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RESEARCH ARTICLE

Enhancing Power Quality in Industry 4.0 Manufacturing Using the Multi-Criteria Selection Method

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ABSTRACT Industry 4.0 technology is growing rapidly in the manufacturing industry and other businesses. Devices used in Industry 4.0 are manufactured with high-frequency switching functions and generate harmonics that negatively affect power quality. Choosing the direct or parallel connection method of the harmonic current absorber depends on the specific requirements of the system and the goal of improving power quality. Shunt Active Power Filter (SAPF) is the best device currently used to improve power quality. This study proposes to use the fuzzy-rough MARCOS method to make decisions on SAPF selection based on experts' opinions to improve the quality of power sources at the source of smart manufacturing plants using Industry 4.0 devices. This study implements two decision-making methods in Multi-Criteria Decision-Making (MCDM). The first is the SWARA method (Stepwise Weight Assessment Ratio Analysis), and the second is the MARCOS method (Measurement Alternatives and Ranking According to Compromise Solution). The fuzzy-rough method is used to incorporate uncertain information into the results of decision-making and to use linguistic values. The analysis results of the fuzzy-rough SWARA method show that the price factor and power filter range has the greatest influence on the choice of SAPF for harmonic mitigation. Analysis results from the fuzzy-rough MARCOS method show that manufacturer Schneider Electric has the best features according to the evaluation results from decision makers. Sensitivity analysis methods were used to confirm the findings. The harmonic value THDi displayed in the field after installing the harmonic filter is, respectively, THDi1 = 5%, THDi2 = 6%, and THDi3 = 5%, it meets the regulations of Circular 30/2019/TT-BCT. According to this circular, the requirement for total harmonic value (THDi) is below 12%. With THDi1, THDi2, and THDi3 values all below 12%. In operating electrical systems in production and business environments, using SAPF filters for harmonic mitigation helps improve power quality. The fuzzy-rough method is applied, and the decision maker's decisions are used to adjust the intention to use the SAPF set to suit the conditions.

INDEX TERMS Shunt active power filter, fuzzy–rough MARCOS, harmonic mitigation, power quality.

I. INTRODUCTION

As Industry 4.0 technology continues to develop, switching devices are also growing exponentially to meet the development of Industry 4.0 technology [1]. Switching devices generate noise signals, called harmonic currents. Harmonic currents arising in the power source cause complex effects and cause the quality of the power source to deteriorate. Devices that use electricity have poor power quality due to harmonic currents, making the device's operation unstable, possibly exploding, and unstable performance [2]. The development of Industry 4.0 technology is not only in the

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manufacturing industry, but Industry 4.0 technology is developing and penetrating all industries, Electrical equipment in industries that use Industry 4.0 technology is affected by harmonic currents generated by switching devices in Industry 4.0 technology [3]. Electronic devices or devices that use power sources always perform well when they are provided with a quality power source according to IEEE 519:2022 standards [4], which is a Total Harmonic Distortion (THD) value of less than 5%. However, in the power transmission network system, many switching devices, such as inverters, contactors, and power conversion devices are used. Devices that affect the quality of the power source and affect the THD value may exceed the standard value. Controlling the THD value within the allowable standards of IEEE 519:2022 is necessary [5]. Due to the characteristics of the power quality of different types of power sources and power-using devices in the power system, it is necessary to use appropriate THD reduction devices, along with the economic value of the device's controlled THD value [6]. Researchers and power manufacturers are always looking for the best solution to transmit power to devices using the best power quality. This also depends on the type of load (equipment using electricity) in the power source, giving rise to a THD value higher than the 5% value [7], [8], [9].

Electric motors and electrical equipment use electricity to operate. The stable quality of the power supply makes the performance of electric motors and electrical equipment better and more stable [10], [11]. This process contributes to the development of mechanical energy applications, production, and business efficiency, enhancing productivity and efficiency in Industry 4.0 technology [12]. The IEEE 519:2022 standard addresses the issue of harmonic currents in power sources, particularly in high-frequency switching devices harmonic current control with THD values less than 5% is crucial for sustainable development, as higher values can cause overvoltage and explosions in electrical equipment, posing significant risks to consumers [13], [14], [15]. Researchers, power producers, and manufacturers aim to minimize THD in power sources below 5%. However, no research has eliminated THD values, indicating that power quality is not always guaranteed [16]. To improve power source quality, active filters like Shunt Active Power Filters (SAPF) are used, focusing on minimizing harmonic current value and ensuring power quality. In Vietnam, researchers are exploring the use of a SAPF filter in conjunction with modern control to extract components from power sources. This system compensates for harmonic currents, ensuring stable voltage and current signals [17]. However, the high cost and complexity of the filter's implementation pose challenges for small and medium-sized companies with low technical qualifications. Researchers are concerned about the stability of the power supply in Vietnam, as it affects the performance of SAPF. An unstable power supply can lead to a loss of capacity and increased electricity costs [18]. Additionally, conflicts in frequency, voltage, or current can pose challenges for the device, which uses Industry 4.0 technology. Researchers are working on improving the quality of power sources to address the final concern of vibration in SAPF filters. The limited capacity of 9 manufacturers and the potential for high costs make maintenance and replacement difficult. This is a hot topic for researchers and power producers [19].

This study analyzes and promotes the use of SAPF filters in harmonic mitigation activities in power sources to improve quality (absorb harmonic current to assure THD values to less than 5% to meet IEEE 519 standards: 2022) power supply for electrical appliances. The purpose of this research is to select a suitable SAPF type for use in power sources in Vietnam to help the sustainable development process in the power supply system. SAPF filters are manufactured by famous electrical equipment manufacturers, and choosing a type of SAPF filter that is technically suitable for the power system in Vietnam is a challenge. In this research article, the author proposes to use a combination of fuzzy–rough methods [20] in analyzing the characteristics to choose the appropriate SAPF set based on two methods: fuzzy–rough SWARA and MARCOS methods. The fuzzy–rough method is used to decide on the appropriate SAPF type based on the criteria of the user of electrical equipment to have the electrical equipment with the best operating performance based on the use of a power source with guaranteed power quality according to IEEE 519:2022 standards. Therefore, when choosing the appropriate type of SAPF according to the fuzzy–rough method for power sources in Vietnam, in addition to technical factors, technical specifications of the SAPF set also depend on the usage conditions and needs of the electrical equipment user. In which, fuzzy and rough methods are used with linguistic variable values obtained from the final analysis results, fuzzy–rough methods in uncertain environments in decision-making activities. The fuzzy–rough method is implemented with the integration of the advantages of the two fuzzy methods and the rough method, and these two methods complement each other in the process of making decisions in an uncertain environment. The implementation objectives of the fuzzy-rough method in decision-making activities in an uncertain environment are shown as follows:

- Power quality is improved (THD value is less than 5% meeting IEEE 519:2022 standards) after selecting and using the correct type of SAPF in the power source.
- The fuzzy–rough method is considered an improved method proposed to be used to analyze and select the appropriate type of SAPF set.
- The fuzzy–rough method is used in the process of analyzing and adjusting the decision-making process of selecting a SAPF according to technical factors and the intention of the user of electrical equipment.
- Choose the best type of harmonic mitigation equipment for power sources in Vietnam.
- Promote the use of SAPFs in minimizing THD values in power sources and improving power quality.

The research article is structured in the following sections: Section II presents the context of the research. Section III details the characteristics of the fuzzy–rough method and related methods. Section IV presents a case study result. Section V selects the criteria of the SAPF set, performs sensitivity analysis for the selection criteria and evaluates the results of the study. Section VI presents the discussion and results of the research. Section VII details the conclusions and limitations of the study as well as proposes future research directions.

II. GUIDELINES FOR MANUSCRIPT PREPARATION

A. POWER QUALITY

The quality of a power system directly impacts the performance of electrical equipment [21]. A THD value below 5%, as per IEEE 519:2022 standards, ensures efficient operation and long equipment life. Improving the THD value is crucial for a sustainable power system. EMI filters, isolation transformers, active power filters, and harmonic filters are recommended for reducing harmonic components [22], [23], [24]. The Industrial Isolation Transformer is a crucial device for minimizing THD values in power sources, as per IEEE 519:2022 standards. It offers various types of EMI filter devices, including high-current, low-current, PCB, enclosure, DC, and cable EMI filters, and is suitable for various applications such as industrial, medical, appliance, audio, networking, and solar power systems [25], [26], [27].

In uncertain environments, switching devices like transistors and IGBT are crucial for power quality assessment in industries like Industry 4.0 manufacturing, ensuring fast and harmonic currents [2], [28]. Previous research by the IEEE has shown that current control and frequency control are effective in reducing THD in an Industry 4.0 environment. These control properties, combined with SAPF, contribute to improved power quality and efficiency, meeting IEEE 519:2022 standards for power sources.

