SMAGRINET
POWERING SMART GRID
EXPERTISE IN EUROPE

Module I

Artificial Intelligence (AI) in Smart Grids

Technical University of Dresden

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Lectures overview

1. Introduction to AI & ML
2. Forecasting methods
3. Linear and non-linear models (KTU)
4. Generalization issues (KTU)
5. Automatic anomaly detection in Power Quality (PQ) data
6. PQ disturbance detection using AI methods

Introduction to AI & ML

1. Introduction

- Definition
- Application examples

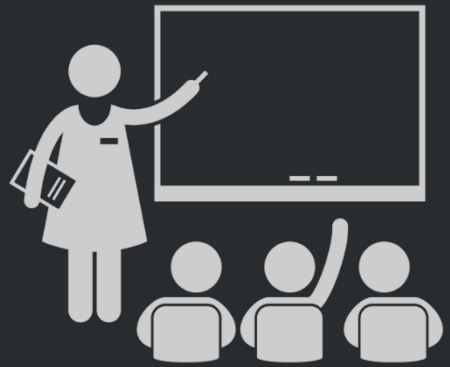
2. Overview of ML methods

- Classification
- Learning paradigms
- Method examples

3. General methodology

- Problem analysis
- Implementation

Introduction to AI & ML

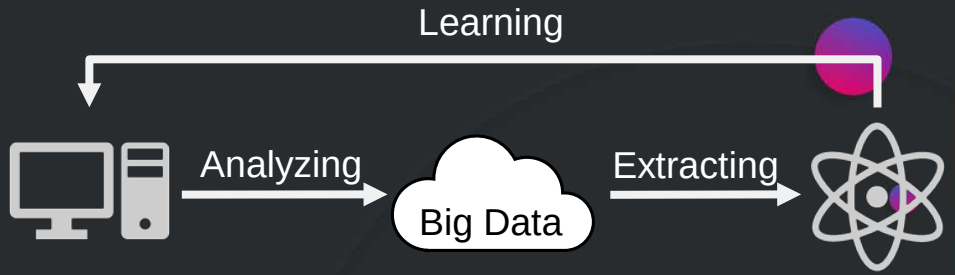


Artificial Intelligence

- Basic requirement: **ability to learn**
- Learning process = Machine Learning

Machine Learning

- Based on certain methods/algorithms
- Depends on teaching
- Analysis of a large volume of data („Big data“)



Introduction to AI & ML

Classification

- The **learning paradigm**
  - Supervised
  - Semi-supervised/reinforcement
  - Unsupervised
- Common **tasks**
  - Approximation/optimization
  - Estimation/forecasting
  - Pattern recognition
  - Decision making
- The working **principle**
  - Connectionist
  - Genetic
  - Probabilistic
  - Classification
  - Clustering

Introduction to AI & ML

Method	Application	Principle
• **Artificial neural network**	Universally usable	Connectionist
• **Particle swarm optimization**	Optimization	Genetic
• **Bayesian statistics** • Bayesian networks	Estimation Forecasting	Probabilistic
• ***k*-nearest neighbors (*k*-NN)** • **Decision tree**/Random forest • **Support vector machine (SVM)**	Pattern recognition Decision making	Classification
• **Hierarchical clustering** • ***k*-means clustering**	Pattern recognition	Clustering

Introduction to AI & ML

Decription of each method

- Working principle
- Application
- Learning method
- Challenges
- Functional description

Introduction to AI & ML

General methodology

Problem definition

Variable selection

Data exploration

Problem analysis

Implementation

Data pre-processing → Feature extraction /selection → Method application and evaluation → Results interpretation and visualization

Forecasting methods

1. Introduction
2. Overview of forecasting methods
3. Regression models
4. Time series models
   - Time series decomposition
   - Exponential smoothing
   - ARIMA models

