LOW COST AND EFFICIENT POWER QUALITY ANALYZER FOR SMALL SCALE INDUSTRIES IN SOUTH INDIA

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***Abstract* -Recently power quality (PQ) has become one of the major issues for residential and industries sectors in south India. To improve power quality, detecting the particular type of disturbance is the foremost thing .So monitoring is needed to detect the power quality disturbance that occurs in a short duration of time. In this paper a power quality analyzer setup is designed using a Arduino microcontroller to capture the real time power quality disturbances that occur in a single phase power system, especially it is used to collect sample of signals across single phase industrial loads from different small scale industries. The samples are stored in the computer, then features are extracted and given as input to classifiers .Support vector machine (SVM) is identified as the most suitable classifier and performance istested using generated samples like normal, sag, swell, interruption, harmonics and transient signals, Finally the PQ analyzer is implemented for real time signals taken from small scale industries. It is observed that this arrangement is of low cost and useful to small scale industries in rural areas .The performance is compared with other feed forward neural network (FFNN) classifier. This proposed method would enhance the detection of PQ distortions in commercial and domestic applications, also provides a faster operation with less cost.**

***Index Terms*— Power quality; Arduino microcontroller; Support vector machine(SVM); Feed forward neural network (FFNN);Total harmonic distortion(THD)**

I. INTRODUCTION

Power quality is becoming an important issue nowadays in domestic and industrial fields. Even in small industries sensitive loads like personal computers, servers, UPS, and distortions due to power electronic devices, adjustable speed drives, microprocessors, logic controllers, switched mode power supplies and Energy efficient lightings cause severe problems to other equipments present in the industry, hence monitoring of power quality is more essential [1]. Accor to the Electrical power research Institute (EPRI) survey $15 billion to $24 billion is losing in US economy due to PQ disturbances [2].The magnitudes and time limits of voltage and current signals are enlisted in IEEE standard 1159-2009[3].Assessment of power quality issues and correction methods are discussed in [4], but the remedy for harmonics is only considered. Different techniques such as short time Fourier transform (STFT), Wavelet Transform (WT),S-transform to detect and classify PQ disturbances is discussed in [5].different features can be extracted from the wavelet coefficients, but selecting the best feature from approximation and detailed coefficients is the key part for further classification Also computational burden represented by the wavelet transform led to the development of a new and simpler detection method .A conjugate gradient back-propagation based artificial neural network for real time power quality assessment is proposed in [6].however voltage sag and swell signals are only sensed using data acquisition system. Detection and classification of power quality disturbance in the power system using radial basis function neural network (RBFNN) in noisy conditions is proposed in [7] still the computational time is more due to training of neural network. In [8] the recommended value limits and power quality indices are mentioned for induction motors operating at different temperature coefficients. A wavelet based detection and faster discrimination of PQ disturbances is proposed in [9] still the voltage events are the only outcome .In [10] a DSP based PQ Analyzer which made the improvement in the detection part, also the number of undetectable events are reduced significantly. A measuring instrument for real time detection and classification using wavelet is proposed in [12] the algorithm can able to process the continuous stream of data. In [13] Energy difference multi resolution analysis (EDMRA) for detection, localization and classification of different types of PQ disturbances, but it concentrates only on noisy environment. The method proposed in [15] can able to detect real time values and waveforms of RMS value, THD values .plots and waveforms of three phase measurements. however authors have generated PQ problems using MATLAB simulation and analyzed using different transforms and classifiers. When it is executed for real time distortions taking place in industries the methodology may fail. So in our proposed work a real time power quality Analyzer that is used to detect and discriminate the type of disturbance is implemented. Some other recent literature were studied regarding power quality and protection techniques [18- 35].

Few power quality Analyzers and Power Recorders such as Fluke 1750, Fluke 43etc. and power analysing software are available commercially to monitor power quality disturbances, but they are highly expensive .Most of the small scale industries avoid such Analyzers and neglect the importance of monitoring also. But this proposed system will encourage and support the small scale industries using this low cost power quality Analyzer. This system can be implemented easily in all industries .In this paper, a real time based model using Adruino microcontroller is presented to collect the sufficient data from various motor loads and industrial appliances This experimental setup is interfaced with computer to store all data in the database for further process. Features are extracted and Support vector machine has been applied to classify the type of disturbances. The classification accuracy is validated by comparing with Back propagation neural network, Feed forward Artificial Neural network (FFNN). The paper is organized in five sections: section II describes the proposed methodology, SVM based classification with algorithm is presented in section III. section IV explains the Real time measurement setup and its operation based on the model. The classification results and performance analysis are discussed in section V.