The urgent content of improving power quality in factories is addressing issues caused by electrical loads, particularly harmonic currents, which can lead to issues such as fire, explosion, low device performance, and equipment longevity, highlighting the need for sustainable development and improved power distribution systems. Apply methods to minimize phenomena that affect electricity quality and specifically use SAPF devices to absorb harmonic current to assure the THD value in the power source to meet IEEE 519:2022 standards below 5%, then the quality of power supplied to electrical loads brings strengths such as operational reliability and stability, increased equipment life and performance, energy savings, reduced electromagnetic interference, and compliance regulations and standards.

From the analysis results of previous studies, it can be concluded that improving the quality of power sources [29] means improving the efficiency of electricity-using loads and reducing harmful effects in the electricity use and distribution environment of power sources, helping to develop a sustainable power system. Thus, electricity quality is an important factor in production and economic development at smart factories, where equipment using Industry 4.0 technology is used and developed. Using SAPF to absorb harmonic current to assure THD values to less than 5% to meet IEEE 519:2022 standards is an urgent requirement.

B. HARMONIC CURRENTS

The quality of the power source in the distribution system [30] to the load's using electricity is subject to many internal and external influences, causing poor power quality (Tab. 1). Identifying the impacts and identifying the functions of the impacts is necessary to find ways to reduce the impacts of the functions on the power source to help improve power quality, ensuring the THD value is below 5% to meet the requirements with IEEE 519:2022 standard.

Harmonic currents arise in power sources from electrical devices that perform high-switching functions [31]. At each switching, and number of harmonic currents is generated, and the faster and more the switching, the corresponding harmonic currents is generated. In manufacturing and business environments using Industry 4.0 technology, a lot of switches are used because they are the basic function of Industry 4.0 technology [32]. Harmonic currents directly impact factors [33] such as Electrical Equipment, Power Loss, Electromagnetic Interference, Voltage and Current, Power Factor, and Temperature. Therefore, reducing the harmonic current value in the power source will reduce the influence of the above factors. THD value is the main element of the harmonic currents, so absorbing harmonic current to assure the THD value in the power source to less than 5% according to IEEE 519:2022 standard ensures that the power source delivers power quality that meets the requirements and eliminates harmful factors dynamics inside and outside the power source affect power quality.

SAPF filter is a type of device [13] used to absorb harmonic current value and improve power quality. The SAPF is a variation of the content filter, but it can work proactively to remove unwanted content components in the power source. SAPF works by measuring and analyzing the input power signal to determine its content components. It then generates counter-response signals to eliminate or minimize these content components. This process ensures that only fundamental frequency components and less noise exist in the output power supply. SAPF is commonly used in power systems with non-linear loads such as inverters, high-power electronic devices, and unbalanced loads. The main applications of SAPF [34] include absorbing harmonic current to assure THD values under 5%. SAPF removes unwanted content components such as wavelengths, triangular waves, and higher frequency components, helping to absorb harmonic current to assure THD values under 5% in power sources. Improved power factor: SAPF is also capable of correcting the power factor of the power system by generating averaging currents and delaying the phase to achieve a power factor close to 1. Voltage Stabilization: SAPF can maintain stable voltage levels in the power system by regulating current flow and minimizing voltage fluctuations. SAPF is often integrated with complex algorithms and control technologies to achieve good performance. It is an effective solution to

TABLE 1. **Factors affecting electricity quality.**

Factors	Functions	Disadvantage
Voltage	Stable and correct voltage ensures power quality.	Unstable voltage can cause problems in electrical devices and reduce their lifespan.
Frequency	The standard frequency is 50 or 60 Hz.	Frequency changes can cause problems in devices such as motors and incandescent lights.
Power factor	The power factor is an indicator of the energy efficiency of an electrical system.	Low power factor can cause power loss and increase energy loss.
Harmonic currents	Harmonic currents are unwanted noises and variations in the power supply.	Harmonic currents can cause operational problems and reduce the stability of electrical equipment.
Electricity short cuts	A power shortage is a problem in the power supply when the current suddenly increases suddenly.	A short power cut can cause equipment damage and endanger the user.
Magnetic contamination	Magnetism is a phenomenon when electrical devices create unwanted electromagnetic signals that affect other devices in the electrical network.	Magnetic contamination can cause problems and reduce power quality.
Voltage stability	Voltage stability is the ability of a power source to maintain the correct voltage level over a long time.	Poor voltage stability can cause problems and shorten the life of devices.

absorb harmonic current values and improve power quality in industrial and commercial power systems (Fig. 1).

The SAPF functions as a power controller and performs the function of generating a compensation current of equal magnitude but opposite to the actual harmonic current that will load the connection to the generated power source [35]. The SAPF model is mounted on the distributed power system according to Figure 1. The voltage source inverter (VSI) in the SAPF is designed with a series inductor (Lf) and a DC link capacitor (Cdc) connected in parallel at the common coupling point (PCC), VSI plays a very important role in the harmonic current's reduction operation of the SAPF.

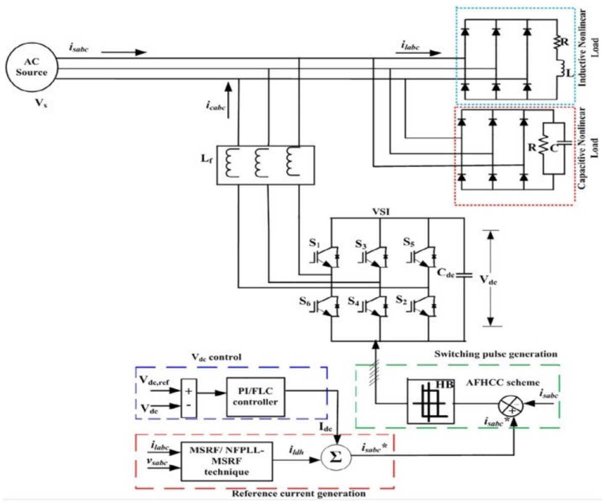

FIGURE 1. **Basic SAPF model.**

- *Voltage Source Inverter (VSI):* VSI is designed with 6 two-way switches. Depending on the usage needs according to power standards, VSI uses different types of switching devices such as IGBT, MOSFET, or GTO. VSI controls SAPF operations based on the switching time of the above types of inverter switches. Inverter switches often operate with high frequency switching to meet the desired voltage levels. However, when performing an actual operation, the voltage changes are limited by the Vdc voltage, switching frequency, and modulation strategy.
- *DC-link Capacitor (Cdc):* Usually manufacturers or designers choose large-sized capacitors. However, to control whether the Vdc value always changes little or does not change, it is necessary to control its value within a certain maximum and minimum limit. The main functions of the Cdc function are: (i) The ripple value of the Vdc value is maintained in a constant configuration. (ii) Performs as an energy storage function to support or compensate to minimize the imbalance in operating capacity of the electrical system in a temporary condition and ensure the system operates without interruption disturbed, and (iii) supports providing a compensation amount so that the reactive power is always guaranteed to be in a stable operating state and guaranteed to be correct under transient conditions. The value used to select the appropriate Cdc value for operation is carried out according to formula (1). The current at the common coupling point (PCC) and the modulation index (m) in the voltage source inverter (VSI) directly impact the selection of the Vdc value. Vdc

value is calculated according to formula (2).

$$C_{dc} = \frac{i_c}{\sqrt{3} \times \omega t \times V_{dc,max}} \tag{1}$$

$$V_{dc} = \left(2\sqrt{\frac{2}{3}} \times V_{LL}\right) \times m \tag{2}$$

where: $V_{dc,max}$: Maximum value of the V_{dc}. i_c: Compensation current. ω: Angular frequency and t: Recovery time.

- *Series Inductor (Lf):* Lf performs the function of attenuating frequency components in the switching current at the power supply (AC source). Lf is connected directly between the VSI and the AC source to ensure control of the current from the input power supply and improve the enhancement of the current. Control the Lf value by adjusting the voltage value in the inductor and the current in the VSI set, the Lf value is calculated according to formula (3).

$$L_f = \frac{V_{dc}}{2 \times (\Delta I_{r,max}) \times f_{s,max}} \tag{3}$$

where, $\Delta I_{r,max}$: Change the maximun ripple's current. $f_{s,max}$: Maximum switching frequency.

The control flow diagram of the SAPF when connected to the power source (AC) performs the function of reducing harmonic currents arising in the power source (is), the SAPF creates a compensation current (i_c) to supply to the PCC position with a corresponding value with the amount of current reduced by the harmonic currents and vice versa with the power source (i_s). The basic equations used in SAPF to perform the compensation current compensation function are shown in detail according to the steps in Table 2.

The compensation current is extracted from the SAPF according to formula (4). There are three main configured blocks in SAPFS: Reference Current Generation (RCG) block, Vdc control block, and PWM signal generation block.

TABLE 2. Step by step of SAPF operation.

