Performance and Fault Detection Analysis of an Induction Motor Using Shapelet

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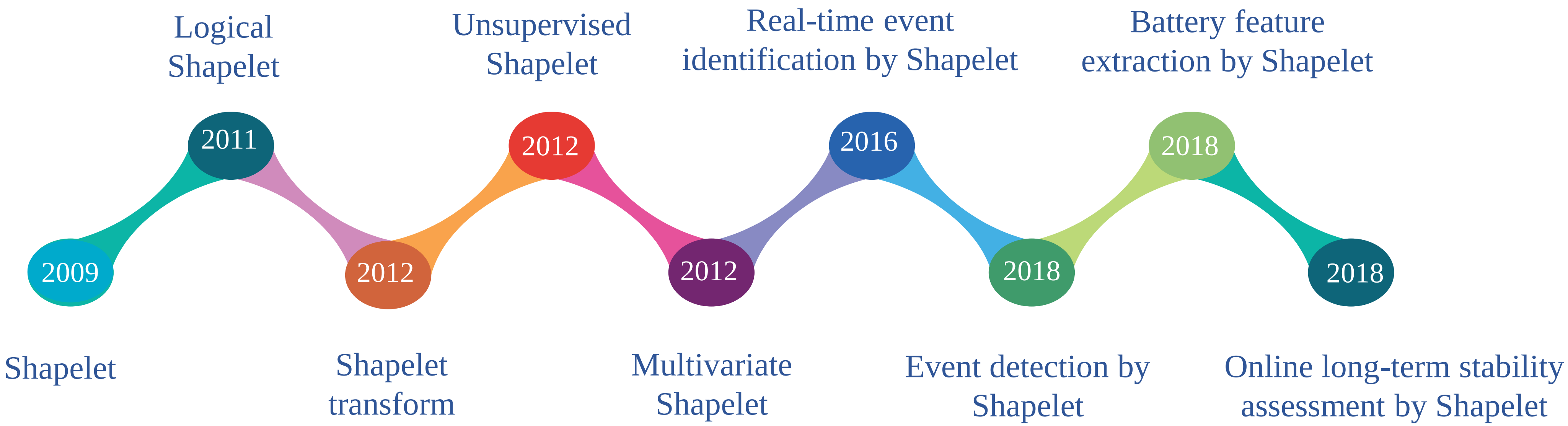
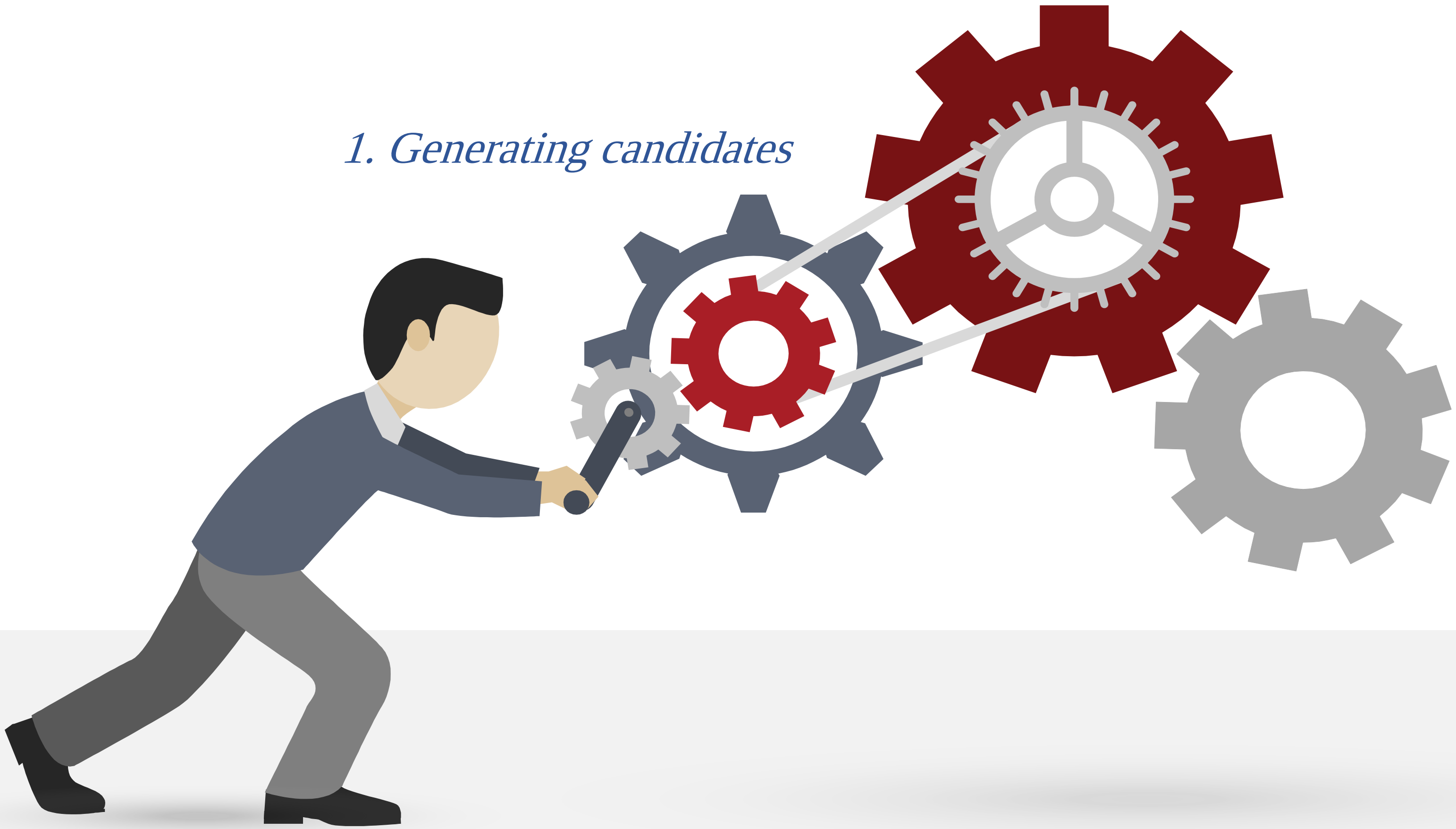
Theory of shapelet