II. PROPOSED METHOD

For the implementation of the proposed methodology in real time industrial applications, the schematic block diagram of proposed power quality Analyzer is shown in fig 1. The experimental setup is used to collect PQ samples from various loads like Induction motors, Personal computers, switching mode power supplies, servers, UPS, capacitor banks, choke, fans, compressors, pumps and other industrial appliances.

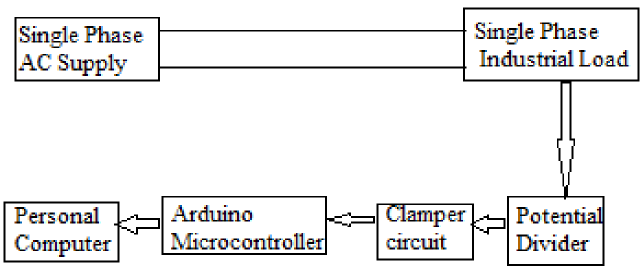


Fig 1. Schematic diagram of proposed power quality Analyzer

A 230 V single phase ac supply given to single phase Industrial loads is measured using a potential divider across the load terminals. It step down the voltage to 5 volt. Arduino microcontroller cannot accept the signals in the negative range. So a clamper circuit is designed which is able to raise the entire waveform above the zero crossing. This output is given to analog port of microcontroller. A serial communication is established between microcontroller and personal computer. The data stored in computer is utilized for further processing

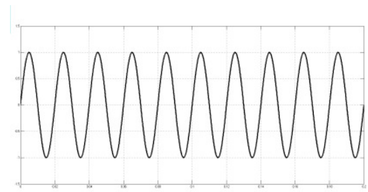
Initially power quality disturbances are generated using parametric equations shown in Table 1 named as pure sinusoid ,pure sag, pure swell, Interruption, harmonics and transient .The control parameters used in the modelling are given in Table 2.About 200 samples are generated and database is stored. Few signal examples are shown in fig 2

Table 1Power quality disturbance model

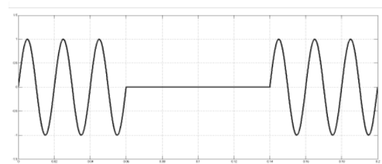
Event	*Parametric Equations*
Pure sinusoid	$V(t)=Vm \sin(\omega t)$
Pure sag	$V(t)=A(1-\alpha(u(t-t_1)-u(t-t_2)))\sin(\omega t)$
Pure swell	$V(t)=A(1+\alpha(u(t-t_1)-u(t-t_2)))\sin(\omega t)$
Harmonics	$V(t)=A(\alpha_1 \sin(\omega t)+\alpha_3 \sin(3\omega t)+ \alpha_5 \sin(5\omega t)$
Interruption	$V(t)=A(1-\alpha(u(t-t_1)-u(t-t_2)))\sin(\omega t)$
Transient	$V(t)=(1+\alpha_1\sin(\beta\omega t))\sin(\omega t)$

Table 2 Parameters used in modelling

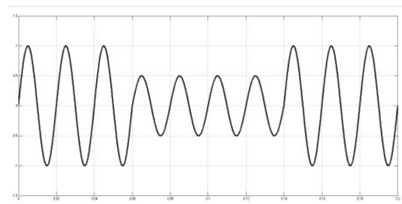
Event	*Parameters*
Pure sinusoid	Amplitude(A)=1;frequency=50Hz
Pure sag	t_1=0.06; t_2=0.14;α=0.5;
Pure swell	t_1=0.06; t_2=0.14;α=1.5;
Harmonics	A=1;frequency=50-150Hz;order:2,3,4
Interruption	t_1=0.06; t_2=0.14;α<0.1;
Transient	A=1;frequency=50Hz;α_1=0.1-0.2;β=0.05



