

Linear discriminate analysis and k-nearest neighbor based diagnostic analytic of harmonic source identification

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ABSTRACT

The diagnostic analytic of harmonic source is crucial research due to identify and diagnose the harmonic source in the power system. This paper presents a comparison of machine learning (ML) algorithm known as linear discriminate analysis (LDA) and k-nearest neighbor (KNN) in identifying and diagnosing the harmonic sources. Voltage and current features that estimated from time-frequency representation (TFR) of S-transform analysis are used as the input for ML. Several unique cases of harmonic source location are considered, whereas harmonic voltage (Hv) and harmonic current (Hc) source type-load are used in the diagnosing process. To identify the best ML, each ML algorithm is executed 10 times due to prevent any overfitting result and the performance criteria are measured consist of the accuracy, precision, geometric mean, specificity, sensitivity, and F-measure are calculated.

1. INTRODUCTION

The increase in non-linear loads in the industrial, commercial and domestic power system has changed the utilities power quality conditions [1-3]. With the fast development in power electronics, the load behavior changes from linear to non-linear and these loads contribute harmonic pollution in electrical power system [4-6]. Harmonics caused complications such as operation failures of electrical equipment, power losses, overheating, and overloading of power system equipment [7-10]. Thus, it is vital to identify the most suitable methodologies to identify and diagnose the type of harmonic sources in the power system [11-13]. Various methods have been suggested by researchers due to diagnose the type of harmonic sources based on different theoretical principles, features, benefits, and drawbacks. Nevertheless, a high level of technical experience is required to properly diagnose the harmonic source type [14-16].

The literature on the diagnosis method using the stochastic approach and power quality indexing been explained in [17, 18]. However, this method utilizes Fourier and wavelet transform signal processing techniques, whereas many constraints of these signal processing techniques are explained in [19-21]. Furthermore, a diagnosis study using a short-time fourier transform (STFT) and S-transform based on a rules-based classifier is introduced in [22-24]. However, high technical knowledge is essential due to distinguish the rules-based classifier threshold parameter values [25, 26]. Power quality analysis is a tricky task as the presence of complex-linear, as well as nonlinear patterns in the power quality event and old statistical method of auto-regressive integrated moving average (ARIMA), is introduced [27, 28]. To improve the accuracy of the ARIMA approach, the vector autoregressive model and artificial neural networks (ANN) are introduced [29]. This is due to capture the linear interdependence and uncover the non-linear aspects, whereas made this method difficult and complex to apply. Many researchers used statistical learning theory (SLT) for pattern recognition [30, 31]. In [32], Kumar used a neural network-based classification algorithm for distinguishing the disturbance signals. However, this method is not suitable to construct the frequency spectrum, thus results in the loss of frequency components that has low energy components [3]. A computerized optimization algorithm with the mechanics of natural genetics and natural selection option is known as genetic algorithm (GA) also been introduced in in diagnostic analytic [33]. The basic principal of GA is to calculate the highest survival probability of the fittest individual. The main advantage of this technique is, it use variables coding set as a substitute of actual variables. However, the drawback of GA such not applicable for dynamic data set, difficult to decide the fitness function, and the output accuracy is reliant on the problem knowledge [34].

The fuzzy logic (FL) and probabilistic neural network are used in [35] to distinguish type of harmonic sources. However, the total accuracy of this method is decrease whenever new type of load is introduced [23]. But, the FL has a drawback such as the design of the rule-based is complex, and FL is not

flexible to new disturbance types [36, 37]. The logistic regression is one the popular classification algorithms from the machine learning field [38]. The logistic regression is commonly used for classification compared to linear regression [39, 40]. Nevertheless the logistic regression unable to solve the non-linear problems as its decision surface is linear and its great dependence on a proper data presentation [41]. This means that the logistic regression is not a advisable tool unless all the significant independent variables are obtainable [42, 43]. Until now, the artificial intelligence such as machine learning has become one of the vital techniques in the classification of the power quality system [44, 45].

