Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage: https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Harmonic Detection of Electric Current using Machine Learning: A Literature Review

Luqman Assaffat[1,*], Herman Dwi Surjono[1], Fatchul Arifin[1]

[1] Engineering Sciences, Yogyakarta State University, Yogyakarta 55281, Indonesia

ARTICLE INFO

Article history:
Received 6 January 2025
Received in revised form 7 February 2025
Accepted 2 May 2025
Available online 23 May 2025

Keywords:
Electric power quality; electric current harmonics; machine learning

ABSTRACT

The increased use of nonlinear devices makes distortions in the form of current and voltage waves unavoidable in power grids. As a result, harmonics, sub-harmonics and inter-harmonics often occur in the current and voltage spectrum. Harmonics cause many problems such as overpower loss, overvoltage, imbalance, flicker, relay miss operation, etc. Harmonic distortion of electric current can be measured directly in harmonically contaminated systems. Various standards have already been established in different measurement procedures and many other techniques have been proposed for analysing, characterizing and classifying power quality data. Extensive power quality monitoring is often recommended for industrial and distribution systems. Harmonic measurements are usually performed as part of more general power quality measurements to gain insight into the distribution system's state. Detection of electric current harmonics using machine learning has been widely done and provides excellent results. This study is based on a literature review of research journals on machine learning studies that detect electric current harmonics in electric power system networks.

1. Introduction

The problem of the quality of electrical energy is the quality of the electrical power itself. Power quality has gained increasing attention in recent years due to the increased use of nonlinear loads using sophisticated solid-state power switching devices in many industrial and commercial applications. The operation of solid-state power switching devices in power electronic converters worsens power quality because they inject harmonics into the power system, leading to increased distortions, malfunctions and equipment and load losses [1]. Efficient power quality control and mitigation parameters rely heavily on accurate and timely power quality detection [2].

Harmonic pollution is one of the most critical power quality issues in power systems [3,4]. Harmonics can cause many problems, such as overpower loss, overvoltage, system imbalance, flicker, relay misoperation, etc. Engineers have widely researched several methods for detecting power

* *Corresponding author*
E-mail address: assaffat@unimus.ac.id

https://doi.org/10.37934/ard.132.1.140151

system harmonics due to increased harmonic pollution, so detecting harmonics becomes important [5,6].

The problem of harmonics is becoming so worrisome that it demands accurate estimation and reliable mitigation; there is an urgent urgency to identify the exact location of harmonic pollution sources so that corrective measures can be taken to improve power quality in place of consumers [3]. Many guideline and recommendation standards include IEEE 519-1992 and IEC 61000 series standards that have been in force today, including several indices such as Total Harmonic Distortion (THD) and Total Demand Distortion (TDD) used to measure harmonic voltage and electric current [2].

Harmonic measurements are often performed as part of more general power quality measurements to gain some insight into the state of the distribution system [7]. The secondary side of the step-down type transformer is usually equipped with a metering transformer and is suitable for installing measurement equipment and monitoring harmonic distortion [8].

Harmonic monitoring in an electric power system can be done by measuring THD voltage or electric current at PCC or at loads that are indicated to produce high harmonics [9]. One alternative method for monitoring harmonic levels of electric power systems is to identify THD, especially THD electric current. Several studies have been conducted to detect or identify current harmonics, both conventional and non-conventional methods. Harmonic identification using conventional methods includes directly measuring the electric power system using a Quality Meter measuring instrument. Identification with unconventional methods is carried out by modelling and computation, including research on the identification of pseudo-power-based harmonic sources [10], identification of harmonic sources based on a sinusoidal approach [11] and research on the identification of harmonic sources in distribution systems using soft computing [12].

Machine learning (ML) is a field of science that studies how to make AI models learnable. Generally, this AI model is called a ML model, a computational algorithm model that can store and change the knowledge owned through the learning process from data. ML models store knowledge as parameters, representing rules, integer numbers or decimals (float). However, models that use rules as a representation of expertise can update those rules based on the data used to train them [13].

ML is a series of techniques generally used to solve various problems in the real world with the help of computer systems that can learn to solve problems by explicitly deprogramming. In general, ML is distinguished into 2 (two) types, namely Unsupervised ML and Supervised ML [14].

ML algorithms can potentially improve energy efficiency and reduce greenhouse gas emissions. For example, ML algorithms have been used to identify energy consumption patterns and predict demand, enabling energy providers to optimize supply and reduce waste. In addition, ML can help assess the effectiveness of energy transition initiatives, such as the deployment of renewable energy sources, through data analysis from sensors, smart meters and energy monitoring systems [15].