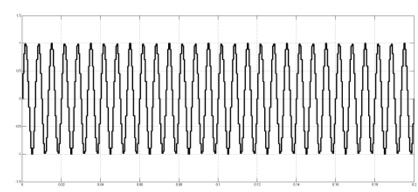
(a)



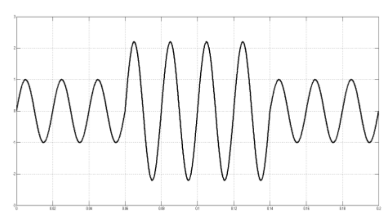
(b)



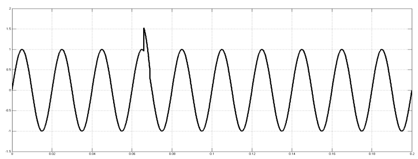
(c)



(d)



(e)



(f)

Fig 2 (a) Pure sinusoid (b) Interruption (c) Pure sag (d) Harmonics (e) Pure swell (f) Transient

A, *Feature Extraction*

Wavelet Transform (WT) is widely used for analyzing non stationary signals when compared to other spectral analysis methods. If continuous wavelet transform(CWT) is used calculating the wavelet coefficients is time consuming, hence Discrete wavelet transform(DWT) is employed to obtain the wavelet and scaling function

Wavelet function $\psi(k) = \sqrt{2}\sum g(n)\ \varphi(2k-1)$ (1)

Scaling function $\varphi(k) = \sqrt{2}\sum h(n)\ \varphi(2k-1)$ (2)

The different types of wavelet functions are Haar, Morlet ,Coiflet, Symlet and Daubechies wavelets .Among the types Daubechies wavelet is more suitable for many applications, because the decomposition level can be controlled according to the power quality application also the tolerance under noisy condition is good.. In multi resolution analysis decomposition the original signal is decomposed into many signals with different levels of resolution. The detailed and approximation coefficients obtained through wavelet decomposition cannot be used directly in classification stage because the features are dimensionally large also cause computational burden. In order to reduce the large dimensional features few feature extractors are available such as mean, standard deviation, RMS value, Entropy, Skewness, Kurtosis, Energy and Form factor. Instead of using all the above feature extractors, the best suitable feature can be identified. Such a way the energy distribution can be estimated. Since Energy distribution is better for voltage events it is implemented in our application.

B, Feature Selection

Feature selection is needed in order to reduce the size of features used for classification .the accuracy of classification depends on the feature selection also it has a considerable effect on reducing the computation time .there are three categories of feature selection (i) Filtering approach (ii) Wrapper approach (iii)Embedded approach. In filtering approach, the feature selection is not based on interclass seperability. In Wrapper approach, feature selection is based on any learning algorithm. Both the approaches are combined in the third embedded approach. Again the feature selection approaches are classified into five methods

- Forward selection
- Backward elimination
- Forward stepwise selection
- Backward stepwise elimination
- Random mutation

K-means based Apriori algorithm used for feature selection is proposed in [18] in which features is selected based on the association among the features k-means clustering make the data ready for processing by Apriori algorithm. A sequential forward selection technique (SFS) is proposed in [19].a robust and adequate features are obtained using this method of feature selection.

C. Classification

In classification stage, the selected features are given as input to SVM classifier, the output of classifier mainly depends on the features, and if features of a particular type of disturbance are not unique the classifier cannot discriminate the type of disturbance. Multiclass SVM is needed for classifying more than two variables, it can be obtained by combining two class SVM's. For validation of the proposed scheme the same features are given as input to neural network classifiers also. Among the different architectures like feed forward neural network (FFNN), Multilayer perceptron (MLP) and Back propagation neural network (BPNN) FFNN is chosen. Thus comparison between SVM and FFNN classifiers is made for analysis. The flow chart for SVM classifier is given in figure 3.

