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

Mohd Hatta Jopri\textsuperscript{1,}Mohd Ruddin Ab Ghani\textsuperscript{2,}Abdul Rahim Abdullah\textsuperscript{3,}Mustafa Manap\textsuperscript{4,}Tole Sutikno\textsuperscript{5,}Jingwei Too\textsuperscript{6}

\textsuperscript{1,4}Faculty of Electrical & Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka, Malaysia
\textsuperscript{2,3}Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
\textsuperscript{3}Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
\textsuperscript{5}Embedded System and Power Electronics Research Group (ESPERG), Yogyakarta, Indonesia

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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.

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Corresponding Author:
Mohd Hatta Jopri,
Faculty of Electrical & Electronic Engineering Technology,
Universiti Teknikal Malaysia Melaka,
Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
Email: hatta@utem.edu.my

1. INTRODUCTION

Today the power quality issue such as harmonic signal has 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.

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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 diagnosis 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 require 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 (Hc) and harmonic voltage source (Hv) 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: (1) current feature set, and (2) 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 (\( V_{\text{rms,ave}} \) and \( I_{\text{rms,ave}} \))

b. The average instantaneous RMS fundamental of voltage and current (\( V_{1\text{rms,ave}} \) and \( I_{1\text{rms,ave}} \))

c. The average instantaneous total harmonic distortion of voltage and current (\( \text{THD}_{\text{ave}} \) and \( \text{THD}_{\text{ave}} \))

d. The average instantaneous total nonharmonic distortion of voltage and current (\( \text{TnHD}_{\text{ave}} \) and \( \text{TnHD}_{\text{ave}} \))

e. The average instantaneous total waveform distortion of voltage and current (\( \text{TWD}_{\text{ave}} \) and \( \text{TWD}_{\text{ave}} \))
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]:

\[
\text{Accuracy} = \frac{\text{No. of corrected diagnosed samples}}{\text{Total number of samples}}
\]

(1)

\[
\text{Precision} = \frac{TP}{TP+FP}
\]

(2)

\[
\text{Sensitivity} = \frac{TP}{TP+FN}
\]

(3)

\[
\text{Specificity} = \frac{TN}{TN+FP}
\]

(4)

\[
F-\text{measure} = \frac{2TP}{2TP+FP+FN}
\]

(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|

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

![Figure 4. Performance evaluation of voltage feature set](image-url)
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.

| 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 voltage 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.
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 the 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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REFERENCES