To understand and know the development of research on the use of ML in the detection of electric current harmonics in electric power systems, this paper presents a review of journals on the detection of electric current harmonics using ML. Some journals related to harmonic reviews include a review of harmonic analysis, modelling and mitigation techniques [16] and a review of AI applications in harmonic analysis in power systems [17].

A review of harmonic analysis, modelling and mitigation techniques states that the study of academic harmonic analysis consists of nonlinear load modelling to develop Norton and Thevenin equivalent device circuits for integration into harmonic analysis software. Experimental researchers often use harmonic analysis to measure harmonics in real systems to evaluate appropriate mitigation alternatives. Distortive power loss forces utilities to increase real power to maintain a reliable and uniform power supply. Harmonic analysers use built-in data acquisition hardware and software algorithms to perform on-site measurements. The harmonic analyser helps to find the actual power factor, total harmonic distortion, reactive and power loss of distortion. Shunt capacitance on the unitary power factor aggravates the situation instead of providing distortive power compensation. Active power factor correction techniques, using intelligent algorithms to eliminate distortive power, have been reviewed for further research. The nonlinear physics of harmonic phenomena is described to explore their applications. Harmonic mitigation technologies have been compared and today's advanced technologies are reviewed and demonstrated by designing harmonic filters. Harmonic measurements, waveform distortion and the power factor of one- and three-phase electronic loads are performed to test their compliance with harmonic standard limits. The concept of energy conservation requires harmonic reduction in distribution networks. The study found a 60 ± 10% reduction in power factor and a more than 2% increase in line loss due to widespread use of nonlinear loads. The utility's power demand is increasing due to unintentional consumer violations of IEC Standard 61000-3-2 and IEEE Standard 519-1992 [16].

A review of the application of AI in harmonic analysis in power systems states that Artificial Intelligence (AI) techniques used in various aspects of analysing harmonics in power grids are reviewed. The tasks of spectral analysis and waveform estimation or prediction, harmonic source classification, location and estimation of harmonic sources, determination of harmonic source contribution, clustering of harmonic data, filter-based harmonic elimination and Distributed Generation (DG) hosting capacity in the context of Harmonics are considered. AI applications in these tasks have been addressed in the Literature and reviewed in this paper. Different AI techniques applied in harmonic studies, such as artificial neural networks, fuzzy systems, support vector machines and decision trees, are reviewed. AI techniques vastly outperform traditional methods in harmonic analysis, especially in a wide range of operating conditions. However, there is still room for improvement regarding combining techniques, ensemble learning, optimal structure, training algorithms and further understanding. This review provides researchers with insight into research trends in harmonic analysis and outlines opportunities for additional research on this increasingly important topic [17].

2. Methodology

The method used in this journal review adopts a guideline method for conducting systematic literature reviews in software engineering [18]. This methodology comprises three phases: planning, implementing and reporting reviews. The process is depicted in Figure 1.

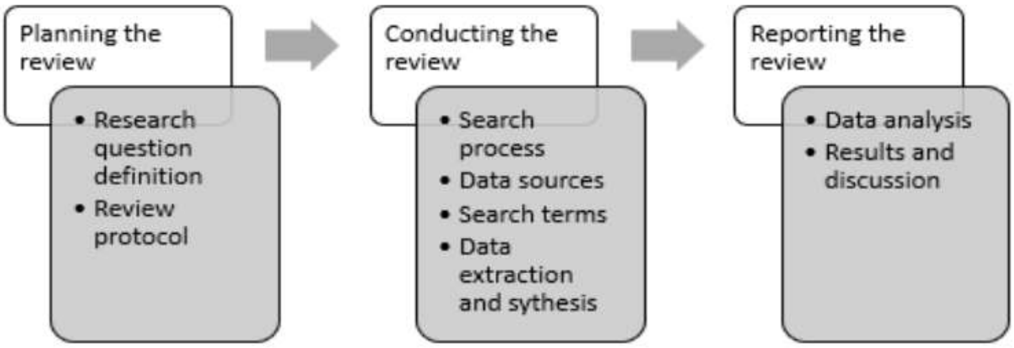

Fig. 1. Review phase

2.1 Planning Review

The first stage is to plan research questions and review protocols to ascertain the need for literature review.

2.1.1 Research questions

The research questions formulated in this study are stated as follows:

i. RQ1: What are the primary studies in research on harmonic detection of electric current using ML?
ii. RQ2: What methods or algorithms are used in the detection of harmonic electric current
iii. RQ3: What are the gaps and limitations in electric current harmonic detection research using ML?