III CLASSIFICATION USING SVM

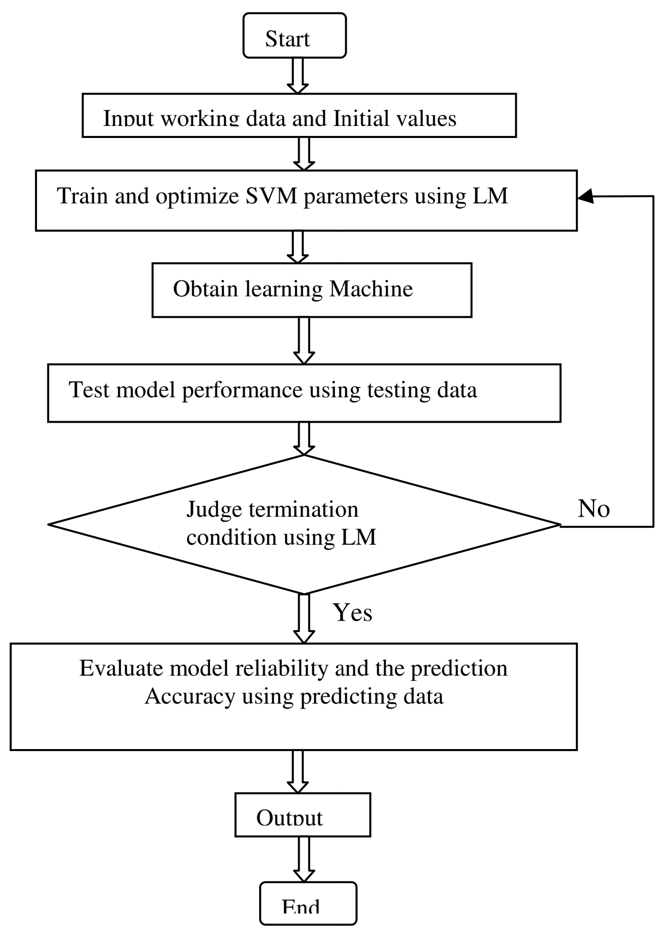


Fig.3 Algorithm of SVM Classifier

IV. REAL TIME TESTING USING PQ ANALYZER

An Adriano meter based experimental setup was designed to collect the real time power quality disturbance data. This arrangement consists of hardware components like

A.Arduino microcontroller

B, Potential divider

C. Clamper circuit

D. Personal computer

E. Interfacing cards and Multimeters

Different types of waveform distortions are created by connecting to an Induction motor, chopper circuit and switching capacitors. Voltage sag is measured during the starting time of Induction motor and voltage swell is measured during switching OFF the load. Flicker is produced by connecting a choke between load and the measuring system .Similarly Transient signal is generated by connecting a switching capacitor between Induction motor and the load. Harmonic signal can be obtained by connecting nonlinear devices across the load and measuring the voltage across it.

A. Arduino Microcontroller

In our experimental setup Arduino MEGA2560 microcontroller is used .This MEGA2560 is can designed for many complex projects. Arduino board is programmed with Arduino software(IDE).It allow us to upload new coding without any external hardware programmer. The data can be transmitted via USB connection to the computer.

Table 3 Specifications of Hardware setup

Microcontroller	AT mega 2560
Digital I/O pins	**54**
Analog inputs	16
Serial ports	4
Memory	256 KB
Operating voltage	5V
Input voltage (recom)	5-12V
Input voltage (limit)	6-20V
DC current per pin	20 mA
DC current for 3.3 pin	50 mA
Clock frequency	16 MHz

B. Clamping circuit

A clamping circuit helps to place the positive peak or negative peak of a signal at a desired level. It is also referred as ac signal level shifter. When the signal is pushed upward by the circuit the negative peak of the signal coincide with the zero level

At least three components are needed to design the clamping circuit, such as diode, capacitor and resistor. The diode conducts current in only one direction and prevents the signal exceeding the reference value. Capacitor provides DC offset from the stored charge and form a time constant with resistor load.

