K-nearest neighbor and naïve Bayes based diagnostic analytic of harmonic source identification

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ABSTRACT

This paper proposes a comparison of machine learning (ML) algorithm known as the k-nearest neighbor (KNN) and naïve Bayes (NB) in identifying and diagnosing the harmonic sources in the power system. A single-point measurement is applied in this proposed method, and using the S-transform the measurement signals are analyzed and extracted into voltage and current parameters. The voltage and current features that estimated from time-frequency representation (TFR) of S-transform analysis are used as the input for MLs. Four significant cases of harmonic source location are considered, whereas harmonic voltage (H_V) and harmonic current (H_C) source type-load are used in the diagnosing process. To identify the best ML, the performance measurement of the proposed method including the accuracy, precision, specificity, sensitivity, and F-measure are calculated. The sufficiency of the proposed methodology is tested and verified on IEEE 4-bust test feeder and each ML algorithm is executed for 10 times due to prevent any overfitting result.

1. INTRODUCTION

Today the power quality issue such as harmonic signals turn into interesting study cross-disciplinary areas, combination of power electronic, power engineering, digital signal processing, artificial intelligence and embedded system [1]-[3]. Harmonics have turn into an important power quality problematic since the distortion level in the power system is increased due to this issue [4], [5]. The harmonic pollution at the point of common coupling (PCC) is the consequence of multiple harmonic sources include non-linear load that connected to the power network system, whereas the injected harmonic components in the power system may caused hardware failure and malfunction of sensitive loads [6], [7]. Therefore, diagnosis, identification, monitoring of harmonic sources become main concern in the power systems [8]. When the harmonic source is identified, its effects on power system can be studied and the proper mitigation methods shall be implemented [9]. Thus, an identification of harmonic source is important and numerous techniques have been proposed by experts due to identify harmonic sources dependent on various hypothetical and advantages [10], [11]. Using random probability distribution of data with fast Fourier transform (FFT) analysis is proposed in [12] due to identify type of harmonic sources.

However, the FFT is not able to accommodate non-stationary signal, which is the changes of spectral characteristic in time [13], [14]. A knowledge-based system namely, fuzzy logic, neural network and machine learning are computer programs that simulate and imitate the abilities of decision-making abilities of human experts within a specified field [2], [15]. An approach using a fuzzy logic (FL) using If-Then rule for identifying and diagnosing are proposed in [16]-[18]. In order to validate the rule-base, all possible rules are examined [19], [20]. Nevertheless, several restrictions of FL including: require enormous number of rules in the information base makes the framework become clumsy and confounds its support particularly on account of unpretentious updates, and the trouble in appointing certainty rating to each rule [21]-[23]. The harmonic source identification using artificial neural networks (ANN) method to the problem of harmonic load diagnosis has some practical issue and they are discussed in [24], [25]. ANN has an ability to study the mathematical relationship of series input and output variables which are independent or predictor variables [26], [27]. However, the ANN model suffers from overfitting of a training data set and bad performance in external test data sets [28], [29]. Currently, one of artificial intelligence sub set which is the machine learning (ML) has become one of the crucial methods in the identification method [30]. Various literatures were stated, that the most used and satisfactory performance of machine learning algorithms are k-nearest neighbor (KNN), naïve Bayes (NB), support vector machine (SVM), and linear discriminate analysis (LDA) in classifying and diagnosing purpose [30]. Although many methods are proposed in the identification of harmonic source, it is still not accurate and fast enough to identify the harmonic sources that connected to the power system network. A good digital signal processing (DSP) technique is required to process input signals that are used in the proposed method [14], [31]. DSP such as S-transform which is a hybrid of short-time Fourier transform (STFT) and wavelet transform (ST) is the most suitable technique as it offers high resolution in time and frequency analysis [32], [33].

This paper proposes accurate and fast method to diagnose the type of harmonic sources in the distribution system with single point measurement at the PCC by utilizing the machine learning techniques [34], [35]. The diagnostic analytic of harmonic sources type is using two popular machine learning algorithms, namely, KNN and NB [36], [37]. The KNN is one of the pretty simple and easy to use classifier in this world [38]. Unlike other algorithms, KNN directly predicts the test data based on the distance measurement on training data, which is computationally less expensive. In this work, the KNN with Euclidean distance and *k*=1 is applied. KNN can usually perform faster to achieve the results and this algorithm not only simple but also computationally efficient. Another reliable classifier, NB is implemented in this work [39] ,[40]. Given the fact that NB is predicting the classes based on a simple Bayesian theorem, NB can be used to identify the multiple harmonic sources in current research. In the present study, the NB with normal distribution is adapted [41], [42]. The effectiveness and powerful of machine learning have motivate us to implement it in the identification of harmonic sources system. Lastly, the best machine learning algorithm is nominated based on the performance measurement criteria for instance the accuracy, precision, specificity, sensitivity and F-measure [43]. Besides, the S-transform is used to process the input signals that measured at the PCC of the power system network [44]-[46].

