

Real-time FPGA classification of power quality disturbances using modified S-transform and RBF neural networks

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Abstract: — Power quality (PQ) disturbances are increasingly affecting modern power systems due to the widespread use of nonlinear loads, renewable energy sources, and power electronic converters. Reliable and real-time classification of PQ disturbances is essential to ensure power system stability and equipment protection. This paper presents an FPGA-based real-time PQ disturbance classification method using a Modified S-Transform (MST) for feature extraction and a Radial Basis Function Neural Network (RBFNN) for classification. The proposed MST improves time–frequency resolution while reducing computational complexity, making it suitable for hardware implementation. Discriminative features extracted from the MST are classified using an RBFNN due to its fast convergence and high classification accuracy. The complete system is implemented on an FPGA platform to achieve real-time performance. Simulation and hardware results demonstrate high classification accuracy for various PQ disturbances, including voltage sag, swell, interruption, harmonics, flicker, and transients, with low latency and efficient hardware utilization.

Keywords: Modified S-Transform, Radial Basis Function Neural Network, Matlab etc..

Introduction

Power quality can be defined as the measure, analysis and improvement of voltage or current to maintain a sinusoidal waveform at rated voltage and frequency. Ideally, the AC voltage wave is a sine wave alternating from a positive peak, with 60Hz frequency without any deformations, spikes or surges.



Fig1.1.Un distorted Sine Wave

In reality different factors such as lighting, disturbances coming from the loads and presence of non – linear devices influence the quality of the wave. Any deviation displayed in those power signals from the normal values is considered as a power quality disturbances.

Voltage Sag - Occurs due to the faults on the distribution or transmission network. Faults during the installation of machines, startup of large motors and connection of heavy loads.

Voltage Swell - Occurs due to the badly regulated transformers, badly dimensioned power sources and start/stop of heavy motors.

Harmonics - arises due to standard sources such as welding machines, DC brush motors and Rectifiers.

Transients - occur due to the disconnection of heavy loads, Lightning and switching of lines.

Flickers - are due to the presence of arc furnaces, frequent start/stop of electric motors and oscillating loads

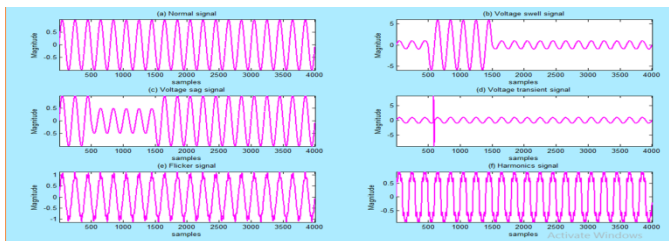


Fig:1.2.Various Disturbance Signal

Related work

A. T. jayasree, D. devaraj & R. sukanesh "power quality disturbance classification using s-transform and radial basis network" applied artificial intelligence, 23:680–693

Findings: The valuation and comparison using different performance metrics for voltage sags and notches. This techniques widely used in time–frequency domain are WT, ST, and HHT, or their combination with other techniques.

B. Agudelo-Martínez, Edwin Rivas-Trujillo¹ and Jan Meyer " a systematic review of real-time detection and classification of power quality disturbances" <https://doi.org/10.1186/s41601-023-00277-y>.

Findings: different performance metrics of Voltage sags, voltage swells, and interruption, transient, are the most common kind of disturbance.

C. G.N. Bonde, S.R. Paraskar, S.S. Jadhao "Review on detection and classification of underlying causes of power quality disturbances using signal processing and soft computing technique" Volume 58, Part 1, 2022, Pages 509-515.

Findings: the valuation and comparison using different performance metrics of Voltage sags, voltage swells using PNN.

Key Contribution

Wavelet analysis is a type of time-frequency approach employing wavelets, which are limited-

energy and average-zero functions, described as $\int_{-\infty}^{\infty} \psi(t) dt = 0$. In wavelet analysis, a particular

wavelet called as mother wavelet is initially chosen as the basis function. The mother wavelet is

then generated in dilated and translated forms, where $\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right)$.

The scale parameter a indicates dilation whereas the translation parameter b is used to alter translation. The location of the wavelet function as it is moved through the signal is related to the translation parameter which in turn matches the time information. The scale parameter is equal to frequency information and is specified as $1/|frequency|$. Scaling causes a signal to either dilate or compress. Small scales compress the signal and give general information about it, whereas large scales widen the signal and reveal hidden values.