Step	Explain step-by-step
Step 1	Calculate the instantaneous value of the power source ($i_s(t)$) according to formula (4). $$i_s(t) = i_l(t) - i_c(t) \tag{4}$$
Step 2	Calculate the load current value ($i_l(t)$) with harmonic currents function, calculated according to formula (5). $$i_l(t) = i_l(sin\omega t + \varphi_1) + \sum_{n=2}^{\infty} i_n(sin\omega t + \varphi_1) \tag{5}$$ Where, i_l: Fundamental current. φ_1: Angle between current and coltage pahses.
Step 3	Calculate the value of energy components in the system, calculated according to formula (6). $$p_l(t) = p_f(t) + p_r(t) + p_h(t) \tag{6}$$ Where, $p_f(t)$: Active power. $p_r(t)$: Reactive power. $p_h(t)$: Harmonic power.
Step 4	Calculate the value of real power in the system, calculated according to formula (7). $$p_f(t) = v_s(t) \times i_s(t) \tag{7}$$
Step 5	Calculate the compensation current ($i_s(t)$) value in the system, calculated according to formula (8). $$i_s(t) = \frac{p_f(t)}{v_s(t)} = i_l cos\varphi_1 \times sin\omega t = I_{sm} sin\omega t \tag{8}$$ Where, $I_{sm} = i_l cos\varphi_1$
Step 6	In the power source, a power source is always maintained to minimize losses caused by frequency switching. Calculate the source current value (I_{sp}) according to formula (9). $$I_{sp} = I_{sm} + I_{dc} \tag{9}$$ Where, I_{dc}: Maximum current.

C. APPLICATION OF MCDM METHODS TO SELECTION OF SAPF FOR HARMONIC MITIGATION

To choose a type of device to reduce harmonic currents [36] in the power source, many related characteristics of that device need to be considered. These criteria are used as criteria for decision makers to select equipment to absorb harmonic current to assure the THD value in the power source. To make the selection of the appropriate equipment type according to specific criteria, the multi-criteria decision making (MCDM) method [37] is preferred in practice. In this paper, the author also provides a systematic review of previous studies in using the MCDM method for SAPF filter selection.

A range of studies have explored the application of multi-criteria decision-making (MCDM) in various contexts. Hashemizadeh and Yu [38] proposed a method for project portfolio selection in construction, combining MCDM with GIS. Singh et al. [39] used MCDM to select suppliers in a TV manufacturing organization, while Tian et al. [40] applied MCDM to rank software defect detection algorithms. Jelassi et al. [41] developed an expert system for selecting MCDM methods. These studies collectively demonstrate the versatility and effectiveness of MCDM in decision-making processes. Huang et al. [42] used a fuzzy MCDM framework to select a CMOS sensor for embedded camera modules, while Nallusamy et al. [43] applied AHP, Fuzzy Logic, and ANN to supplier selection in manufacturing. Yadav et al. [44] used Fuzzy AHP and Topsis to select a suitable metal matrix composite for design applications, and Villacreses et al. [45] applied MCDM methods to select materials for a multi-tubular packed-bed Fischer-Tropsch reactor. These studies demonstrate the versatility and effectiveness of MCDM methods in complex decision-making processes. There has been no previous specific research using the MCDM method to select a suitable SAPF filter to absorb harmonic current to assure the THD value in the power source. This study presents an overview of applying the MCDM method to select criteria to select the appropriate SAPF type for power sources in Vietnam.

A range of studies have demonstrated the effectiveness of Shunt Active Power Filters (SAPF) in reducing Total Harmonic Distortion (THD) in power systems. Bajaj and Singh [46] both highlight the use of advanced control methods, such as Particle Swarm Optimized Artificial Neural Network Controller and Lyapunov-function-based control, to enhance the performance of SAPF to absorb harmonic current to ensure THD value under 5%. Rahman et al. [47] further explore the application of SAPF in grid-connected photovoltaic systems, with the former using a Fuzzy Logic Controller for maximum power point tracking and the latter employing a multi-level inverter. These studies collectively underscore the potential of SAPF to absorb harmonic current to assure THD value in various power system configurations.

Previous studies have proven that applying SAPF to absorb harmonic current to assure THD values below 5% according to IEEE 519:2022 standard in power sources brings many benefits in terms of contents such as stable operation of the power system and minimizing the negative effects of power disturbances. Enhances power quality and reduces interruptions in the operation of sensitive electronic devices. Save energy and reduce operating costs. Integrate into the system flexibly and respond quickly to changes and variations in the electrical system, extending the life of devices, and reducing the risk of failures and incidents. SAPF is necessary to be used in improving power quality because of the following factors absorbs harmonic current to assure THD value and makes the power system more stable. Helps absorb harmonic current to ensure THD values caused by inverters and maintain better power quality. Effectively absorb harmonic current to assure THD value without affecting the operation of other devices in the electrical network. By absorbing harmonic current to assure the THD value, SAPF helps enhance power quality protects devices from negative impacts and ensures that the power system meets the requirements and regulations of industry or relevant national standards related to THD value.

Criteria for operating a SAPF filter [48] in a power system that helps improve the efficiency and performance of the power system include ensuring that the input voltage and frequency of the SAPF correspond to the requirements of the equipment, voltage The input of the SAPF is linked to the main power supply of the system. Ensure that the SAPF is configured correctly to meet the operational needs of the power system. Ensure the SAPF complies with safety regulations and is properly installed to prevent electrical risks and protect users and equipment. Ensure control and adjustment are carried out accurately and continuously to maintain the performance and reliability of the SAPF, and Periodic maintenance and inspection will help detect problems early and ensure that the SAPF operates stably and effectively.

Criteria used to select compatible SAPF in SAPF application to absorb harmonic current to assure THD value in power sources. Previous studies have demonstrated that some specific parameters for selecting the SAPF are appropriate to the characteristics of the power source and the SAPF such as analyzing and evaluating power disturbances in the power system. Evaluate load characteristics in the power system, including power factor, frequency, and load variability. Based on the need to control power disturbances and improve the power factor, the required capacity of the SAPF can be determined. Review SAPF specifications, such as conversion efficiency, component reliability, and auto-tuning capabilities. Consider the economic benefits that SAPF can bring compared to the costs involved. Choosing to comply with electrical safety standards and related regulations, it is necessary to ensure that the SAPF meets the safety requirements and operates safely in the power system, and the Specialist can provide detailed information and appropriate recommendations based on the specific requirements of the electrical system.

In this study, the goal is to select a suitable SAPF to absorb harmonic current to ensure the THD value in the power source meets the IEEE 519:2022 standard.

D. RESEARCH GAPS

Vietnam's power quality is impacted by various issues, including technical issues, load fluctuations, and natural disasters. Disruptions in the power system, short-term instability, and uncontrolled load fluctuations can lead to power supply instability. Effective load management and natural disasters can mitigate these issues [49]. Vietnam is implementing various methods to improve power quality, including absorbing harmonic current to ensure THD values. This is achieved through Vietnam-applied electricity quality standards and regulations, investments in power infrastructure, advanced technology, effective load management, periodic inspection and maintenance of electrical equipment, and increased awareness and training for employees [50]. However, the power quality situation in Vietnam remains unstable, with numerous battery fires and explosions occurring in power sources and manufacturing plants. Despite these efforts, the country still faces challenges in detecting and resolving power quality issues [51].

Specifically, Vietnam power source report in 2019 [52], electricity produced and imported throughout the system reached 239.9 billion kWh, an increase of 2.37 times compared to 2010. Commercial electricity output reached 209.77 billion kWh, an increase of 2.46 times compared to 2010 compared to 2010, corresponding to an average growth of 10.5% in the period 2010 - 2019. Average commercial electricity output per capita increased 2.2 times, from 982 kWh per person (2010) to 2,180 kWh per person (2019). Currently, 100% of communes and 99.52% of households, of which 99.25% of rural households are across the country, have electricity. However, in the context of the existing risk of electricity shortage in the 2021-2024 period (in 2021, the output shortage will be about 370 million kWh and the highest shortage will be up to 13.3 billion kWh in 2023, in 2024 the shortage will decrease). remaining 11 billion kWh), EVN representative proposed increasing electricity imports from countries in the region; Encourage solar power projects to increase installed capacity to about 14,500 MW by 2023.

Power shortages in Vietnam are a result of economic growth, industry development, population growth, a lack of production capacity, technical problems, weather conditions, and natural events. To mitigate these issues, measures include investments in power infrastructure, increased renewable energy development, effective load management, improved project approval processes, strengthening electrical system maintenance, and developing disaster response plans. Implementing a SAPF filter and modern controls can provide the most benefits [52].

Each manufacturer has its own characteristics and products tailored to specific requirements. When selecting equipment, it is important to consider the specific requirements of the electrical system and learn about each manufacturer's features, performance, and reliability to choose the most suitable solution. Their products are designed to minimize harmonics and improve power quality in industrial environments. However, choosing the right manufacturer depends on many factors, such as the scale and specific requirements of the industrial application. Learn more about manufacturers and their products to choose the most suitable one for your industrial application.

Many methods and approaches rely on the criteria of the load source used and the characteristics of the SAPF to select and install the SAPF filter. All the above methods are based on the experience of experts. However, the fuzzy-rough method has not been applied in SAPF selection until now. This method selects based on the technical characteristics of the SAPF filters in that their performance in absorbing harmonic current ensures the THD value in the power supply is similar and does not have significant differences. The criteria used to select SAPF filters change the final rankings and result in SAPFs being ranked better or worse relative to each other, and a special sensitivity analysis is performed to test the significance of a given criterion in a ranking of alternatives. The fuzzy-rough method makes regulatory decision-making suitable for decision-makers, who use only subjective estimates to make alternative evaluations and make choices according to these estimates.