Forecasting methods

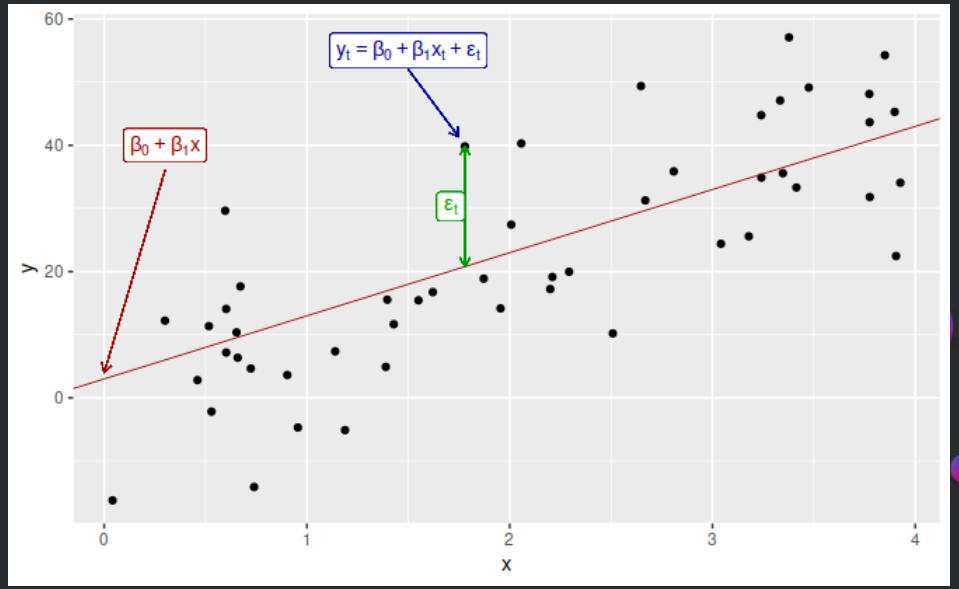
Classification

- The **forecast horizon**
  - (Very) short term (hours to days)
  - Medium term (weeks to months)
  - Long term (years)
- The **input data**
  - Time series models
  - Explanatory models
  - Dynamic regression models

Forecasting methods

Linear regression

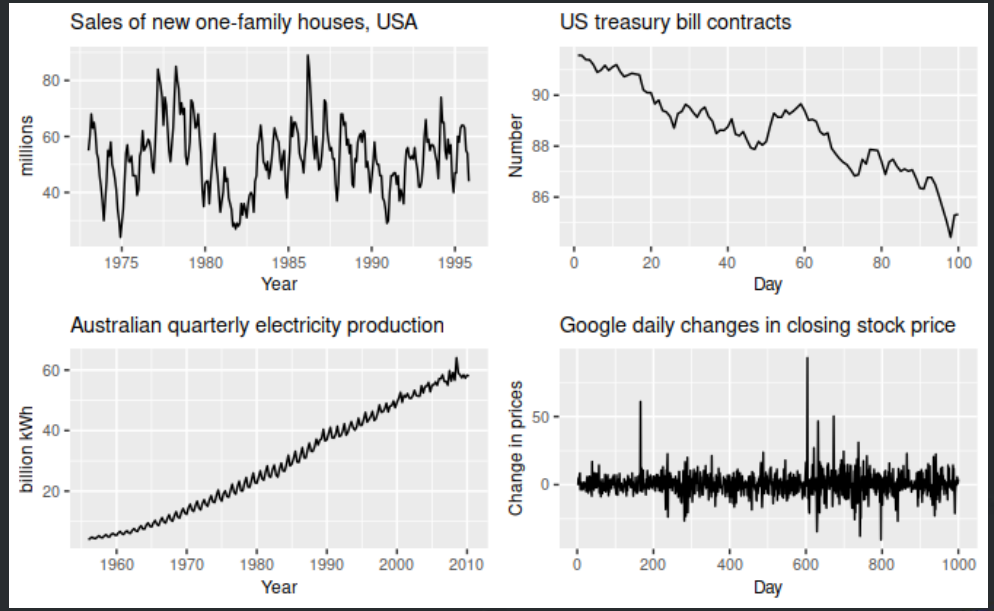
- Fitting the parameters of a linear function to model the observations



Forecasting methods

Time series patterns

- **Trend**
  - Long-term change
- **Seasonality**
  - Fixed frequency (e.g. week/year)
  - Due to seasonal factors
- **Cycle**
  - No fixed frequency
  - Due to other factors (e.g. economic)