2.1.2 Review protocol

The next step is to define the review protocol by stating the inclusion and exclusion criteria. These criteria filter papers so that they are by the research. Research papers are selected if they meet the inclusion criteria and omitted if they meet the exclusion criteria. The inclusion and exclusion criteria are shown in Table 1. In addition to the following criteria, it is also important to note that the accessibility of published papers limits these reviews.

Table 1
Terms of use

Conditions	Description
Research ID	Identifiers for each article
Author and Year of Publication	The author's name and the year when the paper was published.
Heading	Article title
Objek	The object of the research.
Data	Type of data collected and sample size
Methodologists	The methodology used to analyse the collected data,
Category	Research theme and focus
Sumber	Sumber di mana artikel itu diperoleh,

2.2 Review Search

This phase includes declaring the search process, data sources, search terms and data extraction and synthesis.

2.2.1 Search process

The article search process applies inclusion and exclusion criteria; article accessibility limits the search process. ScienceDirect is a website that provides access to a scientific bibliographic database containing a collection of quality full-text documents peer-reviewed by Elsevier. The initial search results obtained a total of 73 journal papers.

2.2.2 Data sources

The collected articles were obtained from an *online* library directed by search results on ScienceDirect. The articles collected are 73 articles in the review domain from 26 journals indexed by Scopus. The list of journals included in this review is summarized in Table 2.

Table 2
Journals included in the study

Name of Journal	Frequency
Mathematics and Computers in Simulation	1
Electric Power Systems Research	25
Measurement	4
Electrical Power and Energy Systems	10
International Federation of Accountants	3
Mechanical Systems and Signal Processing	1
Energy Procedia	1
Engineering Applications of Artificial Intelligence	1
Applied Soft Computing	1
Electrochimica Acta	1
Renewable and Sustainable Energy Reviews	2
Procedia Engineering	1
Engineering Science and Technology, an International Journal	1
Optics and Lasers in Engineering	1
Alexandria Engineering Journal	1
Digital Communications and Networks	1
Sustainable Energy Technologies and Assessments	1
Neurocomputing	1
Energy Reports	3
Applied Energy	2
International Journal of Electrical Power and Energy Systems	6
Infrared Physics and Technology	1
Energy Nexus	1
Transportation Research Procedia	1
Ain Shams Engineering Journal	1
Energy and AI	1

2.2.3 Search terms

When running the search process, the search terms included are "*ML for Detection Current Harmonics*," "ML for Identification Current Harmonics," and " ML for Measurement Current Harmonics." Before selecting articles to include in the review, duplication is carefully checked to ensure no repetition.

2.2.4 Data extraction and data synthesis

Data extraction is applied to the selected papers by carefully analysing and reading each. The steps mentioned above aim to collect relevant data related to this review. Then, data synthesis is carried out so the research questions can be answered and the study's objectives achieved.

2.3 Review Report

This phase consists of data analysis as well as results and discussion. Research questions should be answered in this phase and the goal of providing insight into how the state of electric current harmonic detection research using ML is current, as well as research gaps to find potential research areas for future study, should be achieved.

3. Results

3.1 Key Studies in Research

The number of journal articles successfully tabulated as many as 73 articles, published from 2003 to 2024, is shown in Figure 2 below. The *most ML-themed* articles for detection/identification/measurement of electric current harmonics published in 2022 are 12 articles; in 2023, there are 9 articles and in 2020, there are eight articles.

Of the 37 tabulated data articles, the journal titles that publish the most articles with the theme of *ML* for detection/identification/measurement of electric current harmonics are the Journal of "*Electric Power Systems Research"* with 25 articles, then the Journal of "*Electrical Power and Energy Systems"* with 10 articles and the Journal of "*International Journal of Electrical Power and Energy Systems*" with 6 articles.