The fuzzy–rough method has been used by many researchers in previous studies but combining the MARCOS fuzzy–rough method in SAPF filter selection has not been done before. Although there are many research articles on the design, selection, and implementation of SAPF filters into the power source, they have not been selected using the MCDM method using technical criteria and criteria based on decision-making of the power source. SAPF filter decision makers. This study shows an MCDM method that combines the fuzzy–rough MARCOS approach and is considered the best method for equipment selection in a production and business environment. On that basis, the research also offers a new approach to further develop the MCDM method to solve multi-criteria decision-making problems with difficult problems in an uncertain environment. The method of selecting SAPF filters in absorbing harmonic current to assure THD values in power sources is not new, however, the fuzzy–rough MARCOS method is used to decide on the selection of SAPF filters according to the technical criteria of SAPF filters and combined with the decisions of decision makers in uncertain environments are applied in practice and are highly effective and are considered a transformative application in real environments. The open approach of this research helps expand new approaches for future research directions.

III. RAW MATERIAL AND METHODOLOGY

The research is carried out according to the research model (Tab. 3), shown through each stage in the research. The first phase of the study was to carry out the selection of experts in the field of power quality on SAPF filter applications, but these experts were also the ones who would evaluate the limitations of the alternative selection criteria and criteria for alternative solutions. Next, experts evaluate the criteria and select alternatives using linguistic variables. Evaluate the values of the analysis results, first, these values are converted to fuzzy coefficients, then each number is determined by the upper and lower limit values and the shape is decided from the initial decision-making matrix. This matrix is used in the analysis to determine the weights using the fuzzy–rough MARCOS method and then, to form the ranking list according to the fuzzy–rough MARCOS method. Finally, the Analysis Results Analysis Panel identifies the results and determines their importance using criteria, forming ranked lists of alternatives through the results of sensitivity analysis.

To carry out the process of researching the MCDM method using the fuzzy-rough SWARA method, the following steps are specifically carried out: Step 1: Select experts who have researched and deployed the use of SAPF for over 10 years and have many scientific achievements in researching and applying SAPF in harmonic mitigation. These experts are selected as decision-makers for the constraints on the choice of alternatives and as decision-makers for the selection of evaluation criteria for each of those alternatives. Step 2: Experts are used as evaluators of criteria and alternatives by relying on the analysis results of linguistic variables. Step 3: Convert the values of language variables into fuzzy arithmetic values. Step 4: Determine the upper and lower limits of each fuzzy arithmetic update and form the initial decision matrix. Step 5: The initial decision matrix is used as the basis for the initial analysis in determining the weights that the fuzzy-rough SWARA method performs.

A. DETERMINE THE INITIAL PARAMETER

In the actual environment of issues that need to be decided for implementation. Many methods have been and are being applied. However, in a decision-making environment with inaccurate information or an uncertain decision-making environment, the fuzzification method based on the values of linguistic variables applied to decision-making activities is effective high fruit. The MCDM method is based on decision-making opinions from the experts, and the rough aggregation method is applied to reduce erroneous assessments or

TABLE 3. Phase by phase of the research model.

Phase	Items	Explain detail
Phase 1	Preparation of research phases	(i) Selection of experts. (ii) Identification of limitations when selecting alternatives, and (ii) Selection of criteria.
Phase 2	Evaluation of criteria and alternatives	(i) Evaluation of criteria by experts, and (ii) Evaluation of alternatives by experts.
Phase 3	Preparation for analysis	(i) Convert linguistic variable estimates to fuzzy arithmetic. (ii) Deploy and apply the rough method. (iii) Establish an initial decision matrix.
Phase 4	Stage of conducting analysis	(i) Use the fuzzy-rough SWARA method to determine the weights. (ii) Perform a ranking of the weights for the alternatives using the fuzzy-rough SWARA method.
Phase 5	Stage of determining results	(i) Perform a determination of the results of the analysis. (ii) Perform sensitivity analysis of analytical results.

TABLE 4. Step by Step of the fuzzy-rough method.

Step	Explain detail Step by Step
Step 1	Calculate the upper and lower bound elements (Eq. 10 and Eq. 11) $$\underline{Lim}(c_i^e) = \frac{1}{\underline{N^e}} \sum_{i=1}^{\underline{N^e}} \varphi \in \underline{A_{pr}}(c_i^e) \quad (10)$$ $$\overline{Lim}(c_i^e) = \frac{1}{\overline{N^e}} \sum_{i=1}^{\overline{N^e}} \varphi \in \overline{A_{pr}}(c_i^e) \quad (11)$$
Step 2	Perform calculations of the upper and lower bound values of the triangular fuzzy arithmetic (Eq. 12). $$FR(\tilde{X}_i) = ([x_i^{lL}, x_i^{lU}], [x_i^{mL}, x_i^{mU}], [x_i^{uL}, x_i^{uU}]) = ([\lim(x_i^l), \overline{Lim}(x_i^l)], [\lim(x_i^m), \overline{Lim}(x_i^m)], [\lim(x_i^u), \overline{Lim}(x_i^u)]) \quad (12)$$
Step 3	Formula to calculate the value of 2 fuzzy-rough numbers (Eq. 13 & Eq. 14). $$FR(\bar{a}) = ([a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, a^{uU}]) \quad (13)$$ $$FR(\bar{b}) = ([b^{lL}, b^{lU}], [b^{mL}, b^{mU}], [b^{uL}, b^{uU}]) \quad (14)$$
Step 4	Calculate values during the execution of the fuzzy-rough model, Calculate the value of the addition parameter (Eq. 15). $$FR(\bar{a}) + FR(\bar{b}) = ([a^{lL} + b^{lL}, a^{lU} + b^{lU}], [a^{mL} + b^{mL}, a^{mU} + b^{mU}], [a^{uL} + b^{uL}, a^{uU} + b^{uU}]) \quad (15)$$
Step 5	Calculate the value of the subtraction parameter (Eq. 16). $$FR(\bar{a}) - FR(\bar{b}) = ([a^{lL} - b^{lL}, a^{lU} - b^{lU}], [a^{mL} - b^{mL}, a^{mU} - b^{mU}], [a^{uL} - b^{uL}, a^{uU} - b^{uU}]) \quad (16)$$
Step 6	Calculate the value of the multiplication parameter (Eq. 17). $$FR(\bar{a}) \times FR(\bar{b}) = ([a^{lL} \times b^{lL}, a^{lU} \times b^{lU}], [a^{mL} \times b^{mL}, a^{mU} \times b^{mU}], [a^{uL} \times b^{uL}, a^{uU} \times b^{uU}]) \quad (17)$$
Step 7	Calculate the value of the division parameter (Eq. 18). $$FR(\bar{a}) \div FR(\bar{b}) = ([a^{lL} \div b^{lL}, a^{lU} \div b^{lU}], [a^{mL} \div b^{mL}, a^{mU} \div b^{mU}], [a^{uL} \div b^{uL}, a^{uU} \div b^{uU}]) \quad (18)$$
Step 8	Calculate the value of the scalar multiplication parameter (Eq. 19). $$c \times FR(\bar{a}) = c \times ([a^{lL}, a^{lU}], [a^{mL}, a^{mU}], [a^{uL}, a^{uU}]) = ([c \times a^{lL}, c \times a^{lU}], [c \times a^{mL}, c \times a^{mU}], [c \times a^{uL}, c \times a^{uU}]) \quad (19)$$
Step 9	Calculate the value of the scalar division parameter (Eq. 20). $$\frac{FR(\bar{a})}{c} = \frac{([a^{lL}, a^{lU}], [a^{mL}, a^{mU}][a^{uL}, a^{uU}])}{c} = \left(\left[\frac{a^{lL}}{c}, \frac{a^{lU}}{c}\right], \left[\frac{a^{mL}}{c}, \frac{a^{mU}}{c}\right], \left[\frac{a^{uL}}{c}, \frac{a^{uU}}{c}\right]\right) \quad (20)$$

decisions made by these experts themselves uncertain decision-making environments and fuzzy-rough methods prove useful in analyzing data in ambiguous, uncertain environments and providing decision information for that information. This research proposes to use a combination of the above two methods to analyze and make decisions in an uncertain environment, resulting in good results in solving problems of ambiguity and uncertainty.

The new point in this research is that the fuzzy-rough method builds the upper and lower bounds of the rough boundary intervals in classical parameters; the individual fuzzy numbers are clearly identified and evaluated specifically according to the rough approach. According to this study, the rough method is performed to divide the distance of odd fuzzy numbers according to clear upper and lower bounds. Next, the linguistic value variables are converted into fuzzy set systems that are used for many members in the calculation method, and the rough method analyzes them based on upper and lower bounds. The fuzzy-rough method is used to calculate the upper and lower bound variables, as described in detail in Table 4.