Numerous works of literature were stated, that the common machine learning methods, for example, support vector machine (SVM), Naïve Bayes (NB), linear discriminate analysis (LDA), and K-nearest neighbor (KNN) offer satisfactory performance for classifying and diagnosis purpose [46-48]. This paper presents a high accuracy, fast estimation, and costs effective technique to diagnose the type of harmonic sources in the distribution system with single-point measurement at the point of common coupling (PCC) by utilizing the machine learning algorithms [49, 50]. The chosen machine learning algorithms are the LDA and KNN [51, 52]. The LDA is one of the robust machine learning algorithms in this world. LDA not only simple but also efficient. Besides, LDA is faster and computationally less expensive. Generally, the main goal of LDA is to discriminate against the observed features by maximizing the posterior probability [53]. KNN is a common machine learning algorithm that has commonly applied in many engineering applications such as feature selection, pattern recognition, and fault identification [54, 55]. Among the modern algorithms, KNN can usually perform faster to achieve the results. The KNN not only simple but also computationally efficient [56]. In general, KNN predicts the class based on the k most similar training data using the Euclidean distance measurement [57]. At last, the best machine learning method for identifying and diagnosing harmonic sources is selected based on the performance measurement criteria such as the accuracy, precision, geometric mean, and F-measure [58-60].

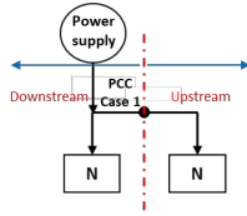
2. RESEARCH METHOD

In this research two types of machine learning algorithms, namely LDA and KNN are employed to diagnose the type of harmonic sources. This is due to their excellent performance in the works of literature. The LDA has less computational complexity and able to discriminate the observed features by maximizing the posterior probability. In this work, LDA with linear function is implemented. Meanwhile, the K-fold cross-validation technique is utilized for performance evaluation. Initially, the data is allocated equally into K parts, and each part is used for testing in succession. Besides, the remaining parts are used to train the classifier. Instead of using a hold-out technique, the cross-validation technique is more preferred because it can prevent overfitting and bias results [47]. In this research, a KNN with $k=1$ is applied.

The main objective of this research is to classify and identify the location and type of harmonic sources that connected to the power system network. The execution of the proposed method is realized using the single-point measurement technique at the PCC as presented in Figures 1 and 2 using IEEE 4-bus test feeders [61]. Furthermore, the measured voltage and current signals are analyzed using time-frequency analysis namely S-transform. The S-transform has been evolved which enjoys the advantages of both STFT and wavelet transform, while has a great advantage in detecting, and classifying the power quality. Two different types of harmonic sources consist of the harmonic current source (H_C) and harmonic voltage source (H_V) type-load are used in this research [62]. In addition, four explicit cases are considered in this research [63, 64]:

- N-N: no harmonic source in the power system (case 1),
- N-H: harmonic source located at the downstream of the PCC (case 2),
- H-H: harmonic source located at the downstream and upstream of the PCC (case 3), and
- H-N: harmonic source located at the upstream of the PCC (case 4).

Figure 3 presents an overview of the proposed method. To begin with the voltage and current signals are measured at the PCC. Next, the S-transform analysis is applied and then the signal parameters can be estimated from the TFR. Two types of feature sets are use as input to the machine learnings include current feature set, and voltage feature set. Finally, the location and type of harmonic sources are obtain using LDA and KNN. The best machine learning will be determined based on the performance measurement and explain in sub-section 2.2



N is a non-harmonic source, which is resistor load, H is harmonic producing load (H can be H_C or H_V)

