DETECTION AND CLASSIFICATION OF POWER QUALITY DISTURBANCES

Ph.D. THESIS

by

UTKARSH SINGH

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247 667 (INDIA)
OCTOBER, 2017

DETECTION AND CLASSIFICATION OF POWER QUALITY DISTURBANCES

A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

in

ALTERNATE HYDRO ENERGY CENTRE

by

UTKARSH SINGH

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE – 247 667 (INDIA)
OCTOBER, 2017

ABSTRACT

Power quality (PQ) research has gained substantial momentum in the past few decades. It primarily deals with the power quality disturbances (PQDs), which may be defined as deviations in voltage and current from their ideal waveforms. Major causes of power quality degradation include faults, load switching, capacitor switching, solid state switching devices, power converters, arc furnaces, and energized transformers. These factors give rise to PQDs such as sag, swell, interruption, transient, harmonics, notch, flicker, and spikes. For timely mitigation of these disturbances, detection and classification are indispensable. Detection refers to the use of signal processing techniques for time-frequency analysis of the disturbances. Prediction of type of disturbances, using classifiers trained with signal features, can be termed as power quality disturbance classification. Diagnosis of the PQDs requires a preliminary analysis of the signals using signal processing techniques like short time Fourier transform (STFT), discrete wavelet transform (DWT), wavelet packet transform (WPT), Stockwell transform (ST), empirical mode decomposition (EMD), and Kalman filter (KF). Thereafter, relevant features are extracted from the processed signals, which contain significant information of the disturbances. These features are finally fed as inputs to a classifier based on decision tree (DT), fuzzy logic (FL), artificial neural network (ANN), and support vector machines (SVM) for the classification of PQDs. Various methodologies have been proposed with different combinations of signal processing techniques and classifiers to enhance the accuracy of classification. However, the complexity, inefficiency, and computational burden of the existing techniques provide enough scope for researchers to strive for better alternatives.

This thesis, thus explores the fast and efficient signal processing, feature extraction, and classification techniques for detection and classification of power quality disturbances. The developed techniques and proposed methods were tested using power quality disturbances simulated on MATLAB according to IEEE-1159 Standards. For validation of the above proposed methodology, real PQDs were acquired from an experimental setup developed in the Alternate Hydro Energy Center at Indian Institute of Technology, Roorkee. The setup comprises of a six-phase self-excited induction generator, supplying power to three-phase load. This setup has an additional provision for grid-connected operation. The intermediate circuitry consists of three-

phase excitation capacitor banks, series compensators, and six-phase to three-phase (Δ-Y: Y) three winding transformer. Investigation on real signals not only validates the proposed techniques, but also confirms their practicality for effective recognition of PQDs. The original contributions of this work can be given as follows:

(i) A novel concept of *multi-domain feature extraction* has been introduced through application of *fractional Fourier transform*, which can transform a signal into time, frequency or intermediate time-frequency domains. The frequency domain representations can be used for disturbance detection, whereas features extracted with fractional powers between 0.5-0.9 can offer high distinction between noisy patterns due to compression of pattern boundaries. This inference is highly relevant and useful for pattern classification problems. Additionally, a first-hand application of *Bagging Predictors* is shown for classification of power quality disturbances. The bagging predictors deliver high accuracy by compromising on computational time, and are thus recommendable for offline classification.

(ii) A novel transform named as the *Time-frequency-scale transform,* has been conceived from the chirplet transform and developed for the analysis of power quality disturbances. It offers remarkable time-frequency resolution and excellent noise immunity. It also offers highly discriminative features, which can be used for pattern classification. A first-hand discussion on *appropriate window length for truncation of periodic signals*, which is given as five times the time period of analyzed signal, is also given. An extensive analysis and comparative assessment is shown for the developed transform, which justifies its aptness for power quality analysis. This technique can also be useful in analysis of other non-stationary signals, like: EEG, ECG, and speech signals.

(iii) A new multi-objective optimal feature selection strategy based on *ant-colony optimization* has been introduced. It minimizes the product of classification error and feature selection ratio. This approach helps in finding feasible solutions by initially compromising on either classification error or feature selection ratio. However, the best solution is updated if and only if a solution set provides minimum error and feature set size. This ensures improved classification accuracy, less computational time, and a feasible feature set. The typical trade-off situation between the feature set size and classification accuracy is also avoided.

(iv) A more scrupulous multi-objective optimal feature selection strategy is also presented using the *non-dominated sorting genetic algorithm II*. It utilizes the concept of pareto-optimality along with a weighing function in order to find the optimal feature set. Candidate feature sets are randomly selected and pareto-optimal fronts are generated though a ranking scheme. The feature sets are iteratively improved during the evolutionary phase, and new pareto-optimal solutions are simultaneously updated by comparing both error and feature set size. When the maximum iteration is reached, the optimal feature set is obtained using the weighing function.