B. FUZZY-ROUGH SWARA METHODOLOGY

Determining correctly and completely the necessary criteria in solving decision-making problems is the top concern and a mandatory requirement of the fuzzy–rough SWARA method. To improve the efficiency of multi-criteria decision-making for decision-makers, a SWARA method correction method was implemented in this study to specifically arrange the criteria in a certain order and their weights are also compared to clear criteria to help decision-makers easily recognize the fourth criteria and make decisions accurately. However, the AHP method compares the weights and criteria of the problem that needs to be decided with other criteria and weights of the problem, which leads to inconsistent evaluation results of the problem issue that needs to be decided. Find a way to compare criteria in the same issue at each lower-ranked criterion with the higher-ranked criteria rather than comparing individual criteria, and this is also the same urgent issue point in this research. In the case of improving the SWARA method, the number of comparisons between criteria is reduced to (n-1) times, however, the number of comparisons between criteria of the AHP method is increased (n*(n-1)). The weakness of the AHP method is that the number of comparisons between criteria is increasing, causing the decision-making results to lack consistency and make it difficult to achieve appropriate decision-making results. The SWARA method is implemented to address the above weaknesses of the AHP method (Tab. 5).

C. FUZZY-ROUGH MARCOS METHODOLOGY

An improved version of the MARCOS method has been implemented in multi-criteria decision-making techniques, applied to analysis and decision-making for research in recent time frames, and has been applied by many research authors. The application is called Fuzzy-rough MARCOS. The fuzzy-rough MARCOS method gives decision-making results that are like the research results in multi-criteria decision-making techniques of other methods and is proven by an overall assessment of the research results previously published in the prestigious journal ISI/SCOPUS. The effectiveness of the fuzzy-rough MARCOS method is good, but in terms of application, some have not really deployed it in conducting research and multi-criteria decision-making. The main purpose of the fuzzy-rough MARCOS method is to perform a ranking of alternative options based on the characteristics of ideal solutions and non-ideal solutions. The value of an alternative solution is in the implementation of multi-criteria decision-making. The sequence of steps to implement the fuzzy-rough MARCOS method is presented in detail (Tab. 6).

IV. CASE STUDY FOR IMPROVEMENT

Electricity Measurement and Testing Company Limited, headquartered in Ho Chi Minh City, Vietnam, is a leading manufacturer and distributor of SAPF equipment in Vietnam, with branches in Hanoi, Da Nang, and its main headquarters in Ho Chi Minh City. Electricity Measurement and Testing Company Limited is expanding its offerings and sales channels on an e-commerce platform, focusing on real-time power quality assessment and surveying. The company uses its own staff and quality measurement equipment to analyze data and choose appropriate equipment for installing, testing,

TABLE 5. Step by step of fuzzy-rough SWARA method.

Step	Explain detail Step by Step
Step 1	Identify specific criteria in the issue that needs to be decided.
Step 2	Develop and determine the selection of experts in the problem that needs to be decided.
Step 3	Develop a criteria table to evaluate issues that need to be decided according to the requirements and assessments of experts. The linguistic assessment sheet is used for experts to evaluate the criteria and determine the importance of each criterion in the decision-making problem to prioritize each criterion according to the ranking. clear and specific.
Step 4	Convert the rankings of the criteria according to the experts' assessment to the original fuzzy–rough method table for decision making (Eq. 21). $FR_i(\overline{X}_i) = ([x_i^{lL}, x_i^{lU}], [x_i^{mL}, x_i^{mU}], [x_i^{uL}, x_i^{uU}])$ (21)
Step 5	Arrange the criteria in order according to each ranking based on the initial decision-making matrix of the fuzzy-rough method.
Step 6	Perform normalization of the initial matrix of the fuzzy-rough method to specifically determine the importance of each criterion in the decision problem (Eq. 22). $FRN(N_j) = [(n_j^{L1}, n_j^{U1}), (n_j^{L1}, n_j^{U1}), (n_j^{L1}, n_j^{U1})]_{1\times m}$ (22)
	Calculate the fuzzy–rough number value for the criterion with the highest level of importance (Eq. 23). $[(n_j^{L1}, n_j^{U1}), (n_j^{L2}, n_j^{U2}), (n_j^{L3}, n_j^{U3})] = [(1.00,1.00), (1.00,1.00), (1.00,1.00)]$ (23)
	Calculating the values of the criteria for which these criteria are calculated involves calculating the importance frequency of their highest (Eq. 24). $FRN(N_j) = \left[\left(\frac{n_j^{L1}}{z_j^{U3}}, \frac{n_j^{U1}}{z_j^{L3}}\right), \left(\frac{n_j^{L2}}{z_j^{U2}}, \frac{n_j^{U2}}{z_j^{L2}}\right), \left(\frac{n_j^{L3}}{z_j^{U1}}, \frac{n_j^{U3}}{z_j^{L1}}\right)\right]_{1\times m}, j = 2,3,4,\ldots m$ (24)
Step 7	Calculate values to determine the importance of each criterion (Eq. 25). $FRN(\tau_j) = [(\tau_j^{L1}, \tau_j^{U1}), (\tau_j^{L2}, \tau_j^{U2}), (\tau_j^{L3}, \tau_j^{U3})]_{1\times m}$ (25)
	Perform fuzzy value normalization by adding 1 to formula 12 (Eq. 26) $FRN(\tau_j) = [(n_j^{L1} + 1, n_j^{U1} + 1), (n_j^{L2} + 1, n_j^{U2} + 1), (n_j^{L3} + 1, n_j^{U3} + 1)]_{1\times m}, j = 2,3,4 \ldots, m$ (26)
Step 8	Perform weight calculations for the criteria in the weight matrix (Eq. 27). $FRN(R_j) = [(R_j^{L1}, R_j^{U1}), (R_j^{L2}, R_j^{U2}), (R_j^{L3}, R_j^{U3})]_{1\times m}$ (27)
	Calculate the values for each element in the decision matrix (Eq. 28). $FRN(R_j) = \begin{bmatrix} R_j^{L1} = \begin{pmatrix} 1.00, j = 1 \\ \frac{R_{j-1}^{L1}}{\tau_j^{U3}}, j > 1 \end{pmatrix}, R_j^{U1} = \begin{pmatrix} 1.00, j = 1 \\ \frac{R_{j-1}^{U1}}{\tau_j^{L3}}, j > 1 \end{pmatrix} \\ R_j^{L2} = \begin{pmatrix} 1.00, j = 1 \\ \frac{R_{j-1}^{L2}}{\tau_j^{U2}}, j > 1 \end{pmatrix}, R_j^{U2} = \begin{pmatrix} 1.00, j = 1 \\ \frac{R_{j-1}^{U2}}{\tau_j^{L2}}, j > 1 \end{pmatrix} \\ R_j^{L3} = \begin{pmatrix} 1.00, j = 1 \\ \frac{R_{j-1}^{L3}}{\tau_j^{U1}}, j > 1 \end{pmatrix}, R_j^{U3} = \begin{pmatrix} 1.00, j = 1 \\ \frac{R_{j-1}^{U3}}{\tau_j^{L1}}, j > 1 \end{pmatrix} \end{bmatrix}$ (28)

TABLE 5. *(Continued.)* Step by step of fuzzy-rough SWARA method.

	Calculate the values of parameters in the criteria of the decision matrix when there is a case where there are two or more criteria of equal importance (Eq. 29) $FRN(R_j) = FRN(R_{j-1}) \quad (29)$
Step 9	The criteria in the decision matrix are reweighted (Eq. 30) $FRN(W_j) = \left[\frac{FRN(R_j)}{FRN(\delta_j)}\right] \quad (30)$ Where, $FRN(\delta_j) = \sum_{j=1}^{m} FRN(FRN(R_j)$
	The final weight value of the criteria in the decision matrix is specifically calculated (Eq. 31) $FRN(W_j) = \left[\left(\frac{R_j^{L1}}{\delta_j^{U3}}, \frac{R_j^{U1}}{\delta_j^{L3}}\right), \left(\frac{R_j^{L2}}{\delta_j^{U2}}, \frac{R_j^{U2}}{\delta_j^{L2}}\right), \left(\frac{R_j^{L3}}{\delta_j^{U1}}, \frac{R_j^{U3}}{\delta_j^{L1}}\right)\right]_{1\times m}, J = 2,3,4,..m \quad (31)$

TABLE 6. Step by step the fuzzy-rough MARCOS method.

