# *Power Quality Monitoring in Emerging Power Systems using Adaptive and Intelligent Techniques*


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## Motivation

- The high proliferation of nonlinear loads, power electronic-based devices and renewable energy sources in the recent years are deteriorating the quality of power supply to quite severe levels.
- The PQ monitoring helps in the understanding of PQ disturbances, their causes and their impact on the power system and the end-user equipment.
- The analysis of time-varying practical voltage and current signals requires an adaptive tool to analyze the disturbances accurately and identify the transitions.

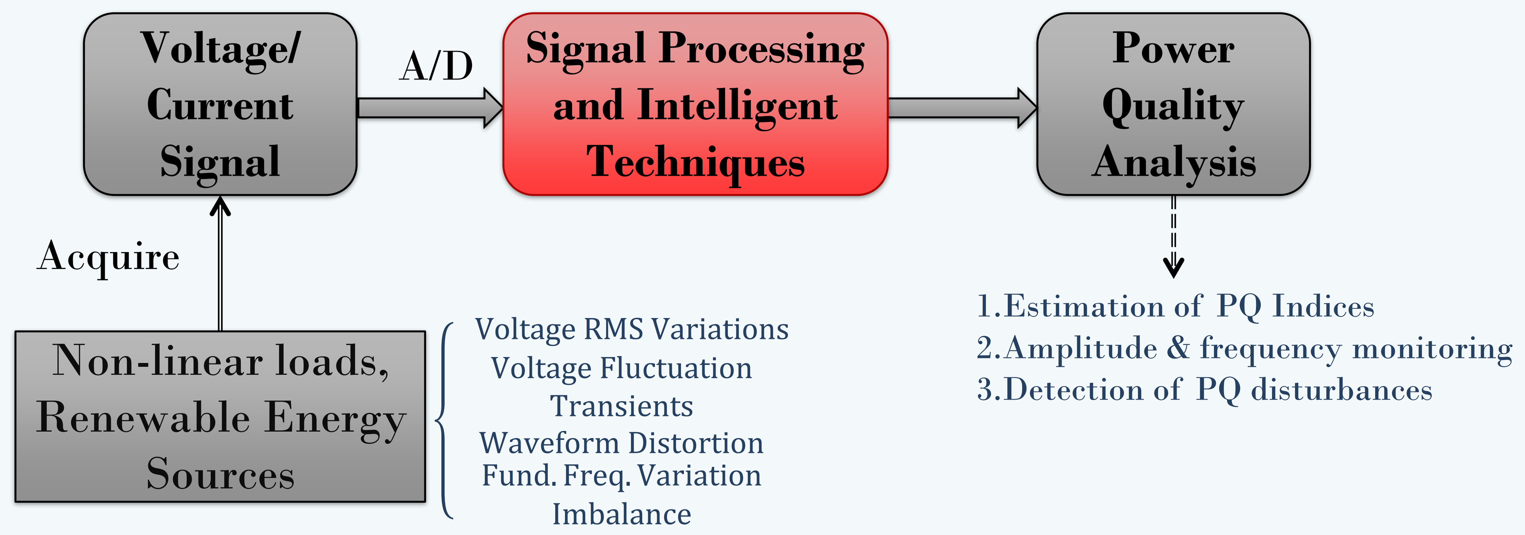
## Objectives

In view of the importance of the accurate and fast PQ monitoring, and limitations of the existing techniques, the main objectives of this work are:

- To accurately estimate the PQ indices of distorted signals containing harmonics and interharmonics with less computational complexity.
- To analyze the time-varying signals having disturbances and visualize their instantaneous amplitude and frequency accurately.
- To extract the actual fundamental frequency component of any distorted voltage/current signal for the computation of time-varying PQ indices.
- To develop a novel online automatic recognition approach for accurate classification of single and combined disturbances under noisy conditions.

