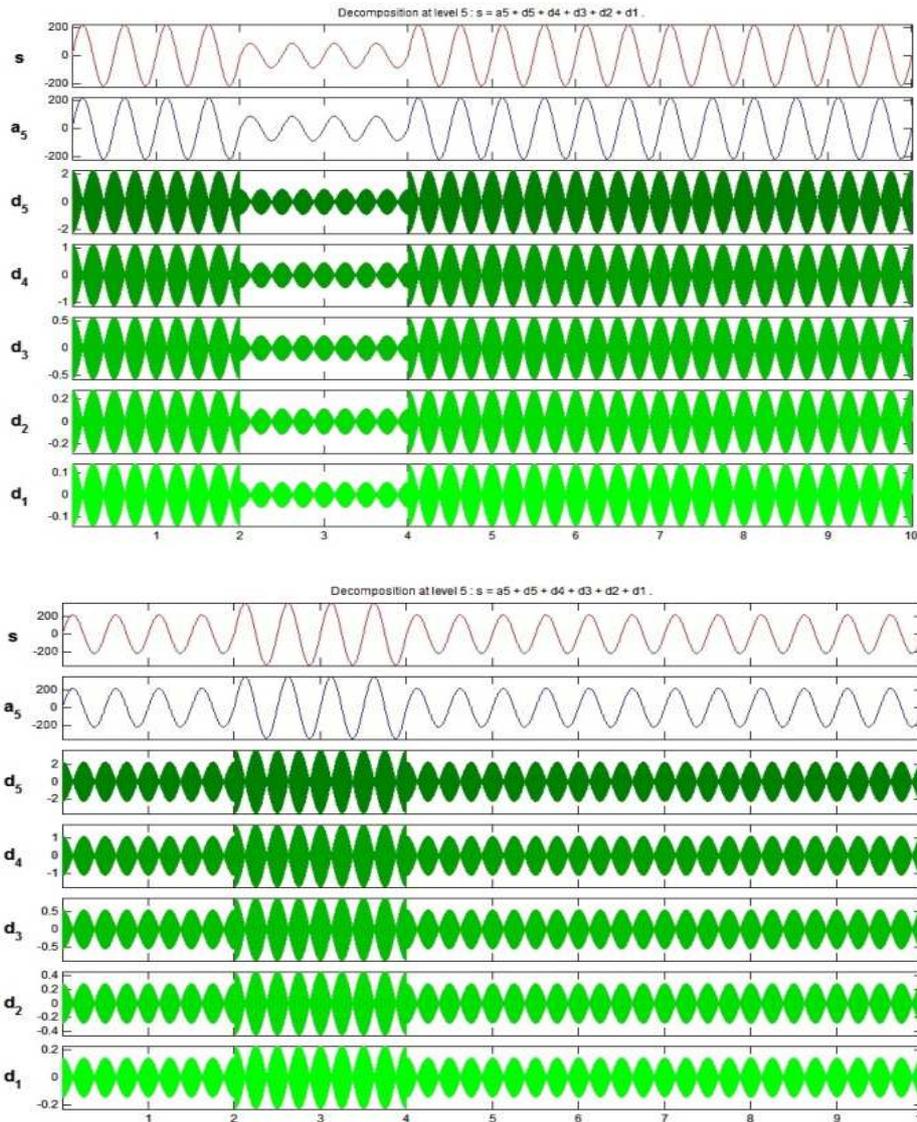


Fig. 4. Wavelet analysis of (a) voltage sag and (b) voltage swell

Support Vector Machines (SVM) are a new technique used in signal processing to separate different patterns by means of pattern recognition. It is based on statistical learning theory made by learning from the collected set of data. The problem of optimization arises in the learning stage itself and the data classification is done by SVM. It is also regarded as a supervised learning method as similar in many artificial intelligent techniques. The SVM chooses a set of samples, known as training examples for signal classification. It can classify in 2-D and also for non linear signals. SVM is regarded as the most efficient feature extraction method available so far. The classification uses Radial Basis Function (RBF) kernel and shows best result (Barros *et al.*, 2012).

The voltage sag and swell waveforms generated are analyzed using “haar wavelet”, which is re

synthesized square shaped signals. This is a particular case of the Daubechies Wavelet (D2). The haar wavelet is the simplest among all other classifications. This can be easily used in simple 2-D signals. When considering the discrete domain, discrete haar wavelets are used for synthesis. The disturbance signals are decomposed at completely at a level of 5.

The above table shows the comparison of various power quality signals using the wavelet tool. The detailed decomposition is studied and relevant classification is done. Sag and swell is generated for a 440 V input using a three phase fault. The disturbance is observed in all the three phases. Table 3 shows the summary of signal statistics, which gives an idea about the signal processing technique used for power quality classification.

Conclusion

The study of power quality became one of the emerging and major concerns for the safe use of sensitive equipments. Extreme accuracy is required in this area as a slight variation in voltage will cause heavy damage to the operating equipment. The importance of signal processing will be there in the safe and fast identification of these new signals. This paper studies the various techniques that are consistently used for the analysis of power quality disturbances. Different techniques like feature extraction, feature selection and feature classification is discussed with the help of Matlab's Simulink tool boxes. The behavior of the voltage sag and swell is discussed using the behavior and statistics of the extracted samples at different decomposition levels. The Daubechies (db) wavelet transform is effectively used for the statistical parameter coefficient estimation. The SVM reduces the number of operations required on the decomposition stage.

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Author's Contributions

Abhijith Augustine: Put forwarded the key design idea of this paper, made many studies in power quality mitigation algorithms and made the research online.

Ruban Deva Prakash: Made the research online, research guide and put forwarded the importance of signal classification and detection of a power quality fault.

Rajy Xavier: Mainly dealing with steganography and other various signal processing algorithms and made the contribution in detection and classification of various signals.

Mareeta Cheriyan Parassery: Field of interest includes power quality mitigation, harmonics detection and power factor correction and designed the mathematical model of fault.

Ethics

This work has not been published elsewhere so there are no ethical issues known to authors that may arise after the publication of this manuscript.

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