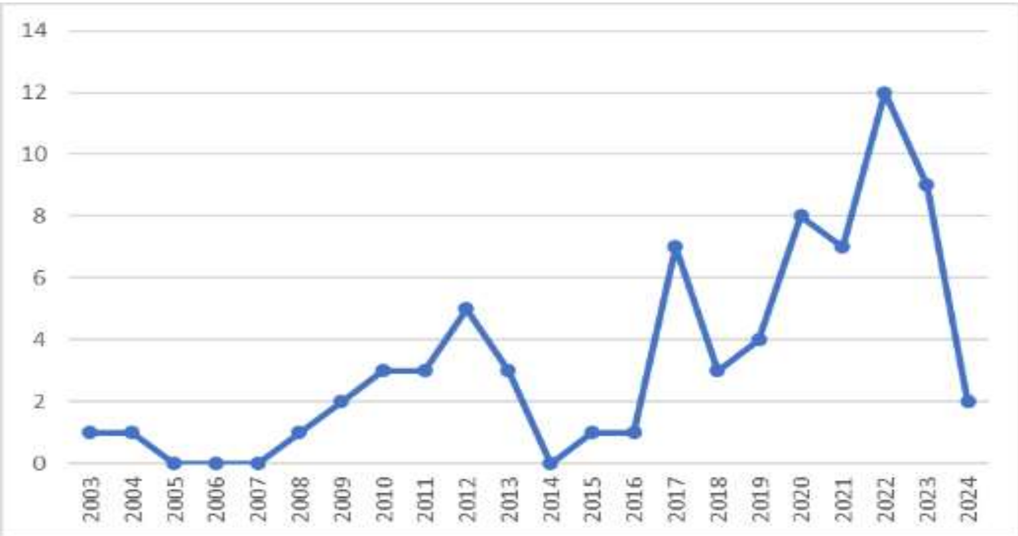

Fig. 2. Number of articles according to year published

There are 2 articles in the form of journal reviews (*Jurnal Review*), namely articles entitled "*Review of harmonic analysis, modelling and mitigation techniques*" [16] and "*Review of AI applications in harmonic analysis in power systems*" [17]. Of the 71 articles, other than journal reviews, 25 (35%) used signal processing simulation methods with Simulink or toolbox on Matlab and 46 (65%) used mathematical modelling. Based on the method or algorithm in the analysis, 42 articles (59%) used artificial intelligence, ML or statistical algorithms and 29 articles (41%) did not use artificial intelligence algorithms or statistics.

Figure 3 shows a visualization of the network using VOSViewer with a co-occurrence analysis type; the minimum number of events is 4 and the number of selected keywords is 64.