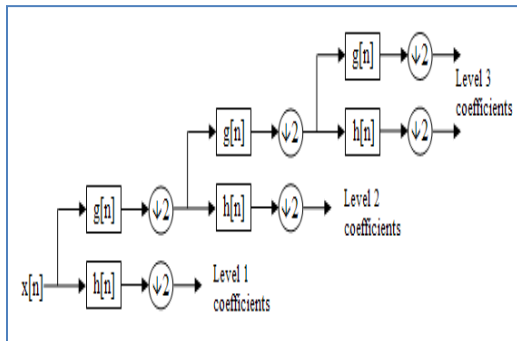


Fig.3.1 Three level DWT- MRA decomposition

Three level of decomposition process of wavelet transform of resolution analysis.

Method, Experiments and Results

Disturbance Detection in the presence of Noise:

Input signals are added with Additive Gaussian noise and the DWT is applied.

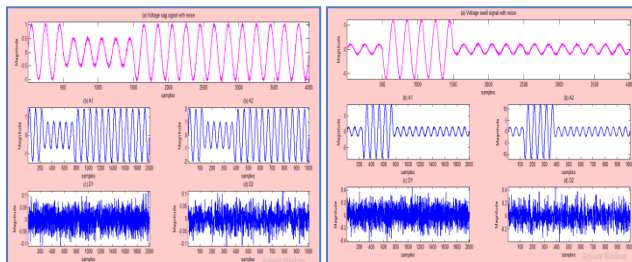


Figure 4.1 Noisy Signals

Mean,

$$M_{avg(2)} = \frac{\sum_{i=1}^N M_i}{L}$$

Median

$$N_{avg(2)} = \frac{\sum_{i=1}^N N_i}{L}$$

Energy

$$E_{avg(2)} = \frac{\sum_{i=1}^N E_i}{L}$$

Variance

$$V_{avg(2)} = \frac{\sum_{i=1}^N V_i}{L}$$

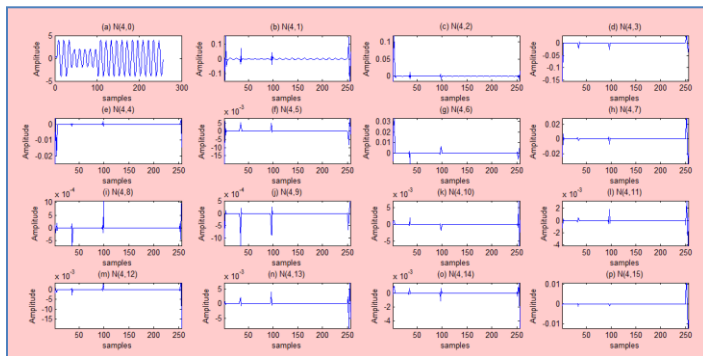


Figure 4.2 Voltage sag disturbance is detected in all sub bands

Figure shows the disturbances of all the sub bands. The sub bands are clearly shows the disturbances of the different ways with respect to the bands

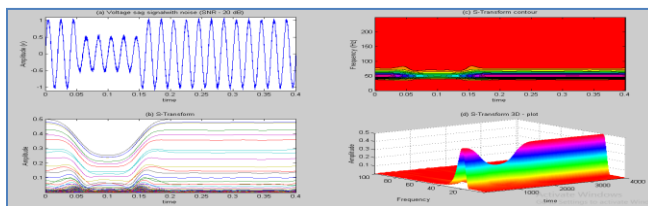


Figure 4.3 Disturbances detection using ST contour and 3D plots

As shown in the Figure, the presence of contour represents the presence of Voltage transient signal with noise with SNR 20 dB

Discussions

The S – Transform of the power quality disturbance signals are found out and subsequently, the ST-Matrix, S–Transform contour and S – Transform 3D plots are obtained. The program for computing S-Transform is written in MATLAB. The results are displayed in this section. Figure 5.2 shows the voltage swell signal, its S-Transform, S-Transform contour and S – Transform 3D plots. Features such as mean, median, energy and variance are calculated for all the power quality disturbances from the ST matrix. As shown in Figure, the values of all the features are different for each disturbance.