- Suppose there is a dataset of n time series $T = \{T_1 T_2, \ldots, T_n\}$ where each T_i has m samples.
- **Shapelet** is a subset of one of the time series in the dataset.
- **Shapelet** is used for finding local shape-based similarity.
- **Shapelet** must be normalized and non-variable to scale and offset.



Shapelet Discovery



Generating candidates

- The length of time series in the dataset is m.
- The goal is to find a candidate with length l .

l can change in the range of $[min, max]$, while $min \geq 3$ and $max \leq m$.

- All normalized subseries of T_i that have l samples are

$$W_{i,l} = \{< t_{i,1}, \dots t_{i,l} > , < t_{i,2}, \dots t_{i,l+1} > , \dots , < t_{i,m-l+1}, \dots t_{i,m} >\}$$

- $W_{i,l}$ for all time series of T are

$$W_l = \{W_{1,l} \cup W_{2,l} \cup \cdots \cup W_{n,l}\}$$

- Collection of W_l for all possible amount of l for dataset T is:

$$W = \{W_{min} \cup \cdots \cup W_{max}\}$$

Shapelet distance calculation

- The distance between two subseries with the same length by square Euclidean distance is calculated as

$$dist(S,R) = \sum_{i=1}^{m} (s_i - r_i)^2$$

where S and R are time series, s_i and r_i are their components and m is their length.

- The distance between a time series by length m (T_i) and a subseries by the length l (S) is

$$d_{S,i} = \min_{R \epsilon W_{i,l}} dist(S,R)$$

- The list of distance between the shapelet candidate S and the time series T is:

$$D_S =< d_{S,1}, d_{S,2}, \dots, d_{S,n} >$$

Shapelet assessment

- The purpose of the shapelet assessment is to determine how accurate this shapelet classifies the dataset based on D_S.
- Information gain (IG) is used as a basic method for the shapelet assessment.