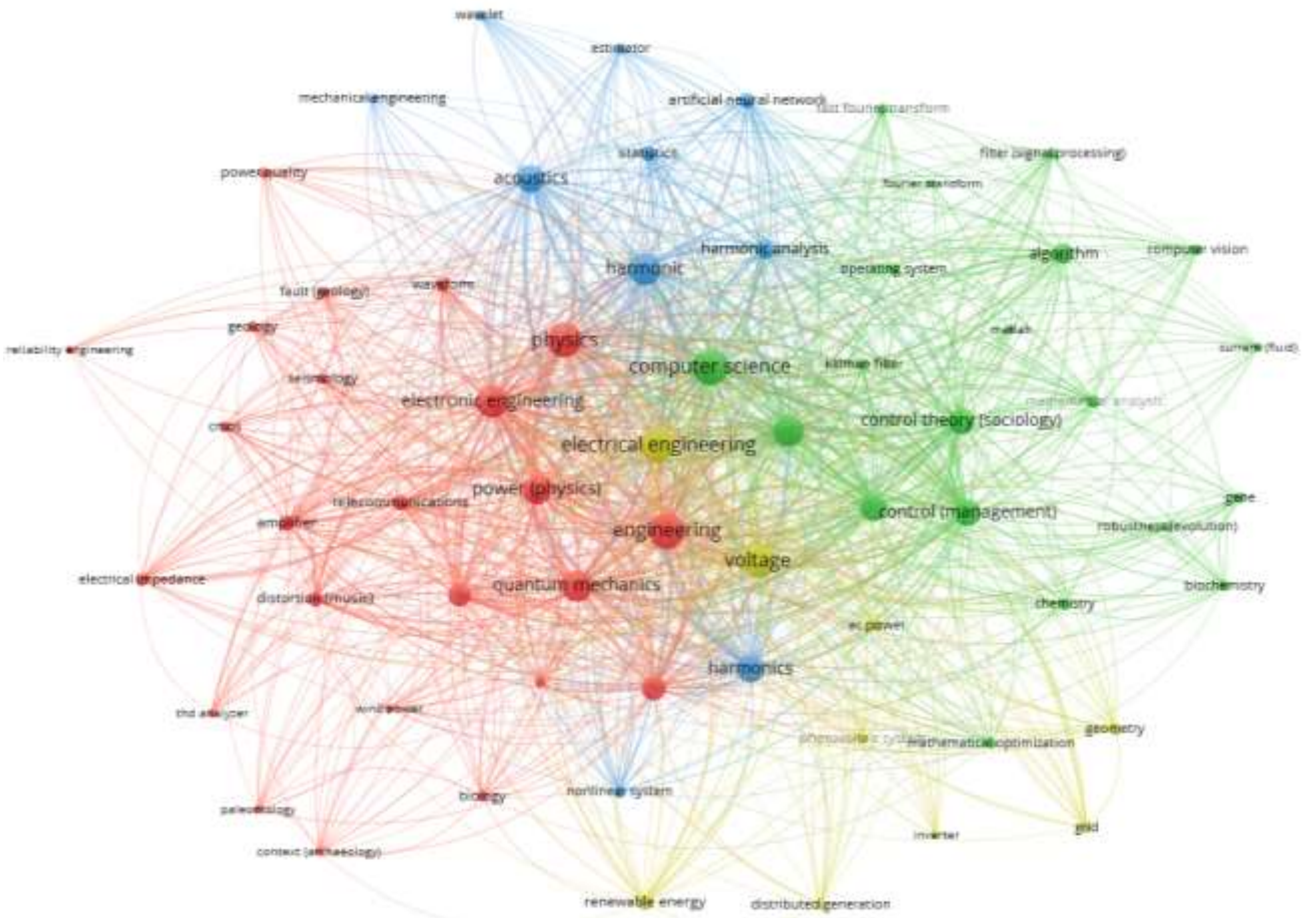

Fig. 3. Map used VOSViewer

3.2 Methods or Algorithms used in Research

Of the 42 articles using artificial intelligence, ML or statistical algorithms, the most used Artificial Neural Network (ANN)-based algorithms, as many as 13 articles (31.0%), Least square-based methods, as many as 4 articles (9.5%) and Wavelet Transformation methods as many as 3 articles (7.1%) and using the Kalman filter method as many as 3 articles (7.1%). A total of 19 articles (45.3%) used other algorithms.

3.3 Gaps and Limitations in Research

Research articles on the use of ML in the detection/prediction/measurement of electric current harmonics are still limited to Simulink modelling or Matlab toolbox and mathematical modelling and have not led to practical use. The artificial intelligence algorithm is still limited to ANN and other statistical methods. So, developing a more practical harmonic detection system and using other ML algorithm development that performs better is necessary.

4. Discussion

Research on electric current harmonic detection using ML primarily focuses on improving accuracy and efficiency in identifying harmonics within power systems (RQ1). This review explores various approaches and methodologies designed to tackle challenges in harmonic detection while highlighting the importance of performance analysis and tailored techniques for specific power system requirements.

The methods analysed in this research are diverse, ranging from traditional techniques like the Discrete Fourier Transform (DFT) to more advanced ML and signal processing methods. These include feed-forward and recurrent ANN, parametric estimation methods such as the modified Burg and covariance method, the Least Squares-Adaline (LS-Adaline) algorithm, the Discrete Wavelet Transform (DWT) and the Cross Frequency Correlation (XCF) method (RQ2). Each method exhibits unique advantages and limitations, with specific applications suited to modern power systems' varying conditions and demands.

One key finding highlights the efficacy of artificial neural networks in detecting harmonics under distorted wave conditions, offering high accuracy and adaptability. Parametric and non-parametric estimation methods have shown promise in detecting non-integer harmonics and sub-harmonics. Furthermore, innovative approaches such as LS-Adaline and wavelet-based techniques have demonstrated substantial potential in enhancing detection accuracy and efficiency.

Nevertheless, the study identifies significant gaps and limitations (RQ3). A major challenge is the reliance on accurate and diverse datasets, which can be difficult to collect consistently. Additionally, the computational complexity and cost associated with methods like ANN and wavelet transforms pose practical constraints, particularly for real-time applications in resource-constrained systems. Challenges under unpredictable fault conditions, synchronization difficulties and measurement accuracy hinder seamless implementation. Extending these methodologies to other power systems often necessitates significant modifications, highlighting their limited generalizability across varied environments.

Despite these challenges, this research emphasizes the transformative potential of ML in addressing harmonic detection challenges. With technological advancements, it is anticipated that more efficient and adaptable solutions will emerge to enhance power quality and minimize harmonic distortion.

The application of ML techniques for harmonic detection is gaining significant traction in industrial and utility environments. This research delves into real-world applications of these methods, emphasizing their benefits and the challenges encountered during implementation.

For instance, ANN have been successfully utilized in industries with complex, nonlinear systems, such as manufacturing plants and data centres. ANN-based harmonic detection enables real-time monitoring and identification of harmonic sources, ensuring equipment safety and reducing downtime. Its ability to detect harmonics even under distortion conditions and adapt to dynamic system changes makes it a highly versatile tool. However, the high computational demands and the necessity for large training datasets can be significant barriers, particularly for smaller facilities with limited resources.

Wavelet Transform techniques have been effectively applied in time-frequency analysis to detect transient harmonics in renewable energy systems and smart grids. For example, wavelet-based systems integrated into smart meters facilitate real-time monitoring of transient and non-stationary harmonics. While this method excels in detecting harmonics under varying load conditions, it requires careful parameter tuning and can impose computational burdens in large-scale systems.

