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Analysis of Power Quality Disturbances Using Wavelet and S-Transformation Techniques

Pendyala Ravindar
M.E (Power Systems),
ravindar1203@gmail.com

Naveen Kumar D
M.Tech (Power Systems)
navinmudiraj@gmail.com

Gajjeli Rajesh
M.E (Power Systems),
rajeshinou@gmail.com

ABSTRACT:
Power quality issues have been a source of major concern in recent years due to extensive use of power electronic devices and non-linear loads in electrical power system and consequently sensitive detection and accurate classification of power disturbances have become very much necessary. To monitor various power quality problems different analysis techniques are available like Fourier transform, short-time Fourier transform, and wavelet transform. Every analysis technique has its own advantage and disadvantage. To overcome disadvantages a new method S-Transform has been proposed in this project work for detection and classification of power quality disturbance signals.

S-transform provides frequency dependent resolution that simultaneously localizes the real and imaginary spectra. The S-Transform is similar to wavelet transform but with a phase correction. This property is used to obtain useful features of the non-stationary signals that make the pattern recognition much simpler in comparison to the wavelet analysis. Features obtained from S-transform are distinct and understandable. According to rule based decision tree, five disturbance and two complex power disturbances are well recognized and classified. Various power quality disturbances are obtained by experimental work and they are analyzed by S-Transform analysis. Degree of sag and swell for power quality problems like sag, swell also calculated by using S-Transform respectively.

I. INTRODUCTION:
In an ideal ac power system, energy is supplied at a single constant frequency and specified voltage levels of constant magnitudes. However, this situation is difficult to achieve in practice. The undesirable deviation from a perfect sinusoidal waveform (variations in the magnitude and/or the frequency) is generally expressed in terms of power quality. The power quality is an umbrella concept for many individual types of power system disturbances such as harmonic distortion, transients, voltage variations, voltage flicker, etc. Of al1 power line disturbances, harmonics are probably the most degenerative condition to power quality because of being a steady state condition. The power quality problems resulting from harmonics have been getting more and more attention by researchers.

Due to the advantages in technology and the increasing growing of industrial/commercial facilities in regions power quality has been a major concern among industries. Although many industries have currently taken certain measurements to cope with this problems but it is only a short-term basis. Thus in order to maintain the consistent standard of power quality in the near feature with the increasing number of industries and commercial facilities; it would be extremely urgent and tackle the power quality challenges. It should be noted that power quality problems often emerged without any warning signs, which will result in great profit loss to the industries. This is then lead to time wasted while trying to solve the problems. However, certain appropriate measures can be taken to protect the affected equipment or to raise the quality of power supply.

II. POWER QUALITY ANALYSIS USING S-TRANSFORM

S-Transform

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The S-transform is a time-frequency representation known for its local spectral phase properties. A key feature of the S-transform is that it uniquely combines a frequency dependent resolution of the time-frequency space and absolutely referenced local phase information. This allows one to define the meaning of phase in a local spectrum setting, and results in many desirable characteristics. One drawback to the S-transform is the redundant representation of the time-frequency space and the consumption of computing resources this requires (a characteristic it shares with the continuous wavelet transform, the short time Fourier transform, and Cohen's class of generalized time-frequency distributions). The cost of this redundancy is amplified in multidimensional applications as image analysis.

Need For S-Transform Approach:

What distinguishes the S-transform from the many time-frequency representations available is that the S-transform uniquely combines progressive resolution with absolutely referenced phase information. Daubechies has stated that progressive resolution gives a fundamentally more sound time frequency representation. Absolutely referenced phase means that the phase information given by the S-transform is always referenced to time t = 0, which is also true for the phase given by the Fourier transform. This is true for each S-transform sample of the time-frequency space. This is in contrast to a wavelet approach, where the phase of the wavelet transform is relative to the center (in time) of the analyzing wavelet. Thus as the wavelet translates, the reference point of the phase translates. This is called "locally referenced phase" to distinguish it from the phase properties of the S-transform. From one point of view, local spectral analysis is a generalization of the global Fourier spectrum.