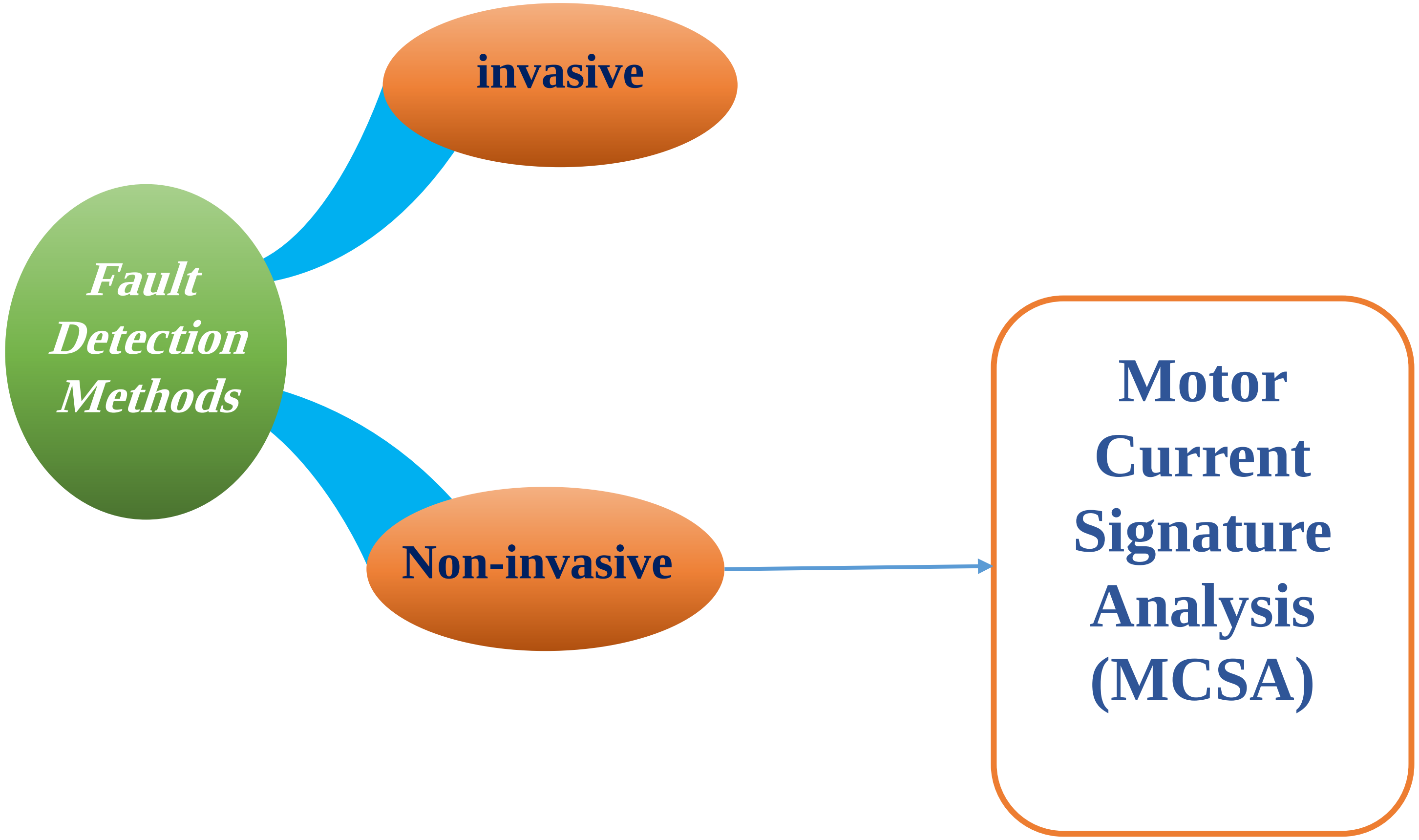
Induction Motor

Advantages

- ✓ Low cost maintenance
- ✓ Highly robust
- ✓ Power efficiency
- ✓ Reliability

Disadvantage

✗ The environmental situation could cause serious faults in IM



Model of healthy induction machine

In the *qd0* reference frame, the IM system is modelled by the following differential equations of the voltages:

$$V_s^{qd0} = r_s^{qd0} i_s^{qd0} + \omega \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \lambda_s^{qd0} + \frac{d\lambda_s^{qd0}}{dt}$$

$$V_r^{qd0} = r_r^{qd0} i_r^{qd0} + (\omega - \omega_r) \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \lambda_r^{qd0} + \frac{d\lambda_r^{qd0}}{dt}$$

$$r_{s,r}^{qd0} = r_{s,r} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad , \quad \begin{bmatrix} \lambda_s^{qd0} \\ \lambda_r^{qd0} \end{bmatrix} = \begin{bmatrix} L_{11} & 0 & 0 & L_{14} & 0 & 0 \\ 0 & L_{22} & 0 & 0 & L_{25} & 0 \\ 0 & 0 & L_{33} & 0 & 0 & 0 \\ L_{41} & 0 & 0 & L_{44} & 0 & 0 \\ 0 & L_{52} & 0 & 0 & L_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & L_{66} \end{bmatrix} \begin{bmatrix} i_s^{qd0} \\ i_r^{qd0} \end{bmatrix}$$

where $\omega = d\theta/dt, \omega_r = d\theta_r/dt$

Model of induction machine with broken rotor bars

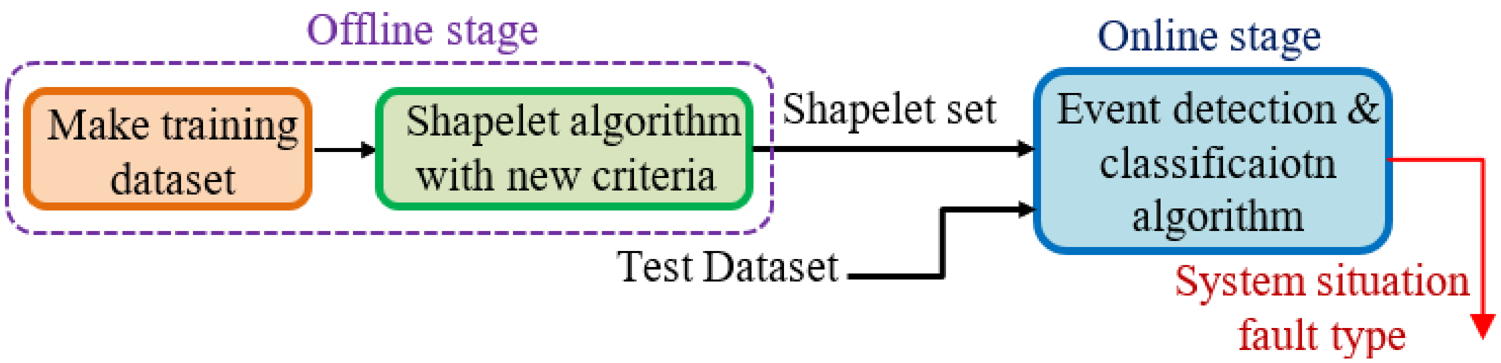
- Broken rotor bar causes asymmetry in the IM rotor
- Broken rotor bar leads to non-symmetrical stator current distribution.
- In broken rotor bar fault in induction motor, the rotor becomes asymmetric by changing in r_r

$$r_r^{new} = r_r + \begin{bmatrix} r_{r11} & r_{r12} & r_{r13} \\ r_{r21} & r_{r22} & r_{r23} \\ r_{r31} & r_{r31} & r_{r33} \end{bmatrix}$$

Proposed approach for Induction motor fault detection using Shapelet

The proposed method has two main parts:

- The first part is the offline process that consists of :
  - a) Modeling the IM and its faults in order to make a comprehensive training dataset
  - b) Shapelet discovery with new criteria for specifying the number of members in all classes
- In the second part, the obtained Shapelets are employed to detect faults online.