Similarly, the LS-Adaline algorithm has proven helpful in utility-scale applications requiring real-time harmonic detection, such as monitoring distribution networks. Its low computational cost and fast response time make it suitable for optimizing power quality in low-voltage systems. However, its accuracy diminishes under high distortion or noise conditions, necessitating complementary techniques to enhance performance.

Real-world case studies illustrate the potential of these techniques. In a manufacturing facility, ANN-based harmonic detection reduced equipment failures by 30%, lowered operational costs and ensured compliance with power quality standards. Wavelet Transform methods in renewable energy systems detected transient harmonics caused by fluctuations in wind turbine output, contributing to grid stability. Utility companies employing LS-Adaline have enhanced power quality monitoring with minimal resource investments.

These examples underscore the significant role of ML in improving power quality and operational efficiency. Nevertheless, addressing challenges such as computational demands, data availability and system adaptability remains critical for achieving broader and more effective implementation in the future.

4.1 Comparative Analysis of Harmonic Detection Methods

Various ML methods have been utilized in the context of harmonic detection in electric power systems, each offering unique strengths and weaknesses. A detailed comparative analysis is provided in Table 3, summarizing the accuracy, computational complexity, data requirements and optimal application contexts of three prominent methods: ANN, Wavelet Transform and LS-Adaline.

Table 3
Comparative analysis of harmonic detection methods

Method	Accuracy	Computational Complexity	Data Requirements	Best Application Context
ANN	High	High	High	Complex, non-linear systems
Wavelet Transform	Moderate to High	Moderate	Moderate	Time-frequency analysis, transient signals
LS-Adaline	Moderate	Low	Moderate	Real-time applications with moderate distortion

The analysis reveals distinct advantages and limitations for each method:

i. <u>Artificial Neural Network (ANN):</u> ANN provides the highest accuracy, particularly in complex, non-linear systems. However, its computational complexity and reliance on extensive datasets make it less ideal for real-time applications. ANN excels in scenarios where accuracy is prioritized over efficiency.
ii. <u>Wavelet Transform:</u> This method balances accuracy and computational complexity. Its ability to perform time-frequency analysis makes it practical for detecting transient harmonics. Nonetheless, its performance depends on the selection of appropriate wavelet functions.
iii. <u>LS-Adaline:</u> Known for its simplicity, LS-Adaline is well-suited for real-time applications due to its low computational demands. However, its accuracy may be insufficient under high distortion or noisy conditions.

This comparative analysis highlights that no single method is universally optimal. The selection of a method should depend on specific operational requirements, such as the need for real-time processing, the level of harmonic distortion and the availability of computational resources.

By integrating this analysis into the review, the study provides a comprehensive understanding of the trade-offs associated with various ML techniques for harmonic detection. Future research should aim to combine the strengths of these methods or develop hybrid approaches to address their respective limitations.

Figure 4 shows a comparison between the accuracy (%) and computational complexity (%) of the three ML methods used for harmonic detection, namely ANN, Wavelet Transform and LS-Adaline. ANN has the highest accuracy of 95% but comes with a high computational complexity of 90%. This confirms that ANN is well suited for complex non-linear systems, although it is less ideal for real-time applications due to its sizeable computational resource requirements. The Wavelet Transform balances accuracy (85%) and computational complexity (70%), making it practical for transient signal analysis via a time-frequency approach. However, its performance depends on the selection of an appropriate wavelet function. On the other hand, LS-Adaline has the advantage of low computational complexity at 50%, but its accuracy is lower than the other methods at 75%. This makes it ideal for real-time applications with moderate distortion levels, although it is less reliable in conditions with high distortion or noise. This figure visually supports the earlier comparative analysis, emphasizing the trade-off between accuracy and computational complexity in each method. Therefore, selecting the optimal method depends on specific needs, such as real-time processing, harmonic distortion and the availability of computational resources. This analysis also reinforces the recommendation to explore hybrid approaches that can combine the advantages of each method to overcome the limitations.