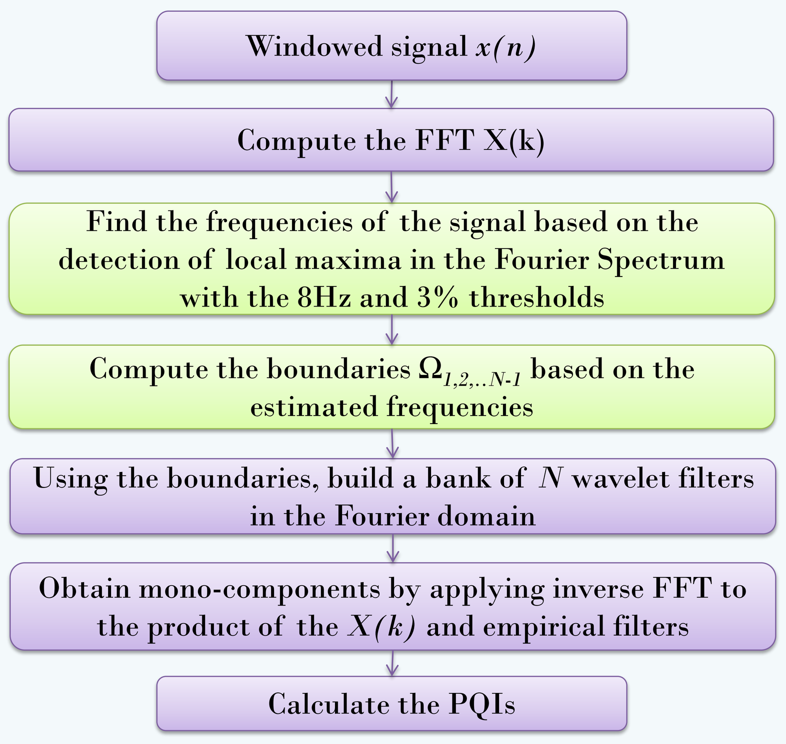
## Power Quality Monitoring Outline

To define, measure, quantify & interpret the disturbances occurring in the system.




## 1. Estimation of PQ indices using EWT

Application of a modified EWT for an accurate estimation of 1-Ø & 3-Ø PQ indices.



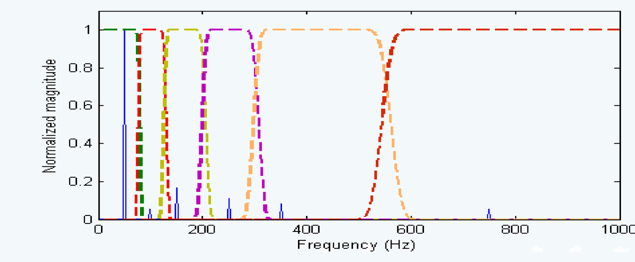



Fig 1. Filter Bank of the EWT

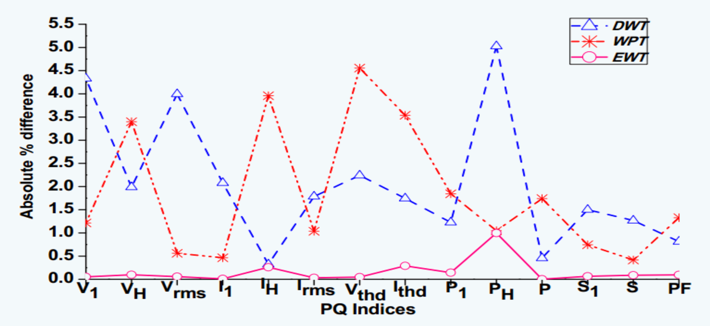


Fig 2. % difference of PQ indices for 3 Approaches

## 2. Adaptive Filtering for continuous monitoring

Proposes an improved two-stage filtering technique utilizing a divide-to-conquer principle based frequency estimation and Hanning window.