C. Potential Divider

Potential divider or voltage divider is a passive linear circuit that produces an output voltage V_0 that is the fraction of the input voltage V_i. It distributes the input voltage among the components. It is commonly used to reduce the magnitude of a voltage also used as signal attenuator.

$$Vout = \frac{Z2}{Z1+Z2} Vin \quad (3)$$

$$\frac{Vout}{Vin} = Z2/(Z1+Z2) \quad (4)$$

D.Interfacing cards and multimeters

Interfacing cards are used to connect Arduino microcontroller along with personal computer and multimeters are used to measure the analog voltage signals,

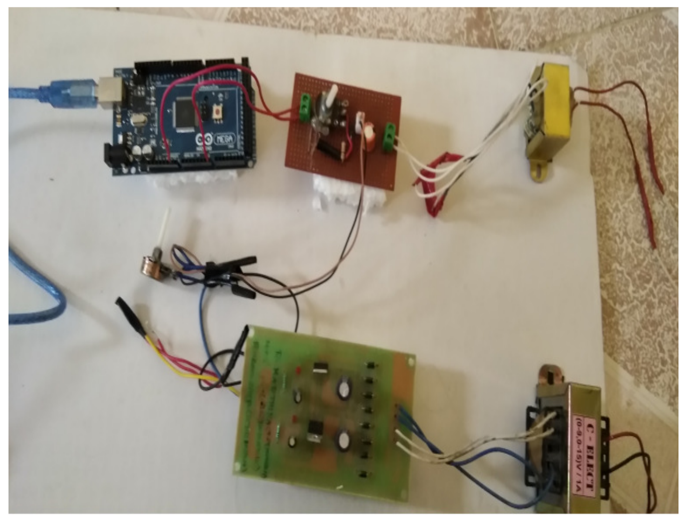


Figure 4 Hardware arrangement of low cost PQ Analyzer

The real time signals are collected from small scale industries using our low cost PQ analyzer, to detect and analyze the type of PQ disturbances .Few samples taken from industry across single phase ac supply, capacitive loads, Inductive loads, SMPS and computer loads are shown in fig 5.The Fast Fourier transform (FFT) is applied to analyze the harmonic distortion and to find the Total Harmonic Distortion (THD) value. Thus the PQ analyzer is not alone detecting the PQ disturbance but also used to find the THD value if a harmonic distortion occurs.

Similarly lot of real time signals are taken using our hardware arrangement is stored in the computer database then the waveforms are reconstructed, based on the features, classifier will detect the type of disturbances. If harmonics is identified, immediately FFT analyzer tool is executed in MATLAB to find the THD value thus finding the severity of harmonics, if not harmonics, it search for the other type of disturbance .Thus the algorithm of PQ analyzer is effectively supporting the person who wishes to analyze the power quality in industries.