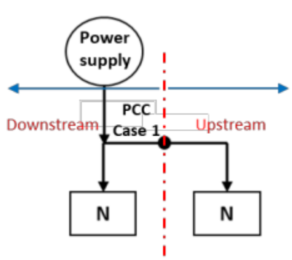
2. RESEARCH METHOD

In this section, the utilized machine learning algorithms, which is also known as classifier, will be described. This work aims to diagnose type of harmonic sources by using the extracted power quality features from both current and voltage signals. Hence, two simple machine learning algorithms, namely, KNN and NB are employed. KNN is one of the pretty simple and easy to use classifier in this world. Unlike other algorithms, KNN directly predicts the test data based on the distance measurement on training data, which is computationally less expensive. In this work, the KNN with Euclidean distance and k=1 is applied. Another reliable classifier, NB is implemented in this work. Given the fact that NB is predicting the classes based on a simple Bayesian theorem, NB can be used to identify the multiple harmonic sources in current research [47]. In the present study, the NB with normal distribution is adapted.

In current literatures, recommend the execution of the proposed technique can be realized using measurement method at the PCC as show in Figures 1 and 2 using IEEE 4-bus test feeders. In addition, the measurement signals are analyzed utilizing S-transform technique [48], and two types of harmonic sources are considered in this research comprise of harmonic current source (H_C) and harmonic voltage source (H_V) type-load [49]. Four specific cases are considered, which are [50], [51]:
- Case 1: no harmonic source in the power system (N-N),
- Case 2: harmonic source located at the downstream (N-H) of the PCC,
- Case 3: harmonic source located at the downstream and upstream of the PCC (H-H),
- Case 4: harmonic source located at the upstream of the PCC (H-N).

The main goal of this research is to identify and diagnose type of harmonic sources in the power system.

Where N is non-harmonic source which is resistor load, H is harmonic producing load whereas H is H_C or H_V, respectively. Figure 3 shows the overview of the proposed method. Initially, the current and voltage signals are measured at the PCC. After that, the S-transform analysis is applied to transform the voltage and current signals into time-frequency representation (TFR). Then, the signal parameters are then estimated from the TFR and the parameters divided into two feature sets: (i) current feature set, and (ii) voltage feature set. The feature sets are normalized and then fed into the machine learning for the diagnosis of harmonic sources. The KNN and NB are applied in order to diagnose the NN, NH, HH, and HN cases for both H_C and H_V.