Fig 3. Setup for Acquiring Signal

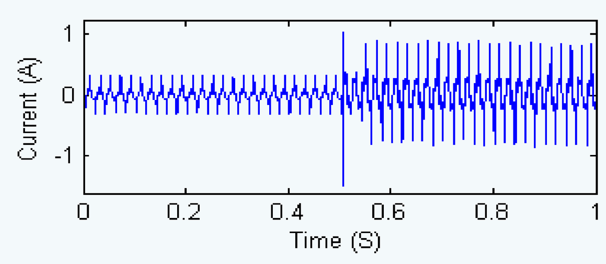


Fig 4. Measured Transient Signal

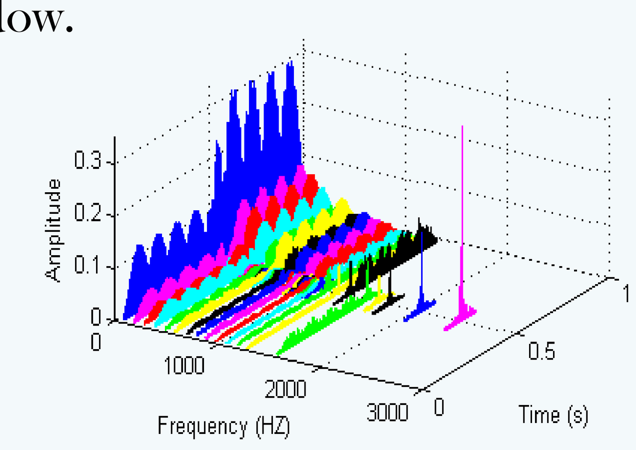


Fig 5. Time-Frequency Amplitude Plot

## 3.GEWT to visualize time-varying PQ indices

- This work proposes a Generalized Empirical Wavelet Transform (GEWT) tailored for assessment of all sort of PQ disturbances.
- The main focus is to accurately extract the fundamental frequency component for tracking of instantaneous PQ indices.

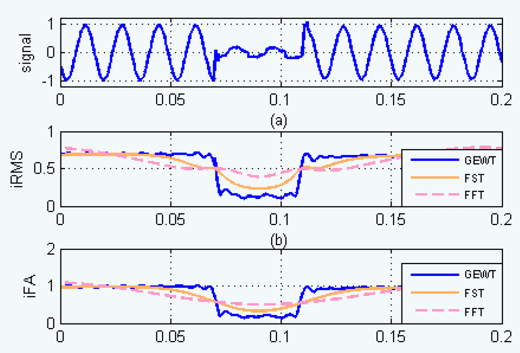


Fig 6. PQ indices of a recorded voltage sag signal

## 4. GEWT based Features for multiple PQDs

This work utilizes the GEWT for feature extraction and SVM for accurate classification of the most frequent 15 disturbances with only six features.

- The combined disturbance, which contains two or more single disturbances simultaneously will exhibit characteristics of all its individual disturbances.
- The proposed SVM model with RBF kernel has the highest classification accuracy of 97.44%.
- The overall classification time is approx. 50 ms.
- Tested on 6 real disturbance signals.

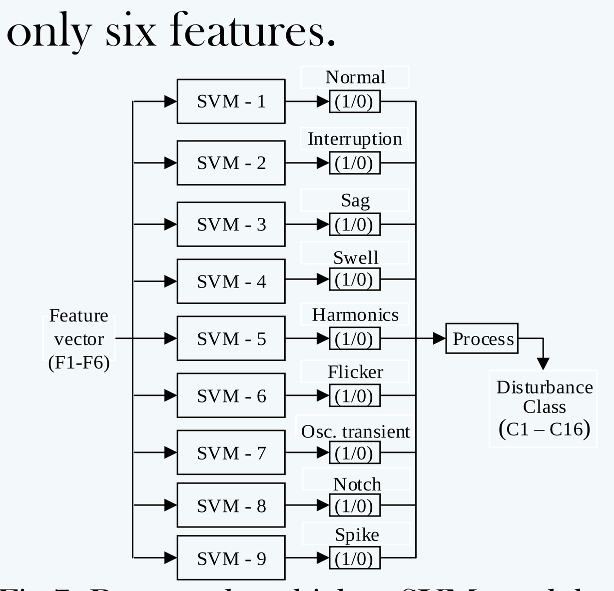



Fig 7. Proposed multiclass SVM model

## 5. Detection of PQDs using TQWT & MSVM

- The proposed approach first investigates the presence of low-frequency interharmonics and then tunes the wavelet for decomposition of signal into fundamental and distortion components.
- The overall accuracy of the dual MSVM and RBF kernel is found to be 97.286 %.
- The mean classification time is 80 ms.

| Signals | TF1 | TF2 | TF3 | TF4 | TF5 | Class detected |
|---|---|---|---|---|---|---|
| Transient | 0.573 | 0.371 | 1.054 | 0.485 | 1.022 | Transient |
| Current harmonic | 0.037 | 0.962 | 0.983 | 0.657 | 0.700 | Harmonics |
| Current harmonic | 0.003 | 0.135 | 0.143 | 0.927 | 0.939 | Harmonics |
| Current interharmonic | 0.346 | 2.190 | 2.490 | 0.470 | 0.519 | Harmonics |
| Voltage sag | 0.431 | 0.032 | 0.068 | 0.177 | 0.975 | Sag |
| Voltage normal | 0.000 | 0.015 | 0.020 | 0.996 | 0.998 | Normal |
| Voltage harmonic | 0.010 | 0.137 | 0.144 | 0.991 | 1.015 | Harmonics |
| Voltage swell + transient | 0.130 | 0.017 | 0.072 | 0.984 | 1.136 | Swell |
| Voltage sag + transient | 0.615 | 0.053 | 0.352 | 0.247 | 1.003 | Sag + transient |