Shapelet discovery with new criteria

- this method has 3 main part, like ordinary Shapelet discovery
  a) Generating candidates
  b) Distance calculation
  c) Shapelet assessment
- This method has some differences in Shapelet assessment part

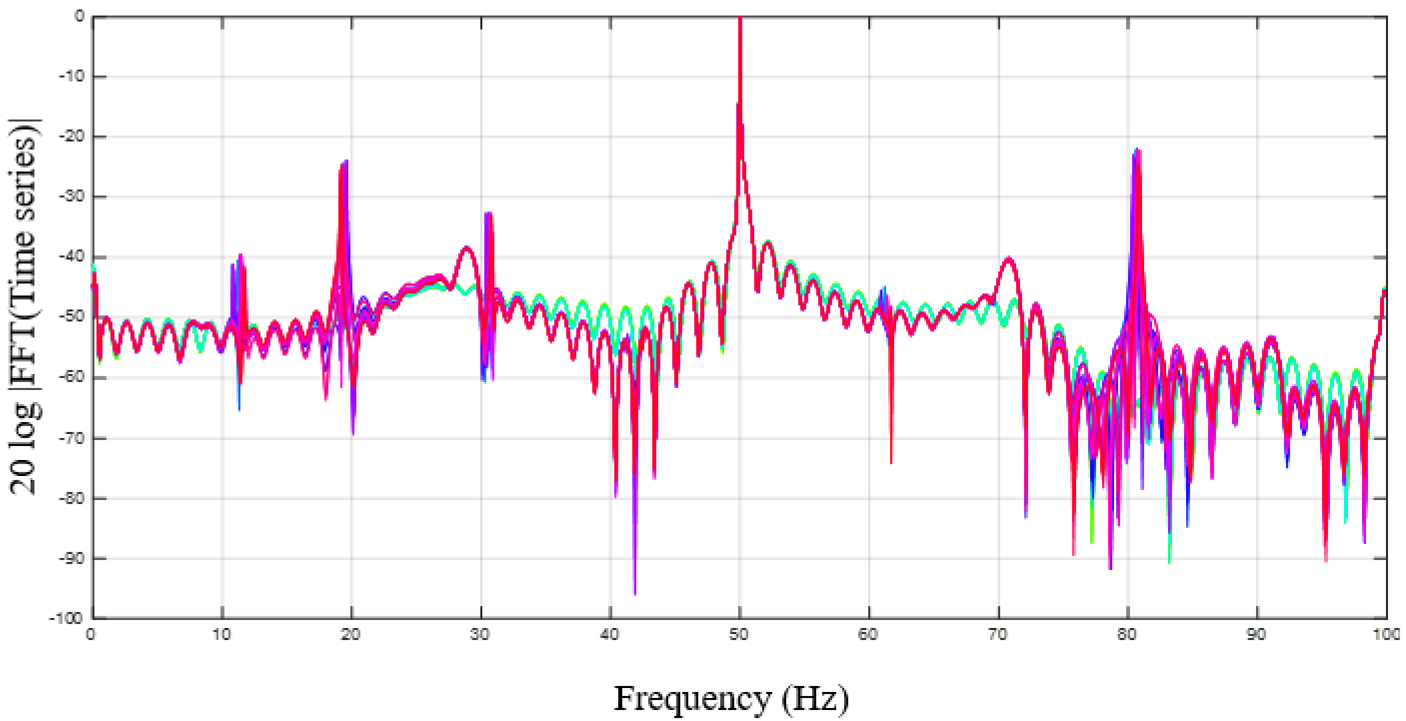
✓ For specifying the quality of Shapelet, new criteria for the maximum and minimum number of each class member (Max_n and Min_n) are considered together and they are employed for IG calculation.