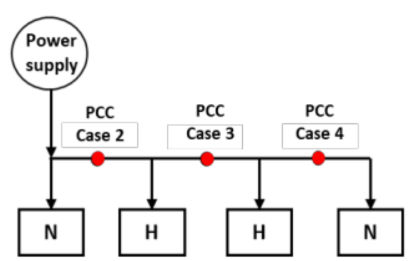


Figure 1. Upstream-Downstream for Case 1

Figure 2. IEEE 4-bus test feeders for Case 2, 3 and 4

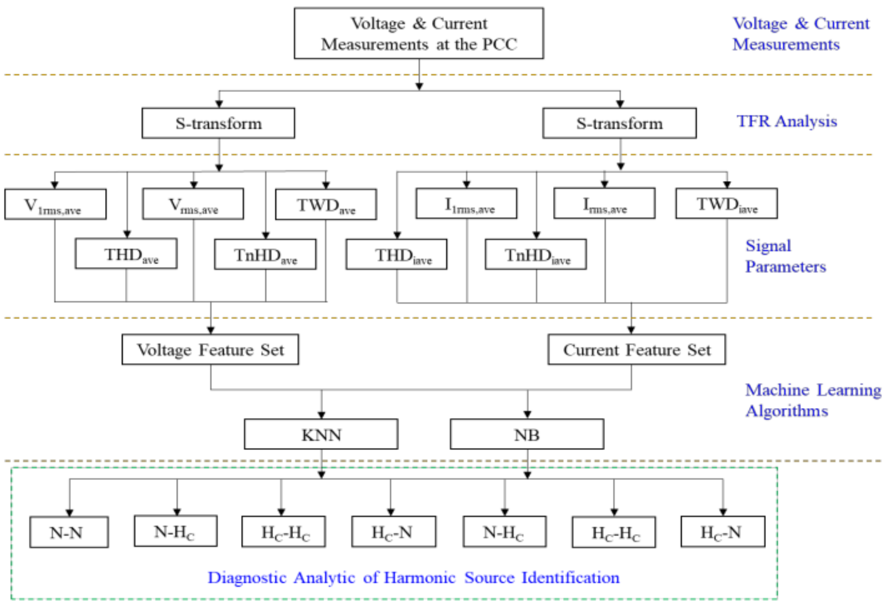


Figure 3. An overview of proposed method

2.1. Voltage and current feature sets

In this research, the voltage and current feature sets contain five signal parameters that estimated from the voltage and current signals of the PCC, respectively [52], [53]:

a. The average instantaneous RMS of voltage and current ($V_{rms,ave}$ and $I_{rms,ave}$)
b. The average instantaneous RMS fundamental of voltage and current ($V_{1rms,ave}$ and $I_{1rms,ave}$)
c. The average instantaneous total harmonic distortion of voltage and current (THD_{ave} and THD_{iave})
d. The average instantaneous total nonharmonic distortion of voltage and current ($TnHD_{ave}$ and $TnHD_{iave}$)
e. The average instantaneous total waveform distortion of voltage and current (TWD_{ave} and TWD_{iave})

2.2. Performance measurement of machine learning

In this research, two feature sets, namely, voltage feature set (feature subset made up of voltage features) and current feature set (feature subset made up by current features) are used. These features are initially estimated from the voltage and current signals. Besides, the min-max normalization method is applied to normalize the features in the ranges between 0 and 1, which aims at preventing the numerical issue. In this work, M-fold cross-validation manner is implemented for performance evaluation. In M-fold cross-validation, the dataset is equally divided into M parts, and each M part is used as testing set in succession. At the same times, the other M-1 parts are used for training set [54]. The KNN and NB are executed for 10 times each. This study set M=10. For performance measurement, five evaluation metrics, namely accuracy, precision, sensitivity, specificity, and F-measure are calculated, and they can be defined as follows [55]:

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

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

$$Sensitivity = \frac{TP}{TP+FN} \quad (3)$$

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

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

where the true positive (TP), true negative (TN), false positive (FP), false negative (FN), which can be obtained from the confusion matrix.

3. RESULTS AND DISCUSSION

Table 1 shows the results of accuracy, precision, sensitivity, specificity, and F-measure for the identification of the harmonic sources using KNN and NB for voltage feature set. A clear representation of results can be found in Figure 4. As can be seen, the performance of voltage feature set was very low. Even though NB show better results of accuracy, precision, sensitivity, specificity, and F-measure with 0.4000, 0.3039, 0.3129, 0.9016, and 0.3037, respectively. However, it is clear that the performances of KNN and NB were below average (less than 50%), which means the voltage features cannot identify the harmonic sources correctly.

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

Evaluation metrics	KNN	NB
Accuracy	0.2600	0.4000
Precision	0.1485	0.3039
Sensitivity	0.1521	0.3129
Specificity	0.8789	0.9016
F-measure	0.1498	0.3072

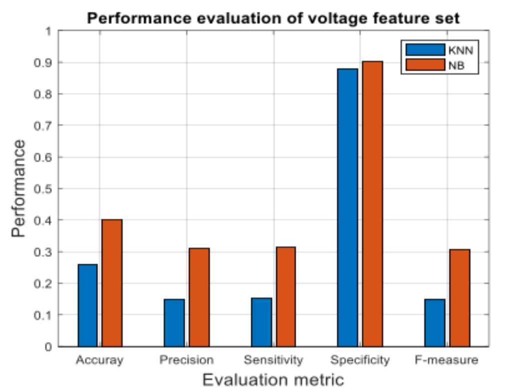


Figure 4. Performance evaluation of voltage feature set

Table 2 displays the results of accuracy, precision, sensitivity, specificity, and F-measure for the identification of the harmonic sources using KNN and NB for current feature set. On the other hand, the bar representation of results is demonstrated in Figure 5. As can be seen, the results achieved by using current feature set was significantly better than voltage feature set. This is because in the harmonic system, the voltage sources are connected in parallel, which only able to produce a very small voltage difference in terms of degree. On the contrary, current signals are different for most case due to parallel connection. Hence, good performance was achieved when current features are utilized.