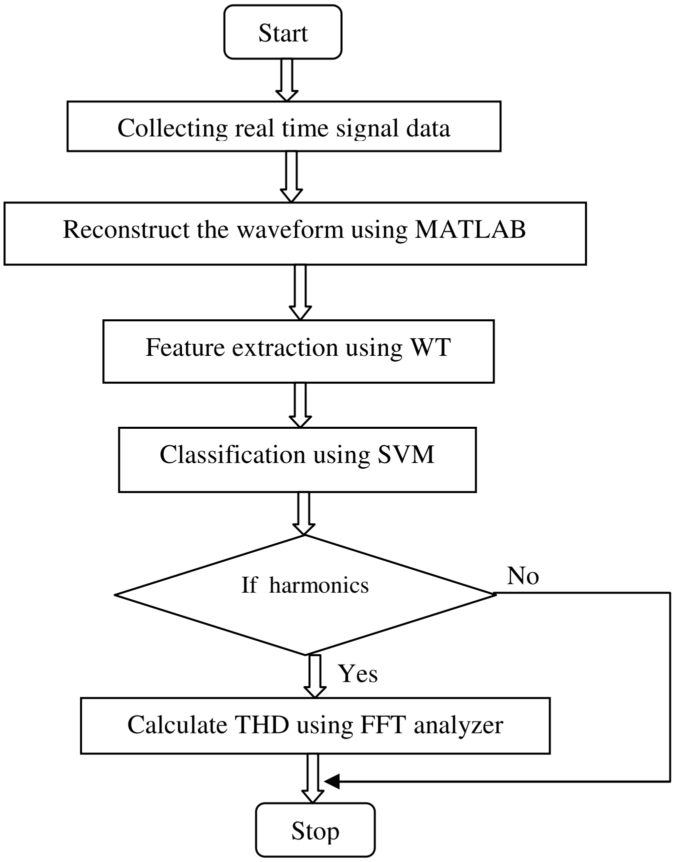


Fig 4 Flow chart of Real time PQ analyzer

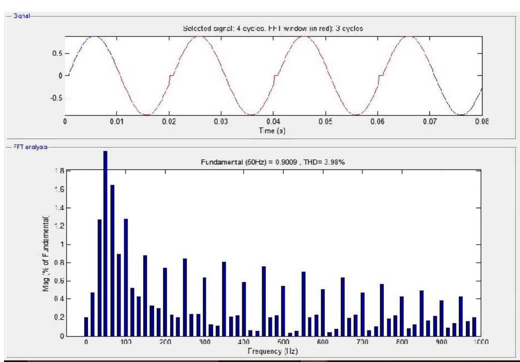


Fig 5(a) Real time signal using PQ analyzer

(ac supply without load)

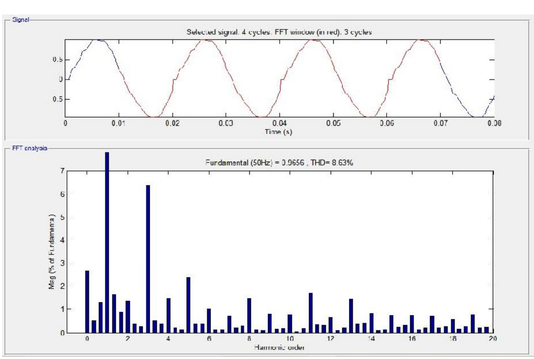


Fig 5(b) Real time signal using PQ analyzer

(Capacitive load)

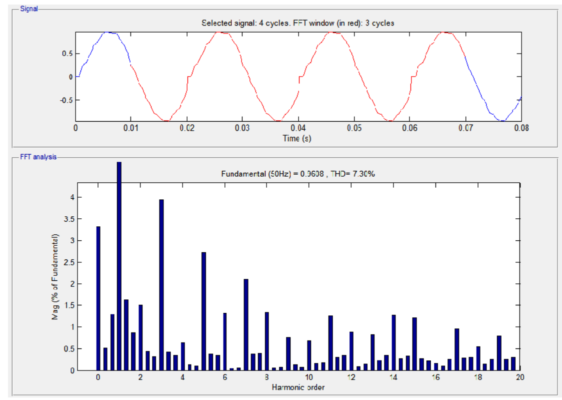


Fig 5 (c) Real time signal using PQ analyzer

(Induction motor load)

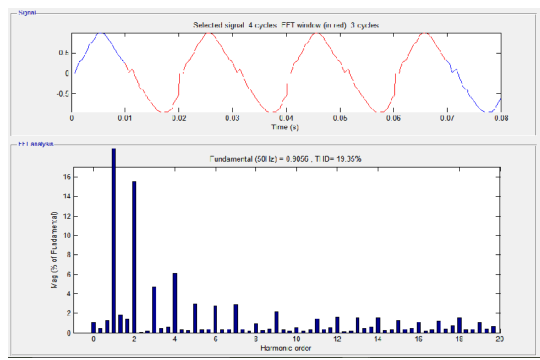


Fig 5 (d) Real time signal using PQ analyzer

(Computer with SMPS load)

Few sample of real time signals obtained using our hardware arrangement in a small industry is shown in figure 5.In 5(a) about 3000 samples are taken for a time duration of 5 sec in a 230 V ac supply without connecting any load .In 5(b) samples are taken across a capacitor bank consists of 25 capacitors used for power factor correction. In 5(c) samples are taken across the terminals of single phase induction motor (8 HP) used for grinding. In 5(d) eight numbers of computers with Switched mode power supply (SMPS) are connected in parallel and signal is captured using our low cost PQ analyzer. The signals are reconstructed in Mat Lab and FFT analyzing tool is applied to measure the harmonic distortion .It gives the THD value in percentage, the type of industrial load and THD values are tabulated in the Table 4.