## 6. DSP Implementation of the EWT for PQ

- To investigate the practical applicability of the modified EWT, it is implemented on a DSP and verified on practical 1-Ø voltage and current signals.

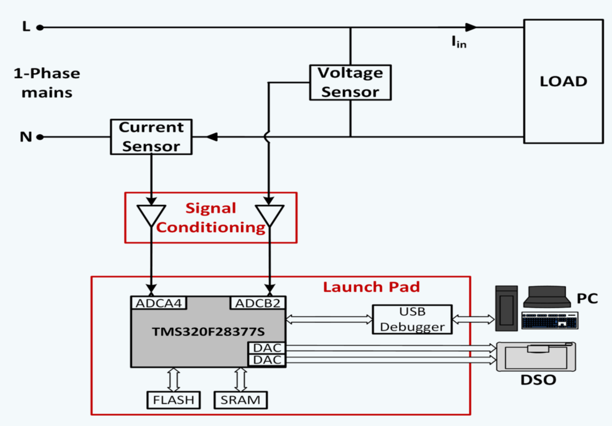


Fig 8. Schematic of DSP based analyzer

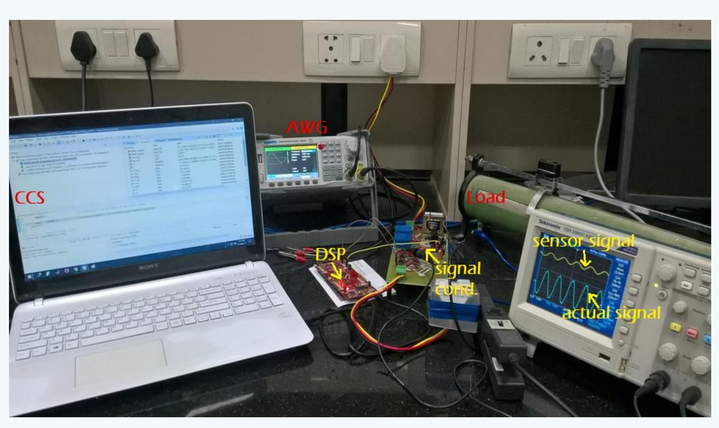


Fig 9. Experimental setup of PQ analyzer

## Conclusions

- Developed adaptive and intelligent techniques for PQ monitoring with an objective of attaining high accuracy with less computational complexity.
- Successfully utilized the potentials of the EWT for PQ analysis.
- The GEWT shows excellent performance in case of PQ disturbances due to its complete adaptiveness.
- Both the two new multiclass SVM classification models are suitable for quick detection of 15 PQ disturbances with an overall accuracy of 97 %.
- Finally, the practicality of the EWT-based PQ measurement is investigated and verified on the TMS320F28377S DSP.

## Journal Papers out of The Thesis Work:


- K. Thirumala, A. C. Umarikar, and T. Jain, "Estimation of Single-phase and Three-phase Power Quality Indices using Empirical Wavelet Transform," IEEE Trans. Power Delivery, vol. 30, no. 1, pp. 445-454, February 2015.
- K. Thirumala, Shantanu, T. Jain, and A. C. Umarikar, "Visualizing Time-Varying Power Quality Indices using Generalized Empirical Wavelet Transform," Electric Power Systems Research, vol. 143, pp. 99-109, October 2016.
- K. Thirumala, M. S. Prasad, T. Jain, and A. C. Umarikar, "Tunable - Q Wavelet Transform and Dual Multi-class SVM for Online Automatic Detection of Power Quality Disturbances," IEEE Trans. Smart Grid, November 2016 (Early access).
- K. Thirumala, A. C. Umarikar, and T. Jain, "An Improved Adaptive Filtering Approach for Power Quality Analysis of Time-Varying Waveforms," Measurement, 2017 (Revision submitted).