In summary, the S-transform has the following unique properties:

- It uniquely combines frequency dependent resolution with absolutely reference phase, and therefore the time average the S-transform equals the Fourier spectrum.
- It simultaneously estimates the local amplitude spectrum and the local phase spectrum, whereas a wavelet approach is only capable of probing the local amplitude/power spectrum.
- It independently probes the positive frequency spectrum and the negative frequency spectrum, whereas many wavelet approaches are incapable of being applied to a complex time series.
- It is sampled at the discrete Fourier transform frequencies unlike the CWT where the sampling is arbitrary.
- Because of the absolutely referenced phase of the S-transform, it is possible to define a channel instantaneous frequency function for each voice.

III. ARTIFICIAL NEURAL NETWORK(ANN)

The neural network was inspired by its inception by the recognition that the human brain computes differently than that of a conventional digital computer. The brain acts as a highly complex, non-linear and parallel computer. A neural network is a massively parallel-distributed processor made up of simple processing units, is known as neurons, which has a propensity for storing, and making easily available, experimental knowledge.

It resembles the human brain in two aspects:

1) Knowledge is acquired by the network from its environment through learning process.

2) Inter-neuron connection strengths, known as synaptic weighs, are used to store the acquired knowledge.

The procedure used to set the connection strengths is called learning, the function of which is to modify the synaptic weights of the network in an orderly fashion to attain a desired design objective.

A neural network derives its computing power through its massively parallel-distributed structure and its ability to learn and therefore generalize. Generalization refers to the neural network producing reasonable outputs for inputs not encountered during training (learning).These two information-processing capabilities make it possible for neural networks to solve complex problems..

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Properties of Neural Network

Non-linearity:

A neural network, made up of an inter connection of nonlinear neurons nonlinear. Moreover nonlinearity is of a special kind in the sense that it is distributed throughout the network. Most real systems, including power systems are nonlinear, so this property is very desirable for its applications in power systems

Input-Output Mapping:

A popular paradigm of learning called learning with a teacher or supervised learning involves modification of synaptic weights of a neural network by applying a set of labeled training samples or task samples. Each example consists of a unique input signal and a corresponding desired response. The network learns from the examples by constructing an input-output mapping for the problem.

Adaptivity:

Neural Networks have a built-in capability to adapt their synaptic weights to changes in the surrounding environment. In particular, a neural network trained to operate in a specific environment can be easily retrained to deal with minor changes in operating environmental conditions. Moreover, when it is operating in a non-stationary environment, a neural network can be designed to change its synaptic weights in real time.

Neural network structures:

Structure of an ANN can be classified into 3 groups as per the arrangement of neurons and connection patterns of the layers:

1. Feed-forward
2. Feedback
3. Self-organizing.

Also neural networks can be roughly categorized into two types in terms of their learning features:
1. Supervised learning algorithms, where networks learn to fit known inputs to known outputs.
2. Unsupervised learning algorithm, where no desired output to a set of input is defined.

The classification is not unique and different research groups make different classifications. The feed-forward neural network consists of three or more layers of nodes: one input layer, one output layer and one or more hidden layers. The input vector x passed to the network is directly passed to the node activation output of input layer without any computation. One or more hidden layers of nodes between input and output layer provide additional computations. Then the output layer generates the mapping output vector z. Each of the hidden and output layers has a set of connections, with a corresponding strength-weight, between itself and each node of preceding layer. Such network structure of a network is called a Multi-Layer Perceptron.

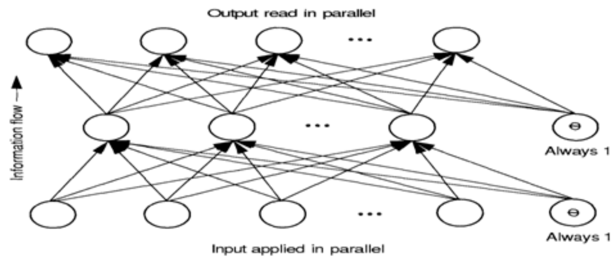

Fig 1: Feed Forward Neural Network

Multilayer perceptron's are the best known and most widely used kind of neural network. Networks with interconnections that do not form any loops are called feed forward. Recurrent or non-feed forward networks in which there are one or more loops of interconnections are used for some kinds of applications. The units are organized in a way that defines the network architecture.
In feed forward networks, units are often arranged in layers: an input layer, one or more hidden layers and an output layer.