Table 4 Output of FFT THD analyzer

Type of Industrial load	THD value (%)
AC supply (without load)	3.98
Capacitive loads(cap banks)	7.30
Induction motors (8 HP)	11.84
Personal computer (8 no's)	19.35

V. RESULTS AND PERFORMANCE ANALYSIS

The features obtained using wavelet and extractors like mean, standard deviation ,skewness, kurtosis and entropy are applied to the SVM classifier .Among those features extracted 50% are given to train the learning algorithm and remaining 50% are given as target. when test samples are given as input to the classifier it gives the desired output, A sample confusion matrix which gives the classification results with mean features and SVM classifier is shown in the Fig 6 The classification results using other features are tabulated in Table 5 .Comparing the results with ANN based classifier SVM classifier gives better results compared to other methods. The confusion matrix shows the accuracy of SVM classifier that can be noticed from the diagonal elements of the matrix given in figure 6.

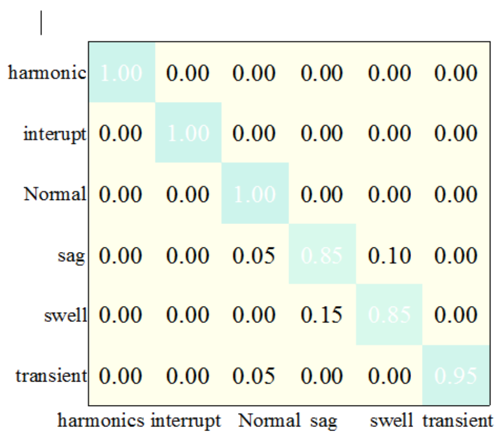


Fig 6 Confusion matrix of SVM classifier

Table 5 Classification results using SVM

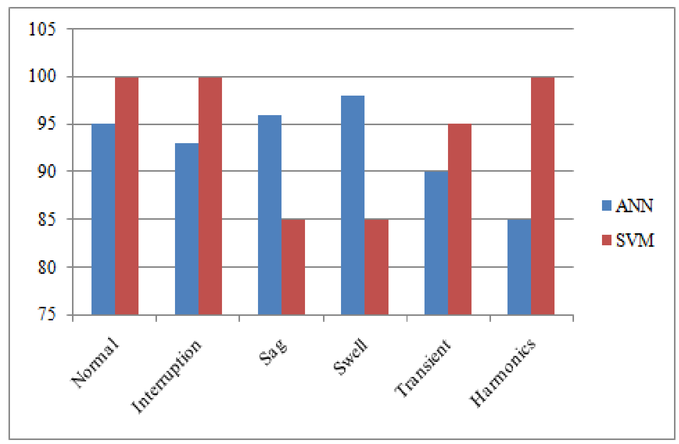
PQ disturbances	Mean	Standard Deviation	Skewness	Kurtosis	Entropy
Normal	100	100	100	100	80
Interruption	100	100	100	100	100
Sag	85	85	100	100	100
Swell	85	75	100	100	100
Transient	95	100	80	90	100
Harmonics	100	100	100	100	100
Accuracy (%)	94.16	93.33	96.66	98.33	96.66

The classification results is compared with ANN classifier and the results are validated which is shown in Table 6.which reveals both classifiers are showing a constant performance .Still SVM is ahead of ANN based classifier

Table 6 Comparison between ANN and SVM classifier

PQ disturbances	Classification accuracy (%)	
	ANN	SVM
Normal	95	100
Interruption	93	100
Sag	96	85
Swell	98	85
Transient	90	95
Harmonics	85	100
Overall (%)	92.83	94.16

Figure 7 Performance comparison of SVM and ANN



VI. CONCLUSION

This paper presented a methodology to detect and classify various power quality disturbances using the low cost power quality analyzer in small scale industries in southern parts of India. Wavelet combined with SVM classifier approach is classifying the PQ disturbances accurately those are considered in this paper. This result will be useful for further mitigation of disturbance signal. THD values obtained using FFT analyzer is used to indicate the severity of harmonic signal. It can be expanded to classify the type of harmonics, inter harmonics etc .Experimental real time setup proves a better choice for small scale industries which are finding difficult in purchasing high cost power quality analyzer, also they can easily analyze the data or signal in often. The comparisons of classifying accuracies indicate the proposed approach is challenging with other classifying methods. Large number of sample data is utilized to check the computation speed.

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