Figure 1. Upstream-downstream for N-N

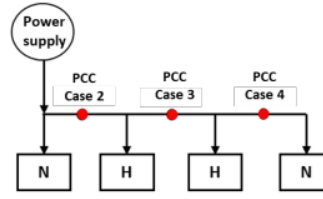


Figure 2. IEEE 4-bus test feeders for N-H, H-H, and H-N

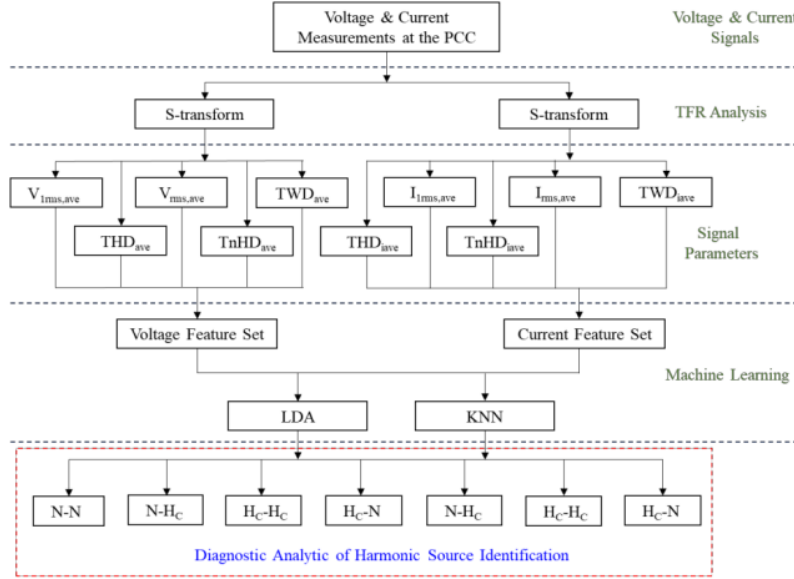


Figure 3. An overview of the proposed method

2.1. Voltage and current feature sets

The feature set consist of five signal parameters of each voltage and current signals [65, 66]:

- The average instantaneous RMS of voltage and current ($V_{rms,ave}$ and $I_{rms,ave}$)
- The average instantaneous $\sqrt{2}$ S fundamental of voltage and current ($V_{I_{rms,ave}}$ and $I_{I_{rms,ave}}$)
- The average instantaneous total harmonic distortion of voltage and current (THD_{ave} and $THD_{I_{ave}}$)
- The average instantaneous total nonharmonic distortion of voltage and current ($TnHD_{ave}$ and $TnHD_{I_{ave}}$)
- The average instantaneous total waveform distortion of voltage and current (TWD_{ave} and $TWD_{I_{ave}}$)

2.2. Machine learning performance measurement

To prevent any numerical analysis problem, the estimated feature sets are normalized between 0 and 1. Subsequently, in the classification process, the feature set is fed into the KNN and LDA, which aims to diagnose the multiple harmonic sources. Note that LDA and KNN are running for 10 times, and the average results are recorded. For performance measurement, four famous evaluation metrics, namely accuracy, precision, geometric mean, and F-measure are used. The performance measurement techniques as follows:

2.2.1 Accuracy

The accuracy is a metric used to measure how accurate the proposed harmonic source diagnosis system can be. It is defined as [58],

$$Accuracy = \frac{\text{No. of corrected diagnosed samples}}{\text{Total number of samples}} \quad (1)$$

2.2.2 Precision

Precision is the proportion of the expected positive samples that corrected, and it can be expressed as,

$$Precision = \frac{TP}{TP+FP} \quad (2)$$

2.2.3 Geometric mean

Geometric mean (G-mean) is an enhanced version of sensitivity and specificity, and it can be calculated as [58],

$$Geometric\ mean = \sqrt{Sensitivity \times Specificity} \quad (3)$$

2.2.4 Specificity

Specificity is another commonly used metric in diagnosis, and it can be calculated as [58],

$$Specificity = \frac{TN}{TN+FP} \quad (4)$$

2.2.5 Sensitivity

Sensitivity is a commonly used metric in diagnosis, and it can be expressed as,

$$F - measure = \frac{2TP}{2TP+FN+FP} \quad (5)$$

2.2.6 F-measure

F-measure is an important metric that supports accuracy, and it is used to characterize the performance of a classifier. It can be defined as [58],

$$F - measure = \frac{2TP}{2TP+FN+FP} \quad (6)$$

Where TP is the true positive, TN is the true negative, FN is the false-negative, and FP is the false positive, which can be obtained from the confusion matrix.

3. RESULTS AND DISCUSSION

Table 1 tabulates the results of accuracy, precision, geometric mean, and F-measure for the identification of the harmonic sources using LDA and KNN for the voltage feature set. From Table 1, one can observe that the performance of LDA and KNN were deficient, which cannot identify the harmonic sources correctly. Even though LDA performed better than KNN, but LDA scored the accuracy of 38.69%, which was lower than 50%. This might be the weak discriminability of voltage features, thus leading to the worst performance in this work. Based on the results obtained, voltage features were not a proper choice for harmonic source identification. Table 2 displays the results of accuracy, precision, geometric mean, and F-measure for the identification of the harmonic sources using LDA and KNN for the current feature set. As can be seen, the performances of LDA and KNN were good. The result shows that current features were able to discriminate the classes between harmonic sources, which contribute to the optimal performance in this work. From Table 2, it is clear that LDA achieved better results as compared to KNN. This might be the high linearity of current features that gives the LDA to provide excellent performance while identifying the harmonic sources.