[1] S. Nath, A. Dey, and A. Chakrabarti, “Detection of Power Quality Disturbances using Wavelet Transform,” World Academy of Science, Engineering and Technology, pp. 869-873, 2009.
[2] M. Mlakić, H. R. Baghaee and S. Nikolovski, “Islanding Detection in Microgrids including VSC-based Renewable/Distributed Energy Resources: An AI-based Technique,” 2018 International Conference on Smart Systems and Technologies (SST), Osijek, pp. 241-246, 2018.
[3] I. S. Qamber, “Power Systems Control and Reliability: Electric Power Design and Enhancement,” CRC Press, 2020.
[4] I. S. Qamber, “Reliability study of two engineering models using LU decomposition,” Reliability Engineering & System Safety, vol. 64, no. 3, pp. 359-364, June 1999.
[5] M. Y. Al-Hamad and I. S. Qamber, “Smart PV grid to reinforce the electrical network,” E3S Web of Conferences vol. 23, pp. 1-13, 2017.
[6] S. Li, Y. Sun, X. Xie, T. Yu, and S. Diao, “Harmonic Contribution Determination of Multiple Harmonic Sources Based on FastICA in Distribution Network,” 2018 2nd International Conference on Computer Science and Intelligent Communication, pp. 168-173, 2018.
[7] A. Rodríguez, J. A. Aguado, F. Martín, J. J. López, F. Muñoz, and J. E. Ruiz, “Rule-based classification of power quality disturbances using S-transform,” Electric Power Systems Research, vol. 86, pp. 113-121, May 2012.
[8] I. S. Qamber, “Peak load modeling for kingdom of Bahrain,” Journal of Software Engineering and Applications vol. 5, pp. 46-49, 2012.
[9] N. B. Jacobs, “Energy policy: economic effects, security aspects and environmental issues,” Nova Science Publishers, 2009.
[10] H. Zang, X. Qian and X. Yu, “Innovative Location Research of Multiple Harmonic Sources Based on Statistical Data Correlation,” 2012 Asia-Pacific Power and Energy Engineering Conference, Shanghai, pp. 1-4, 2012.
[11] Y. Teekaraman, R. Kuppusamy, and S. Nikolovski, “Solution for Voltage and Frequency Regulation in Standalone Microgrid using Hybrid Multiobjective Symbiotic Organism Search Algorithm,” Energies, vol. 12, no. 14, pp. 1-16, 2019.
[12] A. S. Hussin, A. R. Abdullah, M. H. Jopri, T. Suitkno, N. M. Saad, and W. Tee, “Harmonic load diagnostic techniques and methodologies: A review,” Indonesian Journal of Electrical Engineering and Computer Science, vol. 9, no. 3, pp. 690-695, 2018.
[13] S. Nikolovski, “Osnove analize pouzdanosti elektroenergetskog sustava,” Elektrotehnički fakultet sveučilišta Josipa Jurja Strossmayera, 1995.
[14] N. H. H. A. A. R. Abdullah, N. A. Abidullah, N. H. Shamsudin and and M. H. Jopri, “Performance Verification of Power Quality Signals Classification System,” Applied Mechanics and Materials, vol. 752-753, pp. 1158-1163, April 2015.
[15] M. S. Manikandan, S. R. Samantaray and I. Kamwa, “Detection and Classification of Power Quality Disturbances Using Sparse Signal Decomposition on Hybrid Dictionaries,” in IEEE Transactions on Instrumentation and Measurement, vol. 64, no. 1, pp. 27-38, Jan 2015.
[16] A. Moeed Amjad and Z. Salam, “A review of soft computing methods for harmonics elimination PWM for inverters in renewable energy conversion systems,” Renewable and Sustainable Energy Reviews, vol. 33, pp. 141–153, May 2014.
[17] I. Petrović, S. Nikolovski, H. R. Baghaee and H. Glavaš, “Determining Impact of Lightning Strike Location on Failures in Transmission Network Elements Using Fuzzy Decision-Making,” in IEEE Systems Journal, vol. 14, no. 2, pp. 2665-2675, June 2020.
[18] Z. L. Baus, S. N. Nikolovski, and P. Ž. Marić, “Process control for thermal comfort maintenance using fuzzy logic,” Journal of Electrical Engineering, vol. 59, no. 1, pp. 34-39, 2008.

K-nearest neighbor and naïve Bayes based diagnostic analytic of harmonic source... (Mohd Hatta Jopri)
[19] Y. Teeakaram, R. Kuppusamy, H. R. Baghaee, M. Vukobratović, Z. Balkić, and S. Nikolovski, “Current Compensation in Grid-Connected VSCs using Advanced Fuzzy Logic-based Fluffy-Built SVM Switching,” *Energies*, vol. 13, no. 5, p. 1259, 2020.

[20] H. R. Baghaee, D. Mlakić, S. Nikolovski and T. Dragičević, “Anti-Islanding Protection of PV-Based Microgrids Consisting of PHEVs Using SVMs,” in *IEEE Transactions on Smart Grid*, vol. 11, no. 1, pp. 483-500, Jan 2020.

[21] H. S. Behera, P. K. Dash, and B. Biswal, “Power quality time series data mining using S-transform and fuzzy expert system,” *Applied Soft Computing*, vol. 10, no. 3, pp. 945-955, June 2010.

[22] A. Banshwar and A. K. Chandel, “Identification of harmonic sources using fuzzy logic,” 2010 Joint International Conference on Power Electronics, Drives and Energy Systems & 2010 Power India, New Delhi, pp. 1-7, 2010.

[23] A. Moradifar, A. Akbari Foroud, and K. Gorgani Firoozjah, “Comprehensive identification of multiple harmonic sources using fuzzy logic and adjusted probabilistic neural network,” *Amir Moradifar, Asghar Akbari Foroud*, vol. 31, no. 1, pp. 543-556, Jan 2019.

[24] S. Varadan and E. B. Makram, “Practical considerations in the application of neural networks to the identification of harmonic loads,” *Electric Power Systems Research*, vol. 30, no. 2, pp. 103-106, 1994.