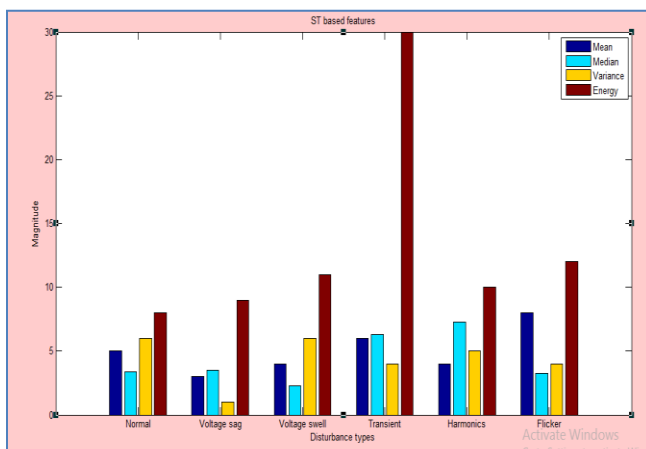


Figure 5.1. Power Quality Disturbances from ST matrix

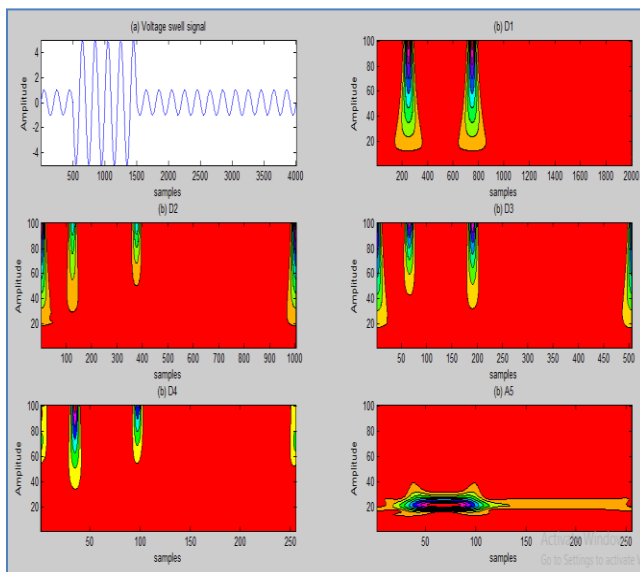


Figure 5.2 ST contours for 3-D plots

The presence of voltage transient disturbance is represented by the presence of contours in all the sub bands. Here it shows the clear information of the signal changes

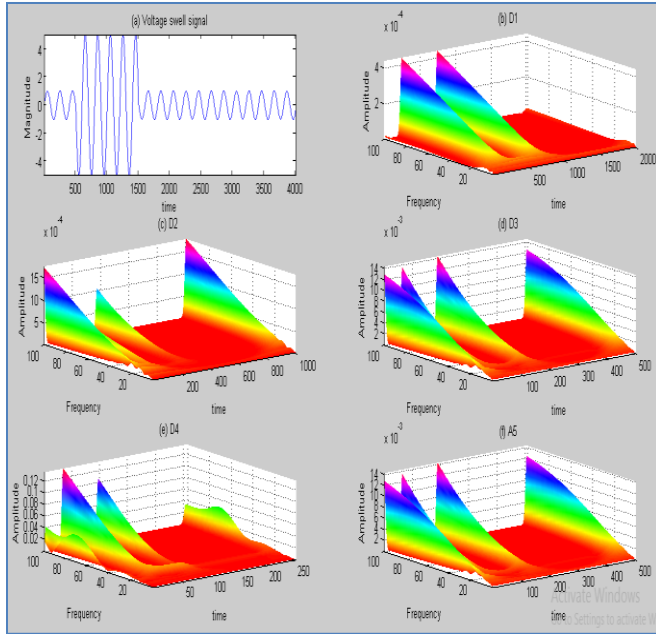


Fig5.3:3D plots – Voltage transient signal

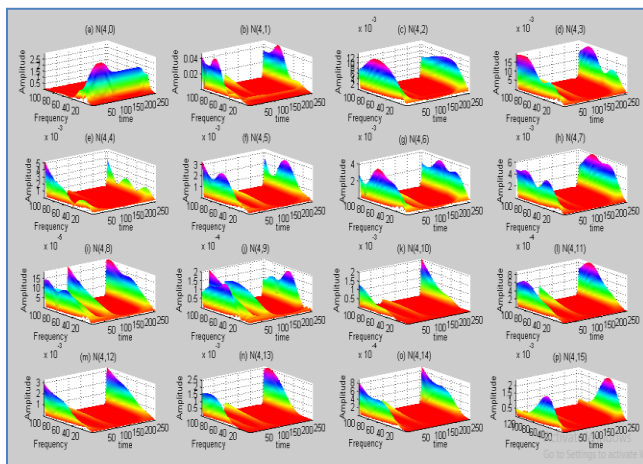


Figure 5.4: DWPT-ST 3D plots for voltage swell signal

Conclusions

The detection and classification of power quality disturbance waveforms using signal processing and ANN techniques are explored in this research work. The significant research findings are also included. The work mainly focused on the application of various transforms for the analysis of power quality disturbances. Besides different types of ANN models for the automatic classification of disturbance waveforms is also explored. The performance measures are also evaluated and compared. The results revealed that the proposed signal processing techniques and Neural Network models are found to be very effective for disturbance detection and classification.

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