IV. WAVELET TRANSFORM AND S-TRANSFORM ANALYSIS OF PQ DISTURBANCES

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This chapter will discuss about the wavelet transform analysis of the power quality disturbances, a distribution network for the generation of power quality disturbances will be presented .Wavelet transform will be applied to the generated disturbances for investigation of standard deviations of all the detailed coefficients, these standard deviations are given as inputs to the neural networks in the next chapter.

Simulation and wavelet-Transform analysis of Power quality disturbances

To simulate various power quality disturbances a simple distribution network consisting of various three-phase loads and non-linear loads has been developed. In which generated voltage at 25kvand three buses are considered for sag, swell, harmonics measurement. Voltage sag generated by the use of three phase fault, swell generated by three phase circuit breaker operated capacitive load. For the harmonics generation a non-linear load in the sub system is taken, here the non-linear load is three-phase rectifier fed the resistive load. A transformer is used to step down the 25kv into 208V for generation of harmonics, a synchronous pulse generator used as pulse source for the three-phase rectifier.

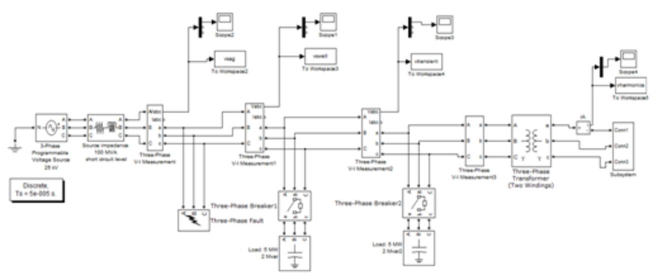

Fig 2: Distribution network considered for Analysis

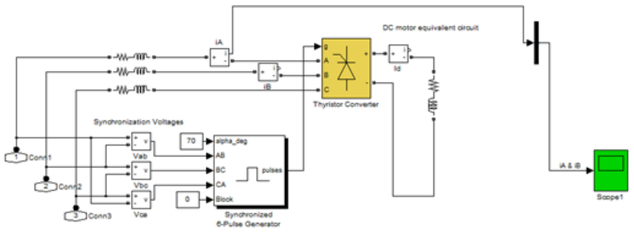

Fig 3: subsystem representing non-linear load

Power quality disturbance signals are generated in matlab/simulink using the circuits shown in fig 2 and fig 3. Sag signal is generated by the fault shown at bus1 of the distribution network, Voltage swell is created by the capacitive load connected through the three phase circuit breaker and harmonics are generated with the use of the non-linear load. Distribution network consists of three phase loads and one non-linear load. Various power quality disturbances like sag, swell, interruption, harmonics, transients, harmonics with sag, and swell have been simulated. By creating three phase fault for certain duration sag has been observed in network over time of five cycles. Similarly by switching a capacitor for five cycles into the network swell has been observed .Transient has created by the switching of large capacitor load for a small amount of time, Because of nonlinear loads harmonics in source current has been observed. Simulation particulars: Total simulation time=1 sec,No of cycles observed=50

Wavelets Transform Analysis of Sag:

By creating fault between three phase fault between the instants 0.2sec and 0.6sec the voltage waveform will dip to the extent 80% or 90% of its original value based on the fault severity. On changing the fault resistance we will get the different voltage sag waveform. Voltage sags can be created not only with the three phase fault but also with the L-G,L-L,L-L-L based on the requirement. The fault transition times can be changed internally in the fault block.fig 6.3 shows the fault with 20%sag level.