Why new criteria are needed?

- For a dataset that consists of several classes two of which have with negligible differences, if no limit is exerted on the maximum number of members in each class, the shapelet algorithm may not distinguish these two classes.
- For a dataset that consists of several classes, if no limit is determined for the minimum number of members in each class, a sample class with various members and small differences among its own members may be considered as a different class.
- In our approach, **novel** algorithms to calculate Min_n **and** Max_n and then IG **based on** Min_n **and** Max_n are suggested.

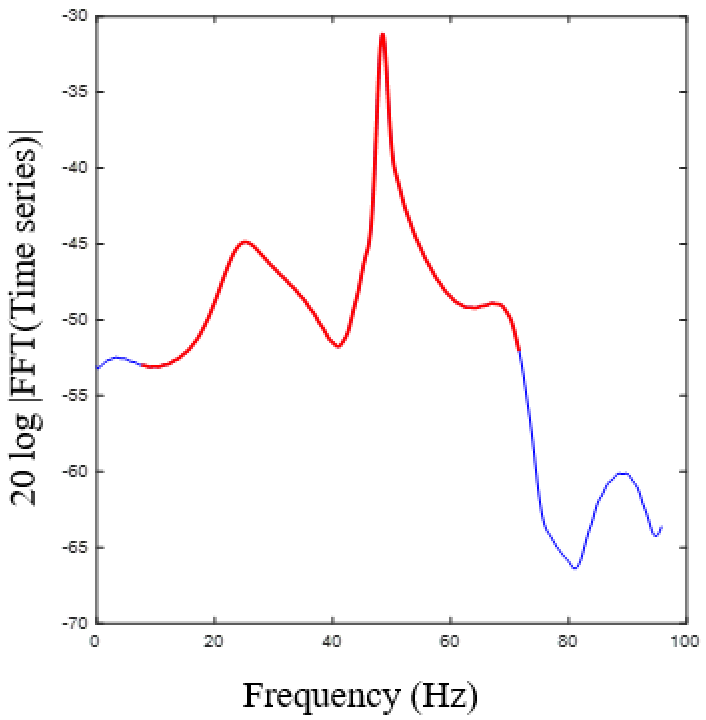
Case Study

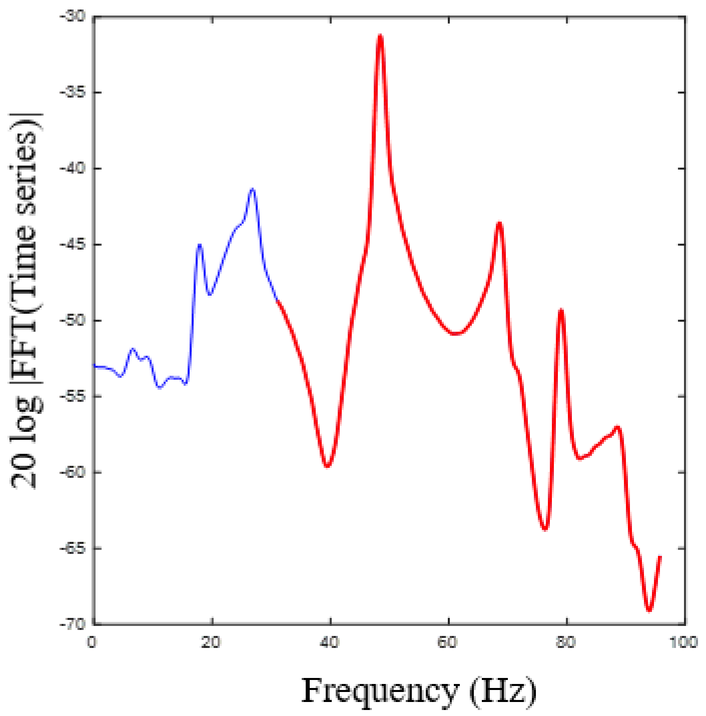
- A 50Hz, 6 poles, three-phase induction motor is modeled in a healthy and 6 BRB situations.
- A dataset of the Fourier transform of stator current for phase a is made for training dataset.
- The dataset consists of 50 series in the frequency domain.



