Classification of Power Quality Events - An Inclusive Review

Abstract. Power Quality is major issue that has led to large amount of research by the industry and academic experts. The increased uses of the electronics in electrical utilities have created a need of monitoring the power quality and provide the mitigation to enhance the performance of the electrical equipment. With advancement in technologies and availability of various online monitoring tools, it is very important to assess and review these technologies. The increased rate of research in this field is proven to be beneficial to the consumers. Customers are now able to request for better quality of service and making the Power Quality issue more important. This paper provide an inclusive review of various application of signal processing on power quality events, analysis of artificial intelligent techniques to classify the signals and optimization techniques for decision making. The paper also explores the upcoming opportunities for power quality classification and further improvement in terms of higher performance of the electrical equipment.

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1. Introduction
During recent years power quality (PQ) has turn out to be a most vital distress to both electric utilities and consumers. The methodology applied in categorization of power quality tended to integrate power engineering understanding primarily together with signal processing method. In recent times, several latest technologies for automatic classification such as pattern recognition, decision making, data mining and networking were integrated [1-4]. Customers are now able to request for better quality of service and making the power quality issue more important. Power quality related research started in 70’s an 80’s with more emphasis on data collection by the field service engineers and few power quality expert groups were there at that time. Generally, the change in basic parameter such as voltage, current and power were considered and were stored in tapes by physical interpretation by the power quality experts. With advancement in electronics and availability of computers and various communication protocols, the late 90’s were the year when some utility companies as well as engineering consultant started using digital signal processing at rapid rate but due to non-availability of fast processor had led to testing of power quality events in manual mode. After the year 2000, widespread increase of computers and advancement in processors, the various researchers utilized the pattern recognition, data mining and various other decisions making techniques. At same time several international and national regulatory bodies also emerged to provide the standard protocols to researchers and industrial organization. In the last decade, the advancement in monitoring, optimization and artificial intelligence lead to real-time/online monitoring of power quality events.
Even though a small amount of research is available on real-time data, a rapid increase is new real-time monitoring is seen in the last two years. The development in analysis techniques for power quality and its mitigation in the last four decades is illustrated in the given as timeline in Figure 1 [5-10].

![Figure 1 Timeline for State of art for Power Quality Technique](image)

2. Power Quality Events

Power industry is the main source for all type of manufacturing sectors, availability of clean power is essential in terms of greater performance of these industries. Power Quality (PQ) is the term which is important and largely applicable to the power sector. In most of the power sectors, it is of at most concern. In the context of PQ, it's going to be worth studying the causes for various PQ disturbances [11-15]. There are various power quality disturbances present in the power system. Supply network is the main source for these disturbances while few disturbances are due to load. Classification of short duration power quality events is given in Table 1.

**Table 1. Short Duration Power Quality Events and their Classification**

| Categories        | Typical duration | Typical voltage magnitude |
|-------------------|------------------|---------------------------|
| **PQ Variation for Short Duration**                          |                  |                           |
| Instantaneous     |                  |                           |
| 1.1 Interruption  | .5-30 cycles     | <.1pu                     |
| 1.2 Sag(dip)      | .5-30 cycles     | .1-.9pu                   |
| 1.3 Swell         | .5-30 cycles     | 1.1-1.8pu                 |
| Momentary         |                  |                           |
| 2.1 Interruption  | 30 cycles -3 sec | <.1pu                     |
| 2.2 Sag(dip)      | 30 cycles -3 sec | .1-.9pu                   |
| 2.3 Swell         | 30 cycles -3 sec | 1.1-1.4pu                 |
| Temporary         |                  |                           |
| 3.1 Interruption  | 3sec – 1 min     | <.1pu                     |
| 3.2 Sag(dip)      | 3sec – 1 min     | .1-.9pu                   |
| 3.3 Swell         | 3sec – 1 min     | 1.1-1.2pu                 |

Short duration voltage disturbances are mainly classified in three types such as temporary, momentary and instantaneous. The power quality events like voltage swells, sag, and interruption are the major reason for the poor quality. A general PQ disturbance classification scheme is shown in Figure 2.
Sag, swell, harmonics, outage are some power quality disturbances which can be generated with the parametric equation given [38]. The parametric equations are given as the standard equation used by various researchers to identify the PQ event. Some PQ events are generated with these parametric equation are given in Figures 3-8. All the power quality events generated in simulation software.
The variation of these PQ events can be generated such as swell and harmonics (shown in Figure 9), sag and harmonics (shown in Figure 10), etc.