Based on the results obtained, KNN and NB were able to identify the multiple harmonic sources in this work. The results show that KNN and NB both perceived the accuracy of 96%. However, as compared to NB, KNN has scored higher values of precision (0.9600), sensitivity (0.9587), specificity (0.9941), and F-measure (0.9590). Hence, it can be concluded that the performance of KNN was better than NB in harmonic sources identification.

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

Evaluation metrics	KNN	NB
Accuracy	0.9600	0.9600
Precision	0.9600	0.9576
Sensitivity	0.9586	0.9557
Specificity	0.9941	0.9934
F-measure	0.9590	0.9561

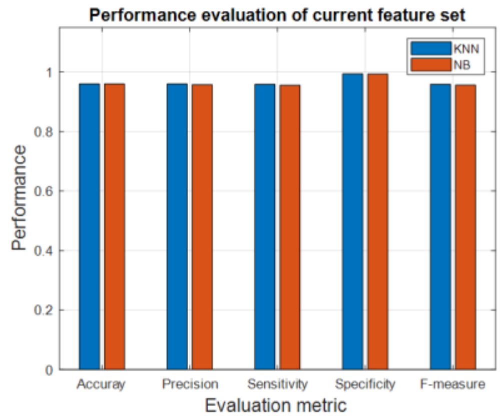


Figure 5. Performance evaluation of current feature set

Figure 6 and Figure 7 demonstrate the confusion matrix of KNN and NB for the identification of harmonic sources using current feature set. It is worth nothing that the confusion matrix of volateg feature set is not presented in this paper due to its worst performance in harmonic source identification. In these figures, it shows that KNN and NB were able to identify the harmonic sources very well. Especially for KNN, the Hc-N, N-N, N-Hv were perfectly identified (100% class-wise accuracy). With NB, only two classes (Hc-Hc and N-Hv were perfectly recognized. Inspecting the results, it can be inferred that KNN was an excellent classifier, which can usually offer high class-wise performance in harmonic sources identification system.

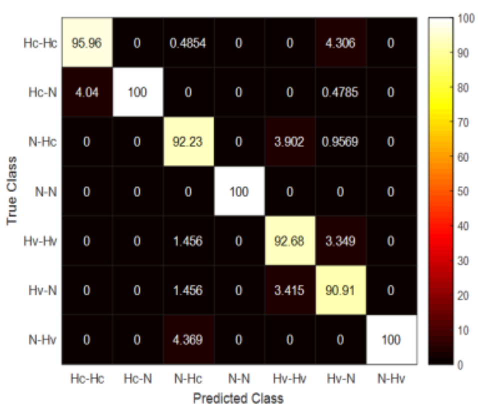


Figure 6. Confusion matrix of KNN using current feature set

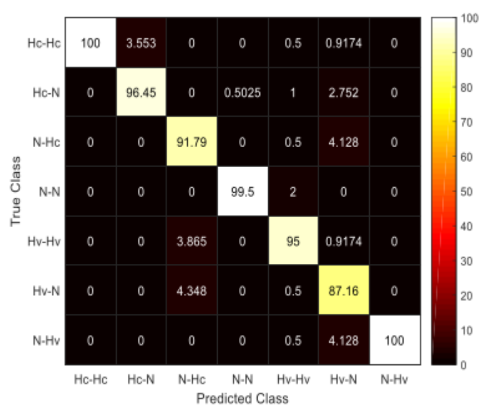


Figure 7. Confusion matrix of NB using current feature set

4. CONCLUSION

In this paper, an excellent power quality system to identify the multiple harmonic sources was proposed. Initially, the power quality signals were generated and collected. Afterward, the voltage and current features were estimated, and formed voltage feature set and current feature set. The proposed diagnostic system implemented machine learning algorithms known as KNN and NB. Based on experimental results, the combination of current features and KNN are more capable to achieve high performance in terms of accuracy, precision, sensitivity, specificity and F-measure in this work. In future, other popular classifier such as convolutional neural network can be applied for harmonic sources identification system.

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