Case Study

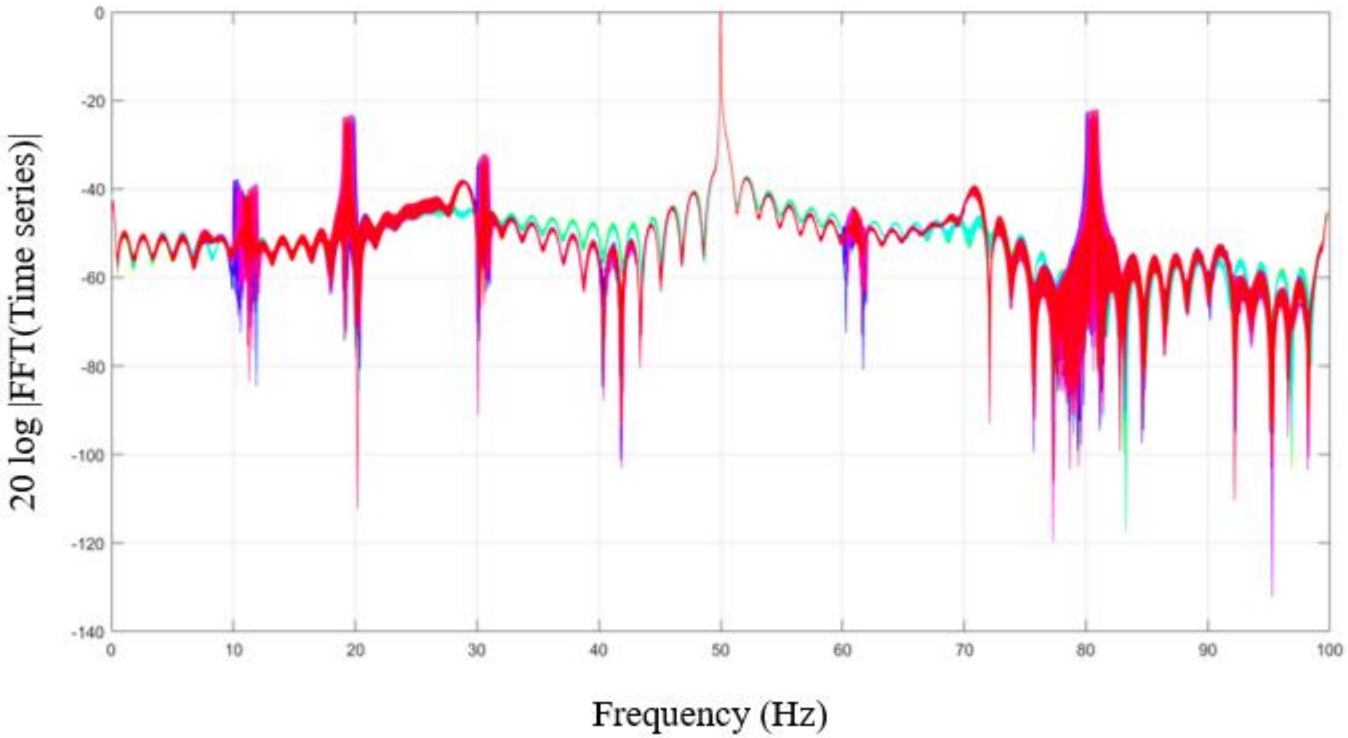
Shapelet Algorithm with new criteria is employed for each condition of the induction motor.