Step	Explain detail step by step
Step 1	Establish a linguistic variable decision matrix based on the results of experts' assessments of criteria for alternatives, and experts assign values to each linguistic variable for each specific alternative that may be related to observational criteria.
Step 2	Perform conversion of language variable values to opaque values.
Step 3	Determine the upper and lower bounds of rough numbers for each type of rough number separately, and this result is used to form the initial fuzzy-rough decision matrix. The steps in the MARCOS method are performed based on the results of the indicators in this matrix.
Step 4	Extend the results of the fuzzy-rough decision matrix by calculating with ideal karma (Eq. 32) and calculating with anti-ideal solutions (Eq. 33) $\begin{cases} AAI = \min_i FR_i(\bar{X}_\iota), benefit\ criteria \\ AAI = \max_i FR_i(\bar{X}_\iota), cost\ criteria \end{cases} \quad (32)$ $\begin{cases} AI = \max_i FR_i(\bar{X}_\iota), benefit\ criteria \\ AI = \min_i FR_i(\bar{X}_\iota), cost\ criteria \end{cases} \quad (33)$
Step 5	Standardize the value of the fuzzy-rough decision matrix according to the suitability of the criteria and the values of the criteria according to the benefit type or the criteria according to the cost type. According to the requirements of the benefit type criteria, the higher the value, the better the result, while the requirement of the cost type criteria is the opposite: the lower the value, the better, so this proves that the alternative solutions for smaller values are better. The decision matrix normalization equation is performed (Eq. 34 and Eq. 35) For benefit type: $\overline{\overline{n_{\iota\jmath}}} = \left(\left[\frac{x_{ij}^{lL}}{maxx_j^{uU}}, \frac{x_{ij}^{lU}}{maxx_j^{uL}}\right], \left[\frac{x_{ij}^{mL}}{maxx_j^{mU}}, \frac{x_{ij}^{mU}}{maxx_j^{mL}}\right], \left[\frac{x_{ij}^{uL}}{maxx_j^{lU}}, \frac{x_{ij}^{uU}}{maxx_j^{lL}}\right]\right) \quad (34)$ For cost type: $\overline{\overline{n_{\iota\jmath}}} = \left(\left[\frac{minx_j^{lL}}{x_{ij}^{uU}}, \frac{minx_j^{lU}}{x_{ij}^{uL}}\right], \left[\frac{minx_j^{mL}}{x_{ij}^{mU}}, \frac{minx_j^{mU}}{x_{ij}^{mL}}\right], \left[\frac{minx_j^{uL}}{x_{ij}^{lU}}, \frac{minx_j^{uU}}{x_{ij}^{lL}}\right]\right) \quad (35)$
Step 6	Perform the normalization of the weight parameter of the fuzzy-rough decision matrix by multiplying it with an appropriate parameter (Eq. 36). $\overline{\overline{v_{\iota\jmath}}} = \overline{\overline{w_\jmath}} \times \overline{\overline{n_{\iota\jmath}}} \quad (36)$
Step 7	Calculate the utility value of alternatives according to the criteria of ideal solutions (Eq. 37) and anti-ideal solutions (Eq. 38) $\bar{\bar{K}}_i^- = \frac{\bar{\bar{S}}_i}{\bar{\bar{S}}_{aai}} \quad (37)$ $\bar{\bar{K}}_i^+ = \frac{\bar{\bar{S}}_i}{\bar{\bar{S}}_{ai}} \quad (38)$ Where, $\bar{\bar{S}}_i = \sum_{i=1}^{m} \bar{\bar{v}}_{ij} \quad (39)$
Step 8	Perform calculation of the average values of the fuzzy-rough parameters (Eq. 40).

and operating the SAPF system. They also offer operation and maintenance training services. The SAPF system offers maintenance components and replacement components to meet customer requirements, ensuring optimal performance and efficiency.

The market for SAPF equipment is very diverse, and many large companies in the world produce and supply SAPF equipment. Choosing the right SAPF type and meeting the market demand in Vietnam is necessary, so the company has repeatedly formed a group of experts to evaluate the market for SAPF equipment from other manufacturing companies together. The research team includes 9 experts (those who have installed, operated, and maintained SAPF equipment in Vietnam), including 4 experts from Electricity Measurement and Testing Company Limited and 3 experts from the research laboratory research and technology transfer of a large university in Ho Chi Minh City, Vietnam, and two experts working in the electricity industry of the Vietnamese government based in Ho Chi Minh City, Vietnam.

Among the 4 experts at Electricity Measurement and Testing Company Limited, they have university degrees in electricity and electronics graduated from the largest university in Ho Chi Minh City, Vietnam, and have more than 10 years of experience in direct quality measurement power supply and implementation of the installation, testing, and operation of SAPF equipment at customer companies. Qualifications: 3 experts from the technology transfer research lab with a doctorate or higher (2 experts with a doctorate and 1 expert with a professor degree) and more than 15 years of teaching experience teaching, researching, and transferring technology related to equipment to improve power quality, of which more than 80% are SAPF equipment, and 2 experts from the Vietnamese national power supply and management company (an employee of the Vietnamese government) have

TABLE 6. ***(Continued.)*** **Step by step the fuzzy-rough MARCOS method.**

	$$K_i^{\pm} = \frac{\overline{\overline{K}}_{i1}^{\pm L} + \overline{\overline{K}}_{i1}^{\pm U} + \overline{\overline{K}}_{i2}^{\pm L} + \overline{\overline{K}}_{i2}^{\pm U} + \overline{\overline{K}}_{i3}^{\pm L} + \overline{\overline{K}}_{i3}^{\pm U}}{6} \quad (40)$$
Step 9	Construct the utility change function ($f(K_i)$) based on the compromise of ideal and anti-ideal solutions and this value is implemented according to the specific formula (Eq. 41) $$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}} \quad (41)$$ Where, $$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (42)$$ $$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (43)$$

a university degree and have more than 20 years working in the power supply, distribution, and transmission industry in Vietnam, and they have evaluated, accepted, and monitored operational results. Impact of SAPF equipment directly at the source and evaluate the impact of SAPF on Vietnam's power grid quality. One limitation in research on SAPF equipment selection is that the power quality of the south streak is always unstable, and it is difficult to measure directly for accurate results. Limitations related to the constantly changing temperature environment in Vietnam, such as the period from 11:00 a.m. to 3:00 p.m., are that it is a very hot time frame, causing high power consumption, and during the remaining time frame, the ambient temperature is normal. Another limitation is that Vietnam is a country located in the tropics and often has unpredictable rain and thunderstorms, and when it rains, it is accompanied by a lot of thunder and lightning, causing short circuits and lightning. An electrical explosion can potentially damage SAPF equipment if there is no good lightning protection mechanism. Another economic limitation when deploying SAPF equipment is that most SAPF equipment has a relatively high price, and the finances of small and medium-sized companies are tight. Financial issues are always a concern for many business decision-makers in the company. One limitation that is always the top concern of decision-makers when installing SAPF equipment is the operating level of workers at the company. For SAPF to operate well, maintenance staff is needed and skilled SAPF equipment supervisors; however, the labor skills of operators in Vietnam are still weak when it comes to modern equipment.

In addition to the above limitations, Electricity Measurement and Testing Company Limited also faces another problem: choosing and providing the appropriate type of SAPF equipment (there are 9 manufacturers and suppliers of SAPF equipment in the world) with different quality and initial investment costs for customers using power sources in Vietnam is a solution. In addition to providing main SAPF equipment, there are accompanying services such as SAPF equipment maintenance and repair services, providing replacement equipment, and providing SAPF equipment operation training services to customers when needed. Selecting variations in SAPF equipment types from different manufacturers requires the expert to comprehensively consider the various SAPF equipment manufacturing and supplying companies in the world (Tab. 7). The results of the experts' evaluation are the input data source for decision-makers in the company to make decisions to invest in SAPF equipment to improve the quality of the power supply that the company is using.

TABLE 7. **List of SAPF equipment manufacturers.**

Name of SAPF equipment manufacturers	Variable
Schneider Electronic	V1
Siemens	V2
Mitsubishi Electric	V3
Fuji Electric	V4
Delta Electrical	V5
ABB Group	V6
Eaton	V7
Danfoss	V8
TDK Corporation	V9

Experts plan and specifically select criteria to evaluate and compare SAPF types appropriately and meet the power quality status in Vietnam (Tab. 8)

The evaluation criteria for selecting a SAPF device considers the high cost of installation, which can reach several hundred thousand USD, despite meeting power quality requirements and being equipped with special features. SAPF devices are crucial in identifying and detecting interference signals in electrical signal sources, meeting urgent requirements for efficient power management. They filter noise signal components and adjust energy consumption to save costs. SAPF devices are essential for distributed power sources, ensuring high-quality electrical signal sources and efficient power management. An urgent requirement for the SAPF device is the implementation of a filtering function for voltage and power sources with different frequency levels, ensuring accurate and complete filtering of noise signals, and compensating current or voltage to enhance internal signal source shape. SAPF equipment's performance quality is significantly influenced by the stability of power quality in the power source, which is an important criterion for ensuring efficient use of energy and reducing costs associated with electricity consumption. SAPF equipment is crucial in the Vietnamese electrical system, filtering noise and improving power quality. It must comply with regulations set by the Vietnamese government and the world, ensuring the safety and quality of power sources. As a developing country, many companies invest in Vietnam's power system. Advanced technologies, including SAPF devices, are being utilized in business factories for efficient distribution in Vietnam, addressing complex conditions and noise signals.

TABLE 8. List of criteria used to evaluate and select SAPF equipment.