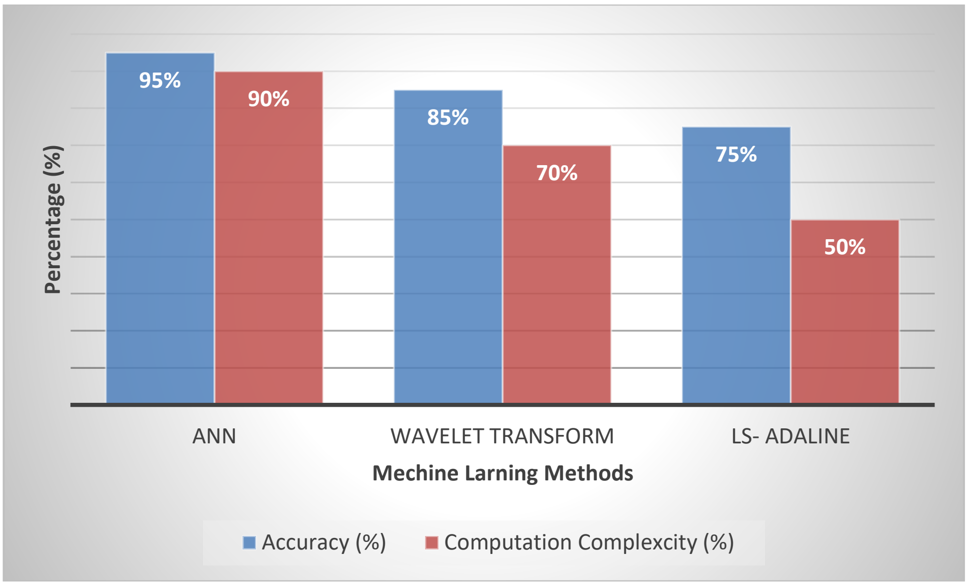

Fig. 4. Illustration accuracy and computation complexity

4.3 Application in Real World

ML methods are increasingly used to detect electrical current harmonics, offering innovative solutions for managing power quality in various settings. Examples include Southern California Edison (SCE), Bosch Manufacturing, Tesla Powerwall Systems and EDF Energy. SCE implemented an ML-based framework to monitor power quality continuously across their distribution network, utilizing neural networks and decision trees to detect harmonic distortions in real time. Bosch's system improved equipment lifespan and reduced operational costs. Bosch also used ML to assess power quality in manufacturing equipment, integrating sensor data with ML algorithms. However, integration with existing systems and skilled personnel required significant upfront investment. Tesla's Powerwall systems use ML to monitor and predict harmonic distortions from solar panels and battery storage in residential energy systems, optimizing energy dispatch and improving overall power quality. EDF Energy implemented ML techniques in their distribution systems to detect harmonic sources, enabling proactive detection and cost-effective solutions. Despite challenges in implementation, data management and personnel expertise, ML offers transformative potential in harmonic detection and power quality management across various sectors.

5. Conclusions

From the literature review and discussion above, it can be concluded that the method of detecting electric current harmonics using ML is still limited to modelling using Simulink and toolbox as well as mathematical modelling and on average, using the ANN algorithm, so there is an opportunity for the development of new methods (novelty).

This study reviews the use of ML in detecting electric current harmonics, focusing on the techniques applied, their advantages and the challenges encountered. The key findings are summarized as follows:

i. Effectiveness of ANN:
- ANN is the most widely used algorithm for harmonic detection due to its high accuracy, particularly under distorted wave conditions.
- It is well-suited for complex and non-linear systems. However, it has limitations in terms of requiring large datasets and significant computational resources, making it less ideal for real-time applications.

ii. Application of Wavelet Transform:
- Wavelet Transform proves effective in time-frequency analysis, particularly for detecting transient harmonics in renewable energy systems and smart grids.
- It balances accuracy and computational complexity, but its performance depends on selecting appropriate wavelet parameters.

iii. Advantages and Limitations of LS-Adaline:
- LS-Adaline is advantageous for real-time applications due to its low computational cost and fast response time, making it suitable for optimizing power quality in low-voltage systems.
- However, its accuracy diminishes under high distortion or noisy conditions, necessitating complementary techniques for improved performance.

iv. Research Gaps and Challenges:
- Current research is limited to MATLAB or Simulink simulations and mathematical modelling, with minimal practical implementation.
- The availability of diverse and accurate datasets remains a significant challenge in developing more generalized ML algorithms.
- High computational complexity in methods like ANN and Wavelet Transform restricts their deployment in resource-constrained systems.

v. Recommendations for Future Research:
- Developing more practical and efficient harmonic detection systems for real-world applications is essential.
- Future work should explore hybrid or ensemble learning algorithms to enhance accuracy and adaptability.

- Expanding datasets to include diverse power system conditions will improve the generalizability of ML models.

References

[1] Yumuşak, Nejat and Feyzullah Temurtaş. "Harmonic detection using feed forward and recurrent neural networks for active filters." (2004).