[25] Dragan Mlakić, Srete Nikolovski, and Ljubomir Majdandžić, “Deep Learning Method and Infrared Imaging as a Tool for Transformer Faults Detection,” *Journal of Electrical Engineering*, vol. 6, no. 2, pp. 98-106, 2018.

[26] D. Mlakić, S. Nikolovski and Z. Baus, “Detection of faults in electrical panels using deep learning method,” 2017 *International Conference on Smart Systems and Technologies (ISTS)*, Osijek, pp. 55-61, 2017.

[27] R. Kumar, B. Singh, D. T. Shahani, A. Chandra and K. Al-Haddad, “Recognition of Power-Quality Disturbances Using S-Transform-Based ANN Classifier and Rule-Based Decision Tree,” in *IEEE Transactions on Industrial Applications*, vol. 51, no. 2, pp. 1249-1258, March-April 2015.

[28] Z. Liu et al., “Accuracy analyses and model comparison of machine learning adopted in building energy consumption prediction,” *Energy Exploration & Exploitation*, vol. 37, no. 4, pp. 1426-1451, 2019.

[29] C. B. Khadse, M. A. Chaudhari, and V. B. Borghate, “Conjugate gradient back-propagation based artificial neural network for real time power quality assessment,” *International Journal of Electrical Power & Energy Systems*, vol. 82, pp. 197-206, Nov 2016.

[30] H. R. Baghaee, D. Mlakić, S. Nikolovski and T. Dragičević, “Support Vector Machine Based Fuzzy Logic Method for Determining Customer and Utility Harmonic Contributions at the Point of Common Coupling,” in *IEEE Transactions on Power Delivery*, vol. 15, no. 2, pp. 804-811, April 2000.
[45] A. S. S. Murugan and V. Suresh Kumar, “Determining true harmonic contributions of sources using neural network,” *Neurocomputing*, vol. 173, Part 1, pp. 72-80, 2016.

[46] M. F. B. Habban, M. Manap, A. R. Abdullah, M. H. Jopri, and T. Sutikno, “An evaluation of linear time frequency distribution analysis for VSI switch faults identification,” *International Journal of Power Electronics and Drive System*, vol. 8, no. 1, pp. 1-9, March 2017.

[47] A. Stetco *et al.*, “Machine learning methods for wind turbine condition monitoring: A review,” *Renewable Energy*, vol. 133, pp. 620-635, April 2019.

[48] N. H. T. Huda, A. R. Abdullah and M. H. Jopri, “Power quality signals detection using S-transform,” 2013 *IEEE 7th International Power Engineering and Optimization Conference (PEOCO)*, Langkawi, pp. 552-557, 2013.

[49] F. Z. Peng, H. Akagi and A. Nabae, “A new approach to harmonic compensation in power systems—a combined system of shunt passive and series active filters,” in *IEEE Transactions on Industry Applications*, vol. 26, no. 6, pp. 983-990, Nov-Dec 1990.

[50] A. Dixit and M. Kaur, “Harmonic source identification with optimal placement of PMUs,” *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Delhi, pp. 1-6, 2016.

[51] A. Teshome, “Harmonic source and type identification in a radial distribution system,” *Conference Record of the 1991 IEEE Industry Applications Society Annual Meeting*, Dearborn, MI, vol. 2, pp. 1605-1609, 1991

[52] A. R. Abdullah, N. a. Abdulllah, N. H. Shamsudin, N. H. H. Ahmad, and M. H. Jopri, “Power Quality Signals Classification System Using Time-Frequency Distribution,” *Applied Mechanics and Materials*, vol. 494, pp. 494-495, Feb 2014.

[53] M. H. Jopri, A. R. Abdullah, M. Manap, M. F. Habban, and T. Sutikno, “An Accurate Classification Method of Harmonic Signals in Power Distribution System by Utilising S-Transform,” *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 15, no. 1, pp. 12-20, 2017.

[54] J. Too and A. Rahim Abdullah, “Binary atom search optimisation approaches for feature selection,” *Journal Connection Science*, 2020.

[55] J. Too, Abdullah, and Mohd Saad, “A New Quadratic Binary Harris Hawk Optimization for Feature Selection,” *Electronics*, vol. 8, no. 10, p. 1130, Oct 2019.