Id	Criteria	Explain of criteria	Type of criteria	Reference documents
C1	Price	Value for money when investing in installing SAPF equipment	Cost	[26], [27], [53], [54]
C2	Speed response to power quality	Detects and responds to capacity requirements	Benefit	[13], [14], [55], [56]
C3	Solution response	The range in which the SAPF can perform the function of filtering out noise in the power signal	Benefit	[15], [22]
C4	Power adjustment function	Adjust power consumption	Cost	[23], [34], [57]
C5	Functions compatible with strong distribution grids	Compatible with different voltage levels and different frequency levels	Benefit	[24], [25], [58], [59]
C6	Filter function	Filters noise and distortion signal components in the power supply's signal source	Benefit	[14], [22], [54]
C7	Power quality control function	Ensure the quality of voltage source and current source is always stable in the transmission distribution system	Cost	[28], [34], [15], [58]
C8	Energy-saving function	Improve electrical system performance and save energy	Cost	[13], [34], [60], [61]
C9	Compliance with standards	Comply with standards and regulations related to the quality of voltage source, current source, and performance of the electrical system	Benefit	[13], [14], [62], [63]
C10	Versatile operating functions	Operates at many different frequency levels and operates at different voltage and current levels	Benefit	[15], [22], [33], [64], [65]

To calculate the economic benefits of Shunt Adaptive Power Filter (SAPF), through financial analysis tools. Save energy while reducing energy loss in the power system, improve power system performance by minimizing voltage loss and increasing power factor, minimize equipment damage and reducing the life of devices electricity in the system, protect equipment from negative impacts, reduce maintenance costs and downtime, and to overall evaluate the economic benefits of SAPF, you can use methods such as return on investment (ROI) and net present value (NPV). ROI calculates the rate of return over the cost of an investment, while NPV calculates the present value of net cash flows after taxes.

SAPF device implementation in the Vietnamese market faces specific challenges, particularly in practicality. Decision-makers at manufacturing and business companies struggle to overcome the high cost of this equipment, which is not yet practical in the market. The deployment of SAPF equipment in Vietnam requires careful consideration of initial investment price and financial resources. Universities in the southern region struggle with limited training programs due to high costs, making them less popular than passive filters. SAPF technology filters noise signals in power supply equipment, reducing electrical noise in production processes. However, initial investment costs, operating capacity, delay in noise handling, and maintenance limitations must be considered during installation.

Electricity Measurement and Testing Company Limited's efforts to select SAPF equipment to meet customer needs in the Vietnamese market are carried out in five specific steps, as follows: Step 1 is to evaluate and determine the importance of the criteria to select SAPF equipment and perform an evaluation of alternative solutions after analyzing and selecting alternative solutions based on the selected criteria and the evaluation table ranked according to linguistic variables (Tab. 9). Step 2 determines the mathematical equations of the members in the set of fuzzy numbers of the corresponding ranking table and converts the value from the linguistic variable to the corresponding fuzzy variable. Step 3 applies the rough method to calculate and determine the values of the upper and lower limits of each fuzzy arithmetic, respectively. Step 4 applies the Fuzzy-rough method to evaluate and determine the weights of the criteria and perform the ranking of SAPF equipment types of individual suppliers, and Step 5: Evaluate the results experimental research results and conduct sensitivity analysis to re-examine the impact of certain criteria on the results of SAPF device selection. The above steps were applied experimentally by Electricity Measurement and Testing Company Limited to evaluate and select SAPF equipment suitable for current conditions in the Vietnamese market.

TABLE 9. Language variables and their character functions.

Criteria		Solutions change	
Language variation	Functions	Language variation	Functions
Absolution high (AH)	(0,0,1)	Absolution low (AL)	(0,1,2)
Extreme high (EH)	(1,1,2)	Very low (VL)	(2,2,3)
High (H)	(2,3,3)	Low (L)	(3,4,4)
Medium high (MH)	(3,4,5)	Medium low (ML)	(4,4,5)
Equal (E)	(4,5,5)	Equal (E)	(5,6,7)
Medium low (ML)	(5,6,6)	Medium high (MH)	(6,7,7)
Low (L)	(6,6,7)	High (H)	(7,8,8)
Very low (VL)	(7,8,9)	Extreme high (EH)	(8,8,9)
Absolution low (AL)	(9,9,10)	Absolution high (AH)	(9,10,10)

TABLE 10. First fuzzy decision matrix.

	DM1	DM2	DM3	DM4	DM5	DM6
C1	EH(1,1,2)	H(2,2,3)	EH(1,2,2)	EH(1,2,2)	AH(0,1,1)	AH(0,1,1)
C2	EH(1,1,2)	MH(3,4,4)	EH(1,2,2)	H(2,2,3)	E(4,5,5)	MH(3,4,4)
C3	AH(0,1,1)	AH(0,1,1)	AH(0,1,1)	AH(0,1,1)	MH(3,4,4)	H(2,2,3)
C4	EH(1,2,2)	MH(3,4,4)	EH(1,2,2)	AH(0,1,1)	MH(3,4,4)	H(2,2,3)
C5	EH(1,2,2)	E(4,4,5)	AH(0,1,1)	AH(0,1,1)	EH(1,2,2)	H(2,2,3)
C6	EH(1,2,2)	EH(1,2,2)	H(2,2,3)	EH(1,2,2)	EH(1,2,2)	MH(3,4,4)
C7	EH(1,2,2)	MH(3,4,4)	EH(1,2,2)	EH(1,2,2)	H(2,2,3)	EH(1,2,2)
C8	EH(1,2,2)	EH(1,2,2)	H(2,2,3)	H(2,2,3)	H(2,2,3)	E(4,5,5)
C9	EH(1,2,2)	EH(1,2,2)	EH(1,2,2)	EH(1,2,2)	H(2,2,3)	MH(3,4,4)
C10	AH(0,1,2)	AH(0,1,1)	AH(0,1,1)	EH(1,2,2)	H(2,2,3)	H(2,2,3)

The values of the criteria are evaluated in order of priority: the larger the criterion value, the better, but conversely, the smaller the value of the alternative solutions, the better. The above regulations are applied to evaluate the analysis results based on data in Table 9.

V. RESULT

Determining the weights of the criteria is the first step that needs to be done correctly, and the fuzzy-rough SWARA method is applied to evaluate and determine the weights of the applied criteria used in this study. Experts rely on the results of analysis and ranking of linguistic variables, perform assessments, and determine the importance of criteria (Tab. 10). This result is converted from linguistic variables to fuzzy numbers by operations based on the member's contact functions.

The fuzzy number is calculated after the linguistic variables are converted to fuzzy numbers and done as follows for variable C1.

The rough limit value is calculated for the fuzzy number "l":

$$LimDM1 = \frac{1+1+0+0+1}{5} = 0.59$$

$$LimDM2 = \frac{1+1+0+0+1+2}{6} = 0.82$$

$$LimDM3 = \frac{1+0+0+1+1}{5} = 0.59$$

$$LimDM4 = \frac{1+1+1+0+0}{5} = 0.59$$

$$LimDM5 = \frac{0+0}{2} = 0.00$$

$$LimDM6 = \frac{0+0}{2} = 0.00$$

$$\overline{Lim}DM1 = \frac{1+1+2+1}{4} = 1.24$$

$$\overline{Lim}DM2 = \frac{2}{1} = 2.0$$

$$\overline{Lim}DM3 = \frac{1+1+1+2}{4} = 1.24$$

$$\overline{Lim}DM4 = \frac{2+1+1+1}{4} = 1.24$$

$$\overline{Lim}DM5 = \frac{1+1+2+1+0+0}{6} = 0.82$$

$$\overline{Lim}DM6 = \frac{0+1+0+1+2+1}{6} = 0.82$$

The rough limit value is calculated for the fuzzy number "m":

$$LimDM1 = \frac{2+1+1+2+2}{5} = 1.59$$

$$LimDM2 = \frac{3+2+2+1+1+2}{6} = 1.82$$

$$LimDM3 = \frac{1+1+2+2+2}{5} = 1.59$$

TABLE 11. Construct the initial rough fuzzy decision matrix of the SWARA method.