[2] Jain, Sachin K. and S. N. Singh. "Harmonics estimation in emerging power system: Key issues and challenges." *Electric power systems research* 81, no. 9 (2011): 1754-1766. https://doi.org/10.1016/j.epsr.2011.05.004

[3] Nath, Sudipta, Pampa Sinha and Swapan Kumar Goswami. "A wavelet based novel method for the detection of harmonic sources in power systems." *International Journal of Electrical Power & Energy Systems* 40, no. 1 (2012): 54-61. https://doi.org/10.1016/j.ijepes.2012.02.005

[4] Mauludin, Mochamad Subchan, Moh Khairudin, Rustam Asnawi, Wan Azani Mustafa and Toha Siti Fauziah. "The advancement of artificial intelligence's application in hybrid solar and wind power plant optimization: A study of the literature." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 50, no. 2 (2025): 279-293. https://doi.org/10.37934/araset.50.2.279293

[5] Yilmaz, Ahmet S., Ahmet Alkan and Musa H. Asyali. "Applications of parametric spectral estimation methods on detection of power system harmonics." *Electric Power Systems Research* 78, no. 4 (2008): 683-693. https://doi.org/10.1016/j.epsr.2007.05.011

[6] Respati, Sri Mulyo Bondan, Agung Nugroho, Ilham Iskandar and Mochamad Subchan Mauludin. "Analysis of electric power generated by zeolite grain size variables for porous ceramic materials in battery." *EUREKA: Physics and Engineering* 2 (2024): 190-196. https://doi.org/10.21303/2461-4262.2024.003077

[7] Mauludin, Mochamad Subchan, Singgih Dwi Prasetyo, Noval Fattah Alfaiz and Zainal Arifin. "Techno-Economic Modeling of Hybrid PV-Hydroelectric Generator Systems in Semarang." *Mathematical Modelling of Engineering Problems* 11, no. 3 (2024). https://doi.org/10.18280/mmep.110323

[8] García-Gracia, M., N. El Halabi, A. Montañés, H. M. Khodr and M. Villén. "Improvement of DEA performance against harmonic distortion." *Electric power systems research* 80, no. 5 (2010): 582-591. https://doi.org/10.1016/j.epsr.2009.10.012

[9] Dugan, Roger C., Mark F. McGranaghan, H. Wayne Beaty and Surya Santoso. "Electrical power systems quality." (1996).

[10] Xu, Lin, Rui Xing Lin and Shuang Ting Xu. "Method of harmonic source identification based on harmonic apparent power." In *E3S Web of Conferences*, vol. 38, p. 01001. EDP Sciences, 2018. https://doi.org/10.1051/e3sconf/20183801001

[11] Gao, Peng, Mingxing Tian and Lixun Wang. "Harmonic source identification method based on sinusoidal approximation." In *Journal of Physics: Conference Series*, vol. 2290, no. 1, p. 012054. IOP Publishing, 2022. https://doi.org/10.1088/1742-6596/2290/1/012054

[12] Lenka, Sasmita, Pampa Sinha, Kaushik Paul, Chitrlekha Jena, Swagat Das and Baseem Khan. "Identification of the Dominant Harmonic Source Type in the Distribution Network Using the Soft Computing Technique." *International Transactions on Electrical Energy Systems* 2022, no. 1 (2022): 9995478. https://doi.org/10.1155/2022/9995478

[13] Elwirehardja, Gregorius N., Teddy Suparyanto and Bens Pardamean. "Pengenalan Konsep ML Untuk Pemula." (2022).

[14] Kühl, Niklas, Marc Goutier, Robin Hirt and Gerhard Satzger. "ML in artificial intelligence: Towards a common understanding." *arXiv preprint arXiv:2004.04686* (2020). https://doi.org/10.24251/HICSS.2019.630

[15] Chen, Wei, Wandan Zou, Kaiyang Zhong and Alina Aliyeva. "ML assessment under the development of green technology innovation: A perspective of energy transition." *Renewable Energy* 214 (2023): 65-73. https://doi.org/10.1016/j.renene.2023.05.108

[16] Kalair, A., Naeem Abas, A. Raza Kalair, Zahid Saleem and Nasrullah Khan. "Review of harmonic analysis, modeling and mitigation techniques." *Renewable and Sustainable Energy Reviews* 78 (2017): 1152-1187. https://doi.org/10.1016/j.rser.2017.04.121

[17] Eslami, Ahmadreza, Michael Negnevitsky, Evan Franklin and Sarah Lyden. "Review of AI applications in harmonic analysis in power systems." *Renewable and Sustainable Energy Reviews* 154 (2022): 111897. https://doi.org/10.1016/j.rser.2021.111897

[18] Kitchenham, Barbara and Pearl Brereton. "A systematic review of systematic review process research in software engineering." *Information and software technology* 55, no. 12 (2013): 2049-2075. https://doi.org/10.1016/j.infsof.2013.07.010