Forecasting methods

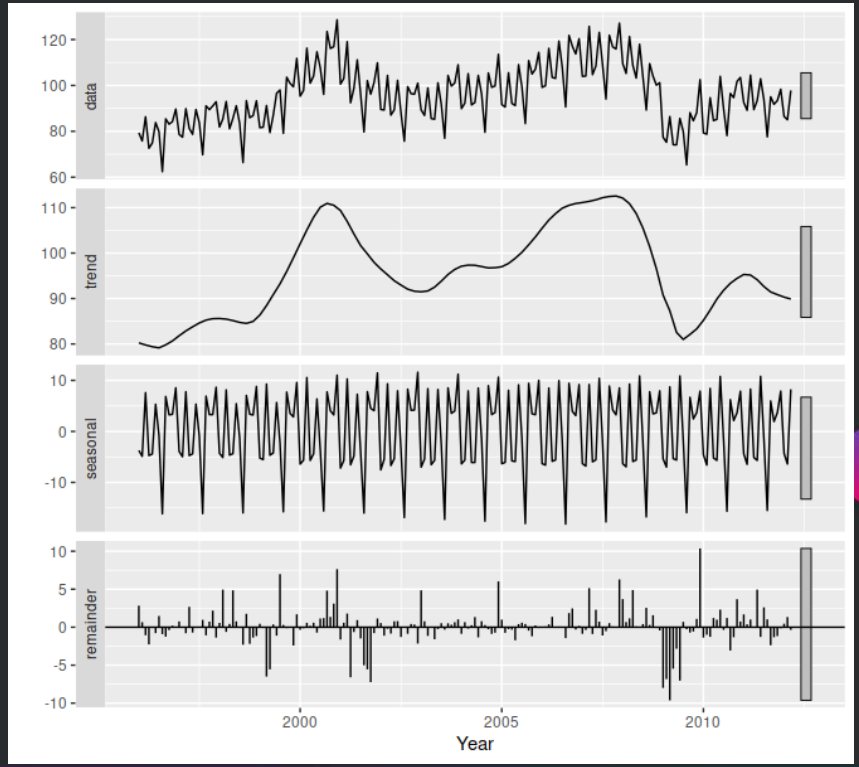
Time series decomposition

Original time series

Trend-cycle component

Seasonal component

Remainder component



Automatic anomaly detection in PQ data

Content

1. Anomaly definition and classification
2. Anomaly detection process
3. Application example

Automatic anomaly detection in PQ data

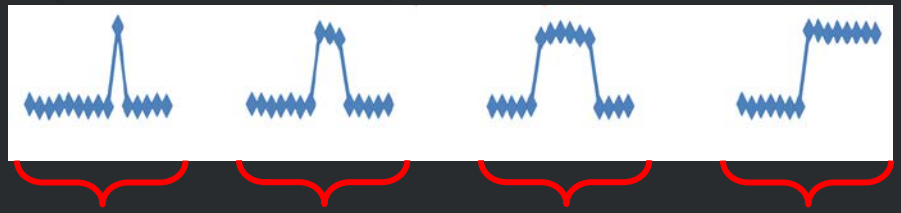
Anomaly definition and classification

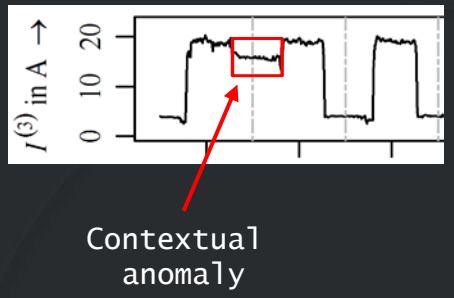
1. What is anomaly?

- Anomalies are defined as rare and significant deviations
- Also know as outlier, event, irregular variation, sudden change

2. Anomaly classification

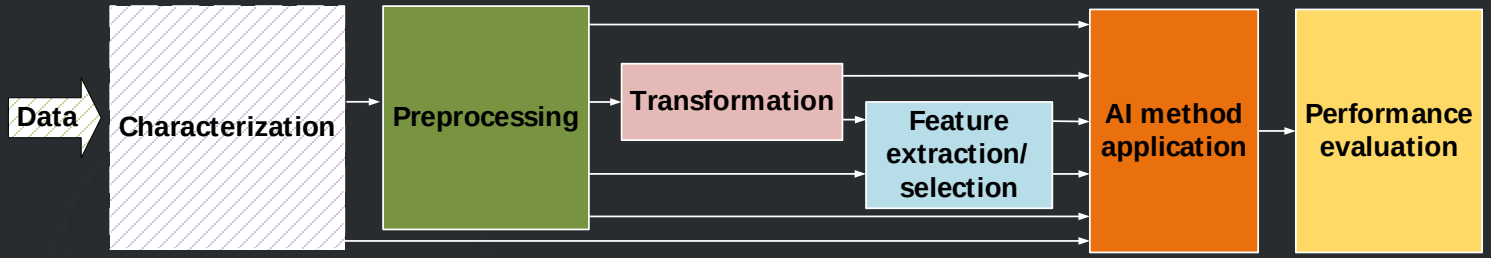
- Four main types of outlier (anomaly)
- Over time new classification and anomalies variants appeared, e.g. contextual anomaly