3. Feature Extraction: Signal Processing In Power Quality

Analysis of signals is widely by utilizing the various signal processing techniques (SPT). Several techniques are available to perform the required processing on the power quality events. Feature
extraction is the most prominent task involved in Power quality. All the power quality events possess some feature which differentiates it from other power quality events. SPT are used to take out the various important features from the power quality event [16-17]. After features are extracted the signal or power quality event can be classified. Various approaches are available for feature extraction from power quality events. The power system utilizes the estimation of the time-varying and non-periodic variations. DFT [18-19] and STFT are used in frequency domains for stationary/periodic signals. STFT faces difficulties for the analysis harmonic distortion because of non-stationary properties of harmonic distortion.

Wavelet transform (WT) [20-23] is used by various researchers to prevail over the abnormalities of STFT. By using wavelet transform with good localization characteristics of signals can be extracted so features were extracted via wavelet transform and these features were used in second stage called classification stage (using multi-layer perceptron) and the combination of both stages was named as wavelet neural network (WNN). The results discussed by author are applicable to limited PQ disturbances with 95.71% accuracy and overall computational time can be limited by using other neural network structure.

Author had proposed a method in which short duration disturbances were classified by using the S-transform and maximum similarity condition which is used in DSP and image processing [24-25]. Some author proposed idea was to classify whether the sag had originated in High Voltage (HV) or Medium Voltage (MV) to take the appropriate action, overall the database was constructed and model had created for HV and MV and finally model was exploited for classification. The average classification rate for substation A and B were 93% and 91% respectively. Furthermore classification was done with linear classifier only but several other non-linear classifiers can be implemented for improvement of the classification rate [26].

Multiwavelet transform [27] is used as the feature extractor and classification is done with K-nearest neighbour classifier. The advantage of using Multiwavelet is that it has more function such scaling and wavelet as compared to general WT. Hilbert transform [28] can also be used for PQ assessment. Some techniques like Sliding-Window ESPRIT methods [29] are used in various research articles. Time-Time transforms [30] and HOS method [31] is also implemented to analyse the PQ.

Hyperbolic S-transform [32], Kalman filtering [33], multi-way principal component analysis (MW-PCA) [34], Adaline method [35], are also used in the past years. In this paper [36], the rationale was to introduce different electrical power quality parameters and is stored in the database. A multi-lingual PQ database with query handler was provided to user which is called as visual user interface. Also NL (Natural language) based interface was rendered for more comfort of the user. They furnished query processing for English of Turkish. The overall paper reading suggested that power quality monitoring was essential and can be done now in natural language.

4. Power Quality Event Classification and Optimization Techniques

Artificial intelligence (AI) is related to somewhat human do, for example critical thinking, analysis of problems and their solution, learning new aspect, making approximate decision with prior knowledge and updating knowledge by visual cues, perception and elaborated logical reasoning. Some AI tools which are generally used in industrial as well as research are: fuzzy logic [37-39], adaptive fuzzy logic, ANN, expert system and genetic algorithm (GA)[40-43] as optimization tool, and particle swarm optimization (PSO) [44], etc. A fuzzy expert system has two key elements [45]: fuzzy sets and fuzzy rule base.
Neural networks [46-50] are mapping of the information as our brain do and to provide a better understanding of the information retrieved from the system. In general, neural networks are used for matching of patterns, classification of events, approximation of various functions, data clustering and their optimization. Support Vector Machine (SVM) is generalized tool for solving problems related to classification of patterns [51]. In this paper author proposed method which said that “how the features are extracted & how they are useful for a specific classifier”. Author had generated the PQ events via experimental system setup, further he constructed the feature vector. Various feature selection methods were employed for feature vector construction. The feature vector obtained were the input to the two classifier i.e., Baye’s classifier and SVM classifier.

5. Conclusion and Future Scope
The inclusive survey done for various power quality events and the technologies used to perform various task such as feature extraction, classification and decision making are elaborated. The various researchers have carried out several analyses to extract the various features from the power quality events. Novel algorithms are proposed by the researchers to encounter the noisy data due to several conditions. Identification of the on-going power quality event is very important in analysis of power quality. A large number of research paper are available in the field of power quality, this is due to need of clean power for the various electronic components used in the industry as well as household equipment. From the literature available, it is clear that most of the techniques are employed on simulated power quality events and few have worked on real-time power quality disturbances.

It can be concluded from the above analysis that real time event identification is of more concern and require more deliberate efforts from the researchers to solve the online power quality disturbances. The future scope is to work on the real time power quality identification techniques with emphasis on handling several events at a time. These require faster processing and classification at rapid rate. With rapid advancement in AI based application, PQ events can be monitored and their online identification can be done. The large amount of data is generated while researching on the identification of power quality events, therefore, data analytics with more emphasis on online data handling is required. Several new software as well as industrial standard smart sensor is also available for collection of online or real time data.

6. References

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