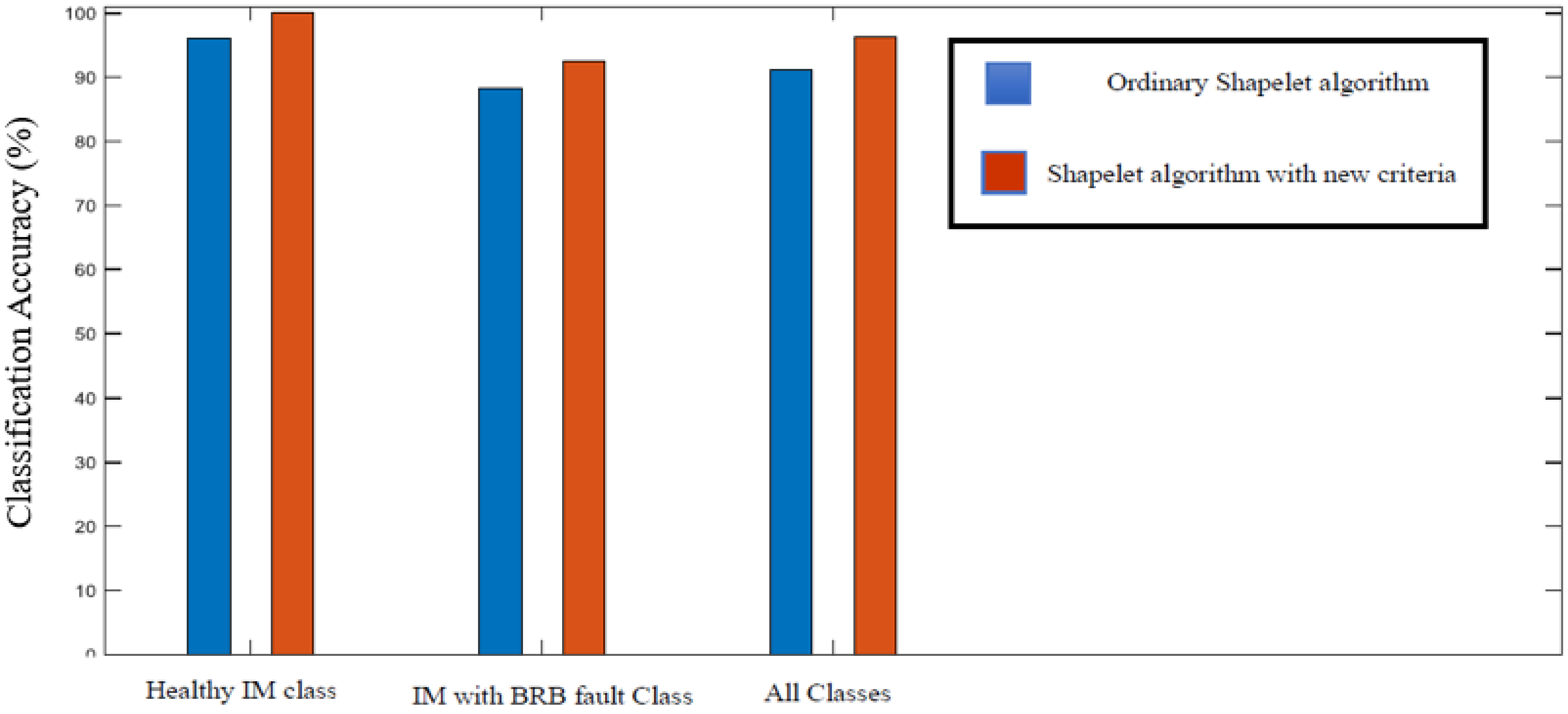


Case Study

- A test dataset with 800 timeseries is made for performance evolution.
- This dataset consists of 400 timeseries in a healthy situation and 400 timeseries for the IM with 6 BRBs.



Assessing the accuracy of test dataset classification with the proposed classification algorithm and ordinary shapelet algorithm



Conclusion

- Novel algorithms to calculate Min_n and Max_n as well as the Information Gain are proposed.
- These new criteria make shapelet algorithm more accurate.
- The classification is more efficient with these criteria.
- Shapelets can be used for feature extraction in order to detect the induction motor faults easily, accurately and efficiently.

Thanks for your attention