Automatic anomaly detection in PQ data

Anomaly detection process

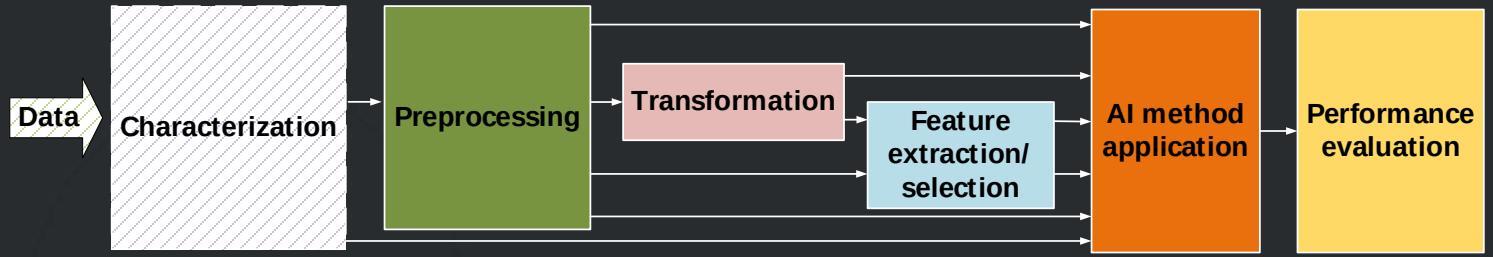


Generally anomaly detection process includes 6 steps:

1. Data characterization
   (Exploratory data analysis)
2. Data preprocessing
   (Data preparation necessary to conduct for meaningful analysis)
3. Data transformation
   (Where a data set may be transformed into a data set with another set of attributes of the same or a different type)

Automatic anomaly detection in PQ data

Anomaly detection process



4. Feature extraction/selection

(The process for generating numerical descriptions of data instances)

5. AI method application

(Design and application of anomaly detection method)

6. Performance evaluation

(Quantify effectiveness of the method)

Automatic anomaly detection in PQ data

Application example

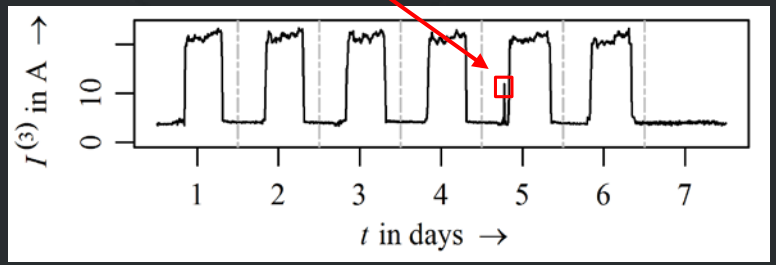
- Current and voltage harmonics
- Anomalies are characterized with 3 properties:

Shape:
-Single
-Multiple

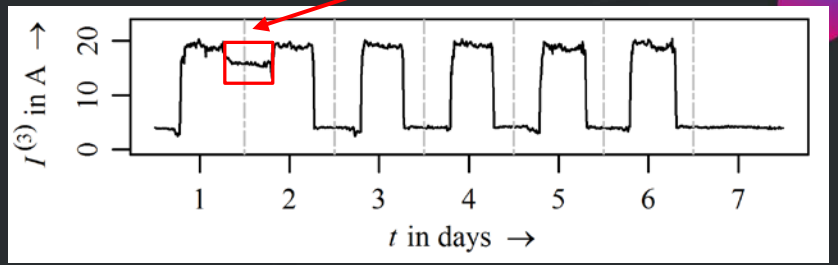
Level of deviation:
-Inner
-Outer

Slope:
-High
-Low

Single; Inner; High



Multiple; Inner; Low



Automatic anomaly detection in PQ data

Application example

- **Single** anomaly detection
- 2 step approach:

1st step:

✓ Apply *LOWESS* to the original time series

✓ Extract the smoothed component

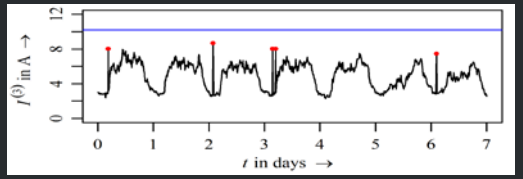
✓ Get the rest component

2nd step:

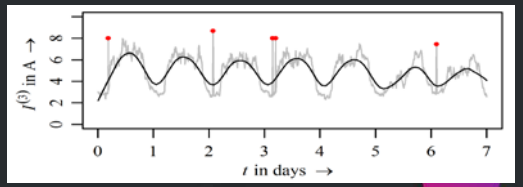
✓ Apply the threshold using Interquartile Range (IQR)

✓ $l_{\mathrm{IQR}} = \begin{cases} x_{[75]} + 1.5 \cdot \mathrm{IQR} \\ x_{[25]} - 1.5 \cdot \mathrm{IQR} \end{cases}$

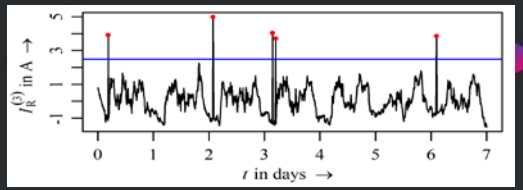
Measurement data



Apply LOWESS



Apply threshold



Automatic anomaly detection in PQ data

Application example

- **Multiple** anomaly detection
- 4 steps approach

Step 1: Data grouping

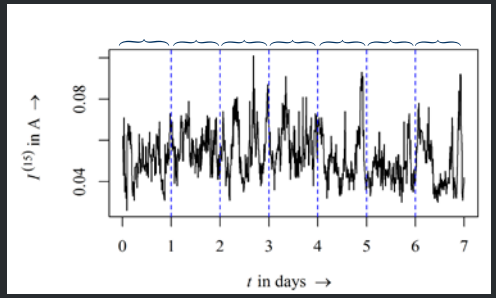
✓ Group data according to day of the week

Step 2: Transformation
(Feature engineering)

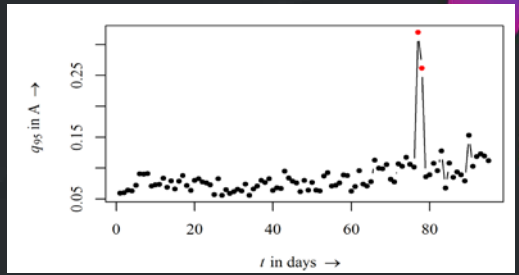
✓ Develop descriptive features

✓ Calculate features on daily base

One week measurement data



Feature-based time series



Automatic anomaly detection in PQ data

Application example

Step 3: Identification

✓ Calculate and apply threshold:

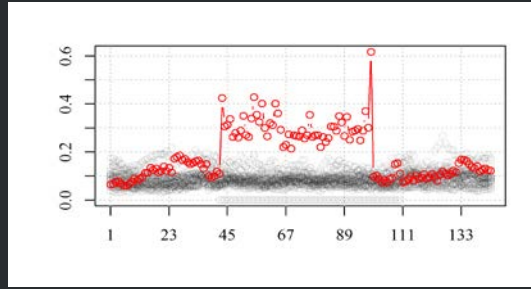
$$l_{\mathrm{MAD}} = \begin{cases} \mathrm{median}(x) + 3 \cdot \mathrm{MAD} \\ \mathrm{median}(x) - 3 \cdot \mathrm{MAD} \end{cases}$$

✓ **Anomaly score** is calculated:

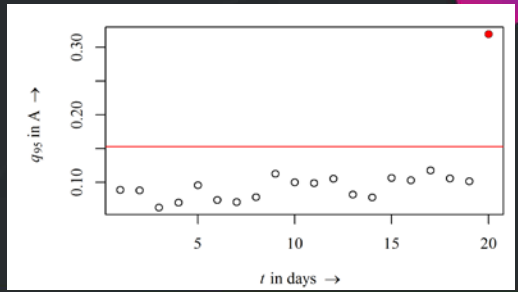
$$S_{\mathrm{A}} = \left(\frac{x_i - l_{\mathrm{MAD}}}{l_{\mathrm{MAD}}} \right)$$

✓ Anomaly detection for $S_{\mathrm{A}} > 0$

Measurement data
(Normal & Abnormal days)



Threshold applied over
feature time series
(Normal & Abnormal days)



Automatic anomaly detection in PQ data

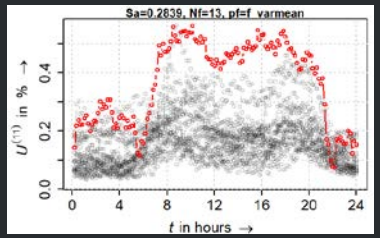
Application example

Step 4: Quantification and aggregation

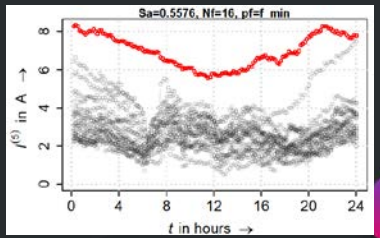
- ✓ Definition of **significance levels** to prioritize anomalies
  - o **Low**
  - o **Medium**
  - o **High**
- ✓ Adjustable to expert interest
- ✓ Used for anomaly ranking
- ✓ Summaries to identify problematic measurements or parameters

- ✓ Anomaly classification based on features

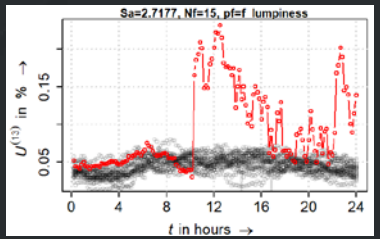
Low



Medium



High



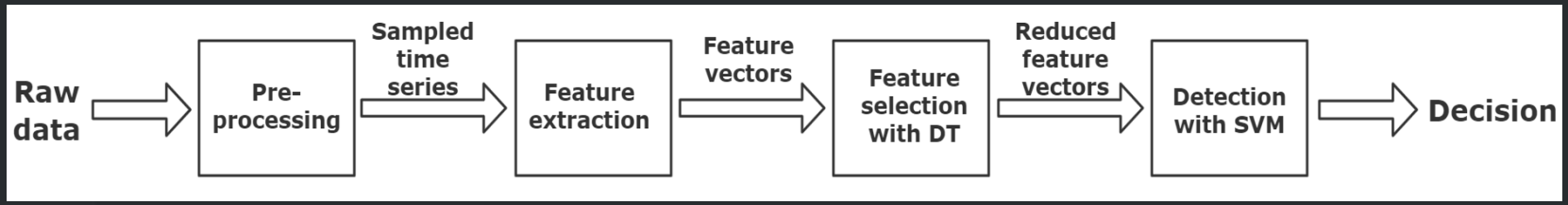
PQ disturbance detection using AI methods

Content

1. Notch detection process
2. Pre-processing
3. Feature extraction
4. Feature selection with DT
5. Detection with SVM

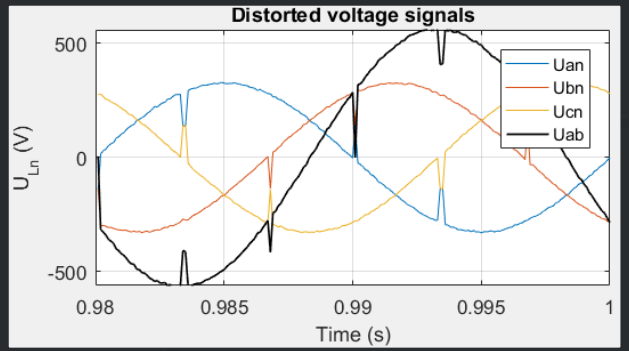
PQ disturbance detection using AI methods

Notch detection process



Method includes 4 stages:

1. Pre-processing stage
2. Feature extraction stage
3. Feature selection with DT stage
4. Detection with SVM stage



PQ disturbance detection using AI methods

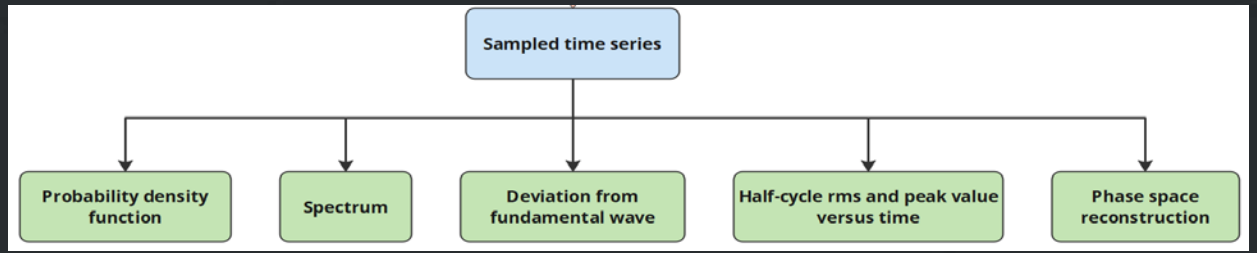
Pre-processing & Feature extraction

Stage 1: Preprocessing stage

- Exploratory data analysis
- Data normalization

Stage 2: Feature extraction

- 5 possible branches of characterization
- Quantify PQ data time-series properties
- 14 features have been developed



PQ disturbance detection using AI methods

Feature selection

Stage 3: Feature selection

✓ **Decision tree (DT)** used for feature selection

✓ Splitting criteria of DT:

(used to estimate the performance of each features)

- Gini index

✓ Pruning parameters:

(used to limit the size of the DT)

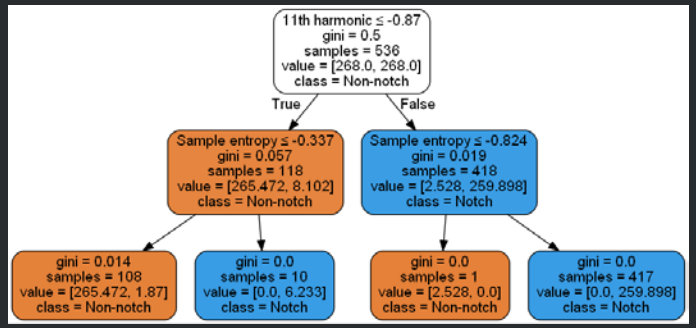
- The maximal depth
- The maximal number of features
- The minimal decrease of impurity to split a node
- The minimal number of samples in a leaf node
- The minimal number of samples to split a node

PQ disturbance detection using AI methods

Feature selection

Stage 3: Feature selection

- ✓ 5 features (out of 14) are selected for classification:
- 11th harmonic
- Sample entropy
- Variance of half-cycle peak value
- Variance of half-cycle RMS value
- Oscillation rate



PQ disturbance detection using AI methods

Detection with SVM

Stage 4:Detection with SVM

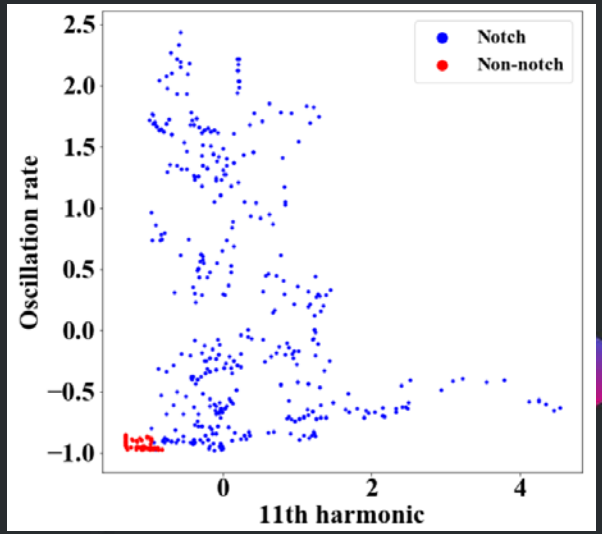
✓ Support vector machine (SVM):

(A binary classification algorithm aiming at the maximal-margin decision surface (classifier) for the binary labeled samples)

✓ Classifier testing has been conducted

- Synthetic data
- Measurement data
- Notch and non-notch data

➢ Final accuracy more than 95%



Literature

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