Figure 4 and Figure 5 illustrate the confusion matrix of LDA and KNN for the identification of harmonic sources using voltage feature set. In these Figures, only N-N can be correctly identified (100%). The performance of KNN was worst compared to LDA. Most classes of KNN were below 10%, which made it fail to identify the harmonic sources correctly. Even though LDA was better than KNN, but its performance was still lower than 30% in most classes. In sum, voltage features are not suitable for harmonic source identification. Figure 6 and Figure 7 demonstrate the confusion matrix of LDA and KNN for the identification of harmonic sources using the current feature set. In these Figures, it shows that LDA and KNN were able to identify the harmonic sources very well, which offered high class-wise accuracy of above 90%. With KNN, the Hc-N, N-N, and N-Hv were perfectly classified (100%). However, the N-Hc, Hv-Hv, and Hv-N were lower than 95% class-wise accuracy. On the other hand, LDA scored 100% class-wise accuracy on Hc-N, N-Hv, and 99% on N-N. Only two classes, N-Hc and Hv-Hv were lower than 95%, which was superior than KNN in harmonic sources identification. The result affirms the LDA can usually provide higher performance than KNN in harmonic sources identification.

Table 1. The performances of LDA and KNN using the voltage feature set

| Evaluation metrics | LDA | KNN |
|--------------------|--------|--------|
| Accuracy (%) | 38.69 | 25.81 |
| Precision | 0.2987 | 0.1485 |
| Geometric mean | 0.4767 | 0.1760 |
| F-measure | 0.2948 | 0.1498 |

Table 2. The performances of LDA and KNN using the current feature set

| Evaluation metrics | LDA | KNN |
|--------------------|--------|--------|
| Accuracy (%) | 97.50 | 96.38 |
| Precision | 0.9733 | 0.9600 |
| Geometric mean | 0.9842 | 0.9761 |
| F-measure | 0.9730 | 0.9590 |

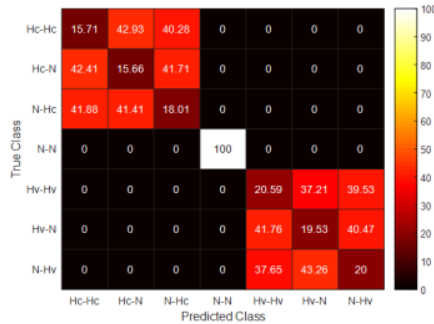


Figure 4. Confusion matrix of LDA using the voltage feature set

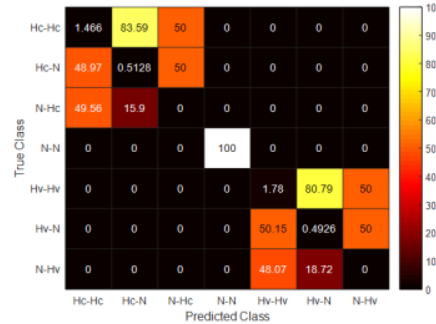


Figure 5. Confusion matrix of KNN using the voltage feature set

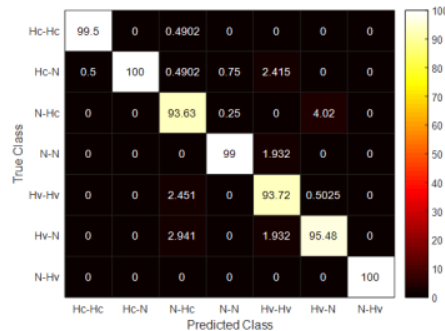


Figure 6. Confusion matrix of LDA using the current feature set

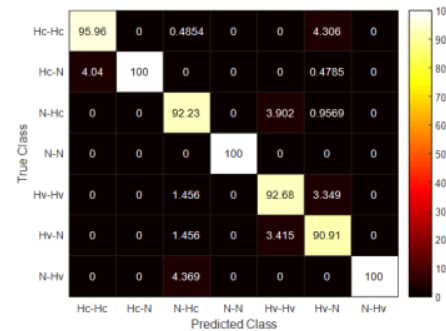


Figure 7. Confusion matrix of KNN using the current feature set

4. CONCLUSION

In this research, the impact of current features and voltage features on the identification of multiple harmonic sources has been investigated. Besides, the performances of proposed feature sets are validated using the machine learning algorithm, namely LDA and KNN. The experimental results show that the current features are more capable of enhancing the accuracy of harmonic source identification rather than using voltage features. Also, current features were good in the diagnostic process, which showed high discriminative power in this work. The results also prove that the performance of LDA was better than KNN in harmonic sources identification. In the future, the combination of current features and LDA can be applied to other power quality applications.

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