	X_i		X_j
C1	[(0.33,1.12), (1.33,2.22), (2.33,3.14)]	C3	[(0.19,1.08), (1.19,1.99), (2.19,3.44)]
C2	[(1.59,2.58), (2.58,3.59), (3.59, 5.04)]	C1	[(0.42,1.19), (1.39,2.19), (2.39, 3.20)]
C3	[(0.19,1.08), (1.19,2.07), (2.19,3.39)]	C10	[(0.29,1.29), (1.28,2.28), (2.29, 3.76)]
C4	[(0.19,1.89), (1.94,2.96), (2.94,4.38)]	C5	[(0.49,1.50), (1.49,2.49), (2.50,4.27)]
C5	[(0.49,1.49), (1.58,2.49), (2.49,4.30)]	C6	[(1.09,1.79), (2.09,2.75), (3.09,3.89)]
C6	[(1.09,1.77), (2.09,2.76), (3.09,3.89)]	C7	[(1.09,1.79), (2.08,2.76), (3.09,3.89)]
C7	[(1.08,1.75), (2.08,2.77), (3.09,3.89)]	C4	[(0.89,1.94), (1.96,2.94), (2.96,4.29)]
C8	[(1.45,2.43), (2.45, 3.39), (3.56, 4.56)]	C9	[(1.19,1.99), (1.19,2.99), (3.19,3.99)]
C9	[(1.21,1.99), (2.20,2.99), (3.21,3.39)]	C8	[(1.46,2.39), (2.39,3.39), (3.40,4.49)]
C10	[(0.29,1.29), (1.28,2.28), (2.29,3.76)]	C2	[(1.59,2.59), (2.58,3.59), (3.58,4.99)]

$$LimDM4 = \frac{2+1+1+2+2}{5} = 1.59$$
$$LimDM5 = \frac{1+1}{2} = 1.00$$
$$LimDM6 = \frac{1+1}{2} = 1.00$$
$$\overline{Lim}DM1 = \frac{2+2+3+2}{4} = 2.24$$
$$\overline{Lim}DM2 = \frac{3}{1} = 3.0$$
$$\overline{Lim}DM3 = \frac{3+2+2+2}{4} = 2.24$$
$$\overline{Lim}DM4 = \frac{2+2+3+2}{4} = 2.24$$
$$\overline{Lim}DM5 = \frac{3+2+2+2+1+1}{6} = 1.82$$
$$\overline{Lim}DM6 = \frac{2+3+2+1+2+1}{6} = 1.82$$

The rough limit value is calculated for the fuzzy number "u":

$$LimDM1 = \frac{2+3+3+3+2}{5} = 2.59$$
$$LimDM2 = \frac{3+4+3+3+2+2}{6} = 2.82$$
$$LimDM3 = \frac{3+3+2+3+2}{5} = 2.59$$
$$LimDM4 = \frac{2+3+3+3+2}{5} = 2.59$$
$$LimDM5 = \frac{2+2}{2} = 2.00$$
$$LimDM6 = \frac{2+2}{2} = 2.00$$
$$\overline{Lim}DM1 = \frac{4+3+3+3}{4} = 3.24$$
$$\overline{Lim}DM2 = \frac{4}{1} = 4.0$$
$$\overline{Lim}DM3 = \frac{3+3+4+3}{4} = 3.24$$
$$\overline{Lim}DM4 = \frac{3+4+3+3}{4} = 3.24$$
$$\overline{Lim}DM5 = \frac{3+3+3+3+2+2}{6} = 2.82$$
$$\overline{Lim}DM6 = \frac{4+3+3+3+2+2}{6} = 2.82$$

Calculate all the decision-makers average values and construct a rough fuzzy decision matrix (Tab. 11). Arrange the criteria in Table 11 in order and evaluate the values according to the standard value. The value is the smaller, is the better. Evaluate each criterion one by one with each corresponding value to determine the best alternative solutions correctly and completely.

The analysis results of Table 11 show that the result of criterion C3 [(0.19,1.08), (1.19,1.99), (2.19,3.44)] gives the smallest value, followed by the second smallest position is criterion C1 [(0.42,1.19), (1.39,2.19), (2.39, 3.20)], and the third smallest is criterion C10 [(0.29,1.29), (1.28,2.28), (2.29, 3.76)], and the value of the criterion giving the highest value is criterion C2 [(1.59,2.59), (2.58,3.59), (3.58,4.99)]. Normalization of the initial value of the fuzzy poetry of the decision matrix is performed. The value of criterion C1 is calculated by dividing by the mean value and the value of C1 = [(0.08, 0.33),(0.40, 0.84),(0.93, 2.00)]. Other values are similarly normalized and then the FRN normalization matrix (Nj) is formed.

The value of target C3 is copied and performed to form the matrix $FRN(R_j)$. value of criterion C1: [(0.08, 0.33),(0.40, 0.84),(0.93, 2.00)] + [(1, 1),(1, 1),(1, 1)] = [(1.08, 1.33),(1.40, 1.84),(1.93, 3.00)], and the values of other criteria are also calculated similarly. The decision matrix is formed by copying the original values (Tab. 12). The value of criterion C1 is recalculated and gives the value FRN (C1) = [(0.33, 0.52),(0.54, 0.72),(0.75, 0.92)].

Continue calculating the values in the matrix FRN (<j) again according to the same calculation formula. Then the weight values of the criteria are calculated, and the matrix FRN (Wj) is formed. This matrix is formed by calculating the individual values of similar performance criteria according to the formula for calculating the value of criterion C1 as FRN (WC1) = [(0.055, 0.153),(0.169, 0.339),(0.366, 0.626)], and all the weights of the criteria are calculated in the same way. The analysis results are shown in detail in Table 12, in which the weight of criterion C3 (solution response) =

TABLE 12. Weight the final value of the criteria.

	$FRN(R_i)$	$FRN(W_i)$
C3	[(0.999,0.999), (0.999,0.999), (0.999,0.999)]	[(0.099,0.198), (0.291,0.395), (0.399,0.583)]
C1	[(0.329,0.499), (0.498,0.699), (0.740,0.899)]	[(0.047,0.094), (0.099,0.381), (0.295,0.578)]
C10	[(0.999,0.289), (0.279,0.499) (0.549,0.859)]	[(0.016,0.079), (0.087,0.119), (0.174,0.501)]
C5	[(0.019,0.093), (0.139,0.359), (0.379,0.798)]	[(0.004,0.038), (0.038,0.089), (0.091,0.487)]
C6	[(0.010,0.059), (0.069,0.199), (0.198,0.599)]	[(0.000,0.009), (0.101,0.099), (0.081,0.379)]
C7	[(0.001,0.019), (0.029,0.099), (0.098,0.499)]	[(0.001,0.007), (0.008,0.069), (0.079.0.284)]
C4	[(0.002,0.009), (0.009,0.089), (0.098,0.399)]	[(0.001,0.005), (0.004,0.039), (0.049,0.299)]
C9	[(0.001,0.004,) (0.069,0.058), (0.068,0.299)]	[(0.002,0.003), (0.001,0.019), (0.028,0.175)]
C8	[(0.000,0.002), (0.002,0.029), (0.039,0.211)]	[(0.001,0.002), (0.000,0.009), (0.018,0.088)]
C2	[(0.001,0.002), (0.002,0.019), (0.019,0199)]	[(0.001,0.000), (0.000,0.009), (0.011,0.381)]
	[(1.399,2.039), (2.099,3.099), (3.298,5.998)]	

TABLE 13. Initial value of the decision matrix of the language of alternatives.

DM1	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	DM2	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
V1	L	ML	ML	M	M	EH	ML	M	M	L	V1	L	M	M	MH	M	H	L	M	M	M
V2	ML	MH	M	ML	ML	MH	H	ML	L	M	V2	ML	MH	MH	MH	M	M	MH	ML	ML	MH
V3	ML	ML	ML	M	M	EH	ML	M	M	L	V3	ML	M	M	MH	M	H	L	M	M	M
V4	ML	ML	ML	M	M	EH	ML	M	ML	MH	V4	ML	ML	M	MH	M	H	L	M	ML	MH
V5	M	ML	ML	M	M	EH	ML	MH	M	MH	V5	M	H	M	MH	M	H	L	M	M	MH
V6	H	MH	M	ML	ML	L	H	L	ML	VL	V6	H	MH	MH	MH	M	VL	MH	ML	ML	ML
V7	H	M	ML	M	M	EH	ML	H	EH	EH	V7	H	MH	ML	MH	M	H	L	MH	EH	H
V8	H	M	ML	M	M	EH	ML	EH	EH	AH	V8	EH	MH	ML	MH	M	H	L	MH	H	EH
V9	H	H	ML	M	M	EH	ML	H	EH	EH	V9	H	H	ML	MH	M	H	L	MH	H	H
DM3	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	DM4	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
V1	VL	L	MH	EH	H	EH	L	M	H	ML	V1	M	MH	EH	EH	H	H	H	VL	EH	H
V2	L	ML	H	H	MH	H	ML	ML	MH	M	V2	MH	H	AH	H	EH	M	EH	L	MH	EH
V3	L	L	MH	EH	H	EH	L	M	H	ML	V3	MH	MH	EH	EH	EH	H	H	VL	H	H
V4	L	L	MH	EH	H	EH	L	M	MH	MH	V4	M	M	EH	EH	EH	H	H	VL	MH	EH
V5	ML	L	M	EH	H	EH	L	M	H	MH	V5	MH	MH	H	H	EH	H	H	VL	EH	H
V6	M	ML	EH	H	MH	M	ML	L	MH	M	V6	ML	H	AH	H	EH	L	EH	VL	MH	MH
V7	M	L	ML	EH	H	EH	L	MH	EH	H	V7	MH	M	H	H	H	H	H	L	EH	H
V8	M	L	ML	EH	H	EH	L	MH	EH	EH	V8	H	MH	H	H	H	H	H	VL	EH	EH
V9	M	ML	ML	EH	H	EH	L	MH	EH	H	V9	EH	H	MH	EH	H	H	H	L	EH