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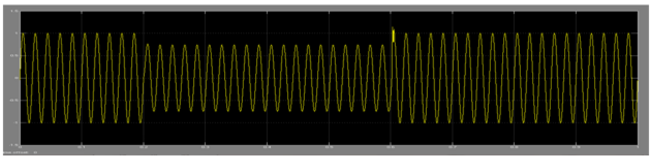

Fig 4:voltage sag waveform with 20%sag and transition times between 0.2to0.6sec

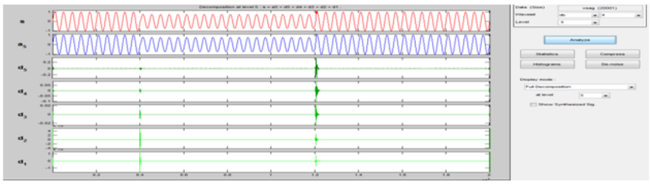

Fig 5: Wavelet analysis of voltage sag waveform

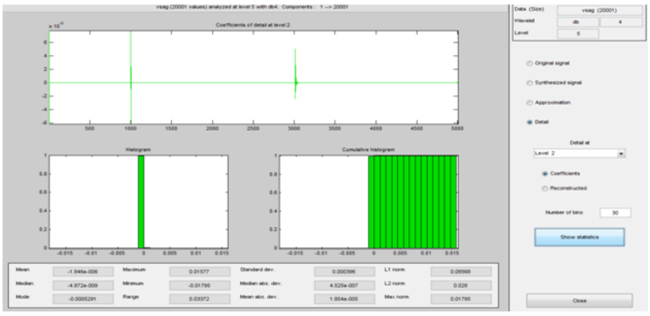

Fig 6: Standard deviation of detailed coefficient D2 of sag waveform

Wavelet Transform Analysis of Swell:

By switching a capacitor for certain duration through the three phase breaker the swell signal can be generated .The transition times of the swell signal are controlled by the three phase circuit breaker. The amplitude of the original waveform will be more than the actual value during the swell transition period. The percentage of swell of the particular waveform can be changed by changing the reactive power consumption of capacitor connected through the three phase circuit breaker.Fig6.6 shows the 20%voltage swell waveform. By loading the voltage swell waveform shown in fig6.6 into the wavelet tool box the required wavelet transform can be applied.

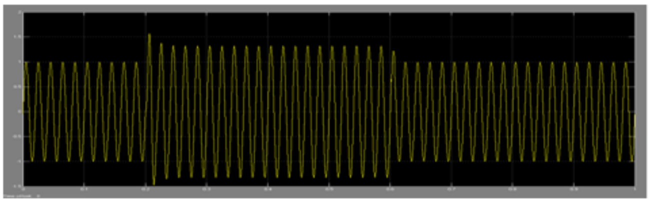

Fig 7:Voltage swell signal with 20% swell

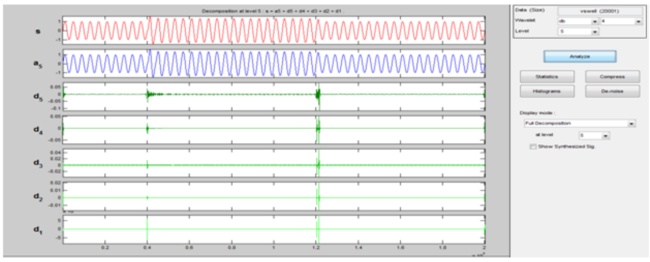

Fig 8:Wavelet analysis of voltage swell

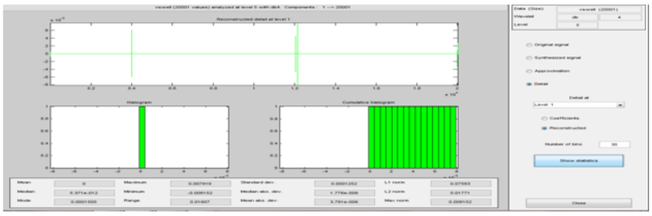

Fig 9: standard deviation of detail coefficient D1 of voltage swell

Wavelet analysis of Transient:

By introducing large capacitive load for small amount of time transients were generated. The transition timings can be controlled by using the three phase circuit breaker. The severity of transient is changed by the capacitance of the capacitive load.

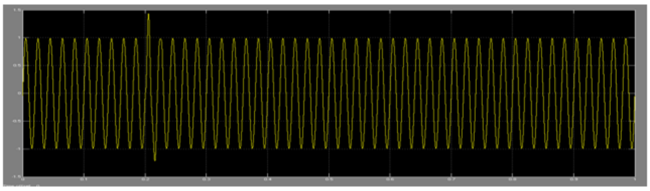

Fig 10:Voltage transient appeared between 0.2and0.24sec

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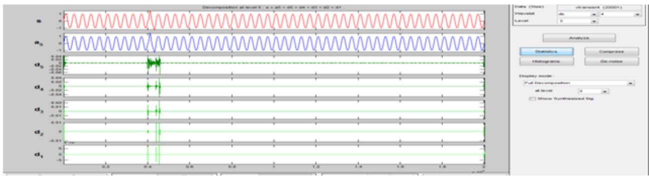

Fig 11:Wavelet analysis of transient

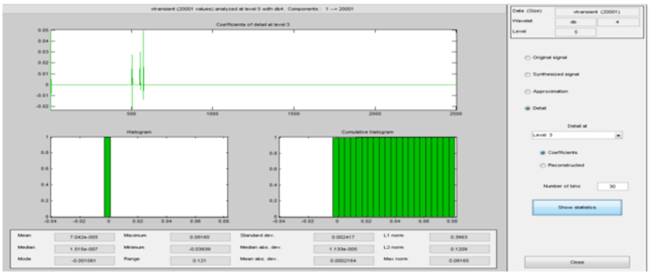

Fig 12:Standard deviation of detailed coefficient D3 of transient

Wavelets transform analysis of harmonics:

Harmonics are generated by connecting a non-linear load to above mentioned distribution system. Non-linear load consists of a three phase converter operating on resistive load. Pulses for the three phase converter can be generated by the synchronous pulse generator. The pulse frequency of generator is 50 Hz and the pulse width is 10 degrees.

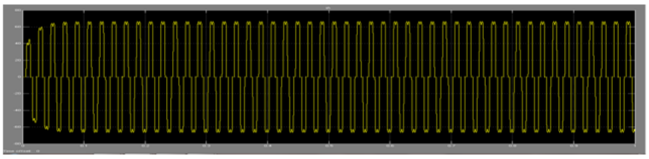

Fig 13: Harmonics at firing angle70degrees

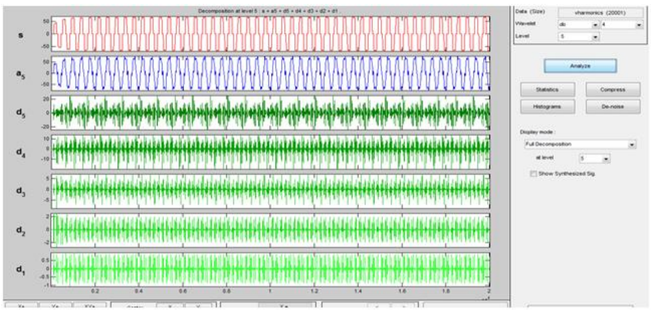

Fig 14:Wavelet analysis of harmonics

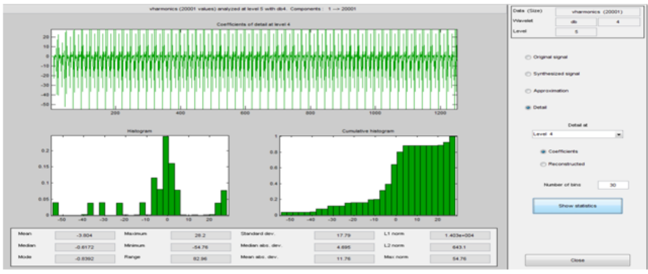

Fig 15: Standard deviation of detailed coefficient D4 of harmonics

If we Observe wavelet transform analysis of all the power quality disturbances the signals sag, swell and transients are having high frequency components at starting and ending of its occurrence but in the harmonics case it is different all low frequency and high frequency components were present .The amplitude of high frequency components is more in transients rather than sag and swell.Generation of hundred signals of each disturbance and finding its wavelet transform for calculation of standard deviation is difficult so going for programming rather than tool box is the better option.

Wavelet Transform and S-Transform:

PQ Disturbance Classifier:

Input layer consists of five neurons corresponding to five detailed coefficients, which is also called a pattern, each power quality disturbance with certain percentage of disturbance can create one pattern. Hidden layer consists of 6 neurons which is 1.5 times the output neurons. Here the criteria for selecting the hidden layers is that, if the no of hidden layers are more it will more training time on the other hand if we take less no of hidden layers the neural network will leads to divergence. Output layer consists of four neurons representing four power quality disturbances.
Weights of this created network will be initialized to random values initially after the training is over i.e the error less than the stipulated value then weights will be stabilized. The ruleused in this network is steepest decent method that is based on the rule that ”error corrects the weights”

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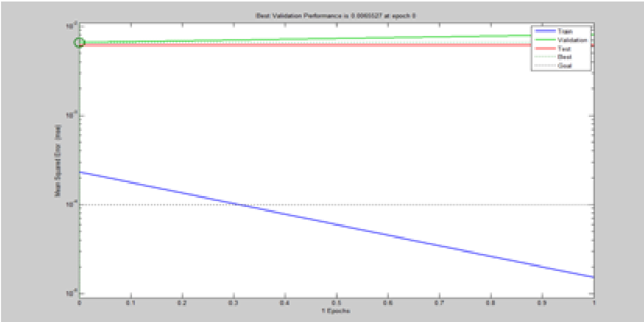

Fig 16: Convergence characteristics of neural network

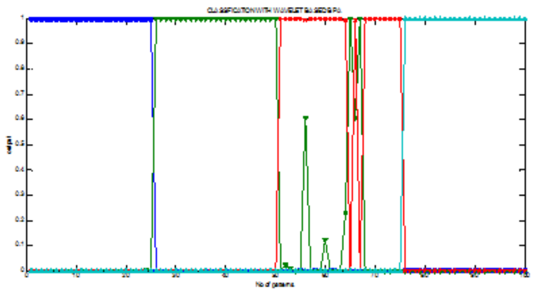

Fig 17: Classification of PQ disturbances using neural network

By observing the waveform shown in fig 6.5 the power quality disturbances have been classified with an accuracy of 99%. Neural network works with the better accuracy when it gets the testing inputs in the range which it was taken for training; otherwise it leads to divergence of neural network.

Classification of PQ Disturbances using S-transform based PNN:

A MATLAB code has been written to classify the various power quality problems by using above features. Features C1, C2 C3, C4, and C5 extracted from simulated sampling signals. According to rule based decision tree these features have been extracted. These constants C1, C2, C3,C4,and C5 are given as input to the probabilistic neural network. The accuracy of this neural network is good.

Simulation Results of S-transform:

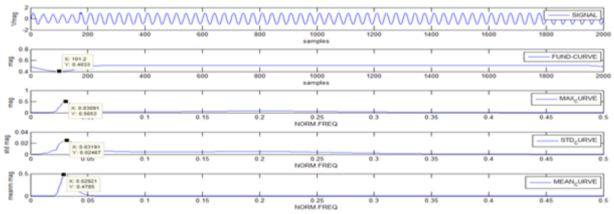

Fig 18: Sag: C1=1 C2= 1 C3=0 C5=0.4467,sag%=10.005

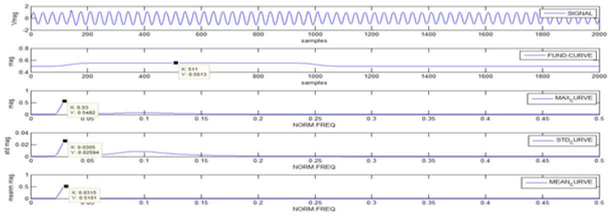

Fig 19: Swell c1=1 c2=1 %swell=3.3525

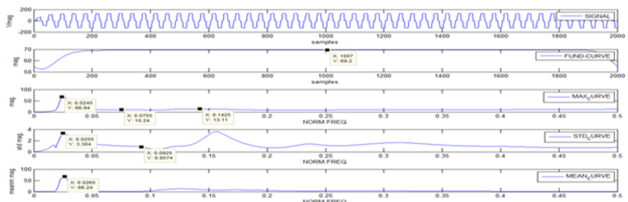

Fig 20: Harmonics C1=3 C2= 0 C3=0

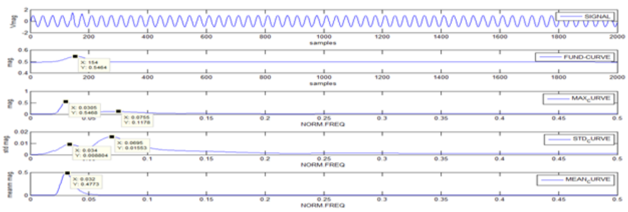

Fig. 21 : Transitent C1=3 C2=0 C3=1

S-transform based PNN Classification results:

There 400 patterns used for the training of the PNN neural network with the speed constant 0.1,and for testing 100 patterns were used in that first 25 are related to sag ,25-50 patterns related to swell,50-75 patterns representing transient,75-100 patterns representing harmonics. On observing the fig 7.10 we can conclude that first 25 disturbances exactly classified as sag ,25-50 are classified as swell,50-75

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are classified as transient and between 75 and 100 they classified as harmonics.

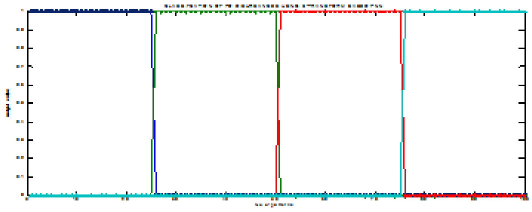

Fig 22: Classification of PQ disturbances with S-transform based PNN

V. CONCLUSIONS AND FUTURE SCOPE OF WORK

Wavelet Transform and S-transform are used in this project work as powerful analysis tool for detection, localization, and classification of power quality problems. The time-frequency plot of the Wavelet Transform has a significant to wavelet analysis in classifying the power quality waveforms. Wavelet Transform uniquely provides frequency resolution while maintaining the time information. Wavelet transform is used in this thesis work as a tool for feature extraction. The Modified discrete wavelet transform termed "S-Transform" is used in this project work as powerful analysis tool for detection, localization, and classification of power quality problems. The time-frequency plot of the S-Transform has a significant to wavelet analysis in classifying the power quality waveforms. The S-Transform gives real and imaginary spectra. S-Transform uniquely provides frequency resolution while maintaining a direct relationship with the Fourier spectrum. The proposed method is a simple and effective methodology for detection and classification of power quality disturbances. By using the S-transform Amplitude matrix (STA), five distinguished time-frequency statistical features of each type of disturbances are extracted. Four power disturbances i.e voltage sag, swell, harmonics and transients have been classified. The statistical features obtained from rule based algorithm were given as inputs to PNN (probabilistic neural network). Probabilistic neural network works based on the clustering technique.

Four hundred patterns had given for training of the probabilistic neural network i.e hundred patterns from each disturbance. Testing of the PNN had done with the hundred patterns. All the disturbances are classified with the 100% accuracy. Several power quality problems have been analyzed and the S-Transform provides an interesting and significant tool in detecting and classifying the problem. This method has great potentiality for the future development of fully automated monitoring systems with online classification capabilities. Wavelet Transform and S-transform are used in this project work as powerful analysis tool for detection, localization, and classification of power quality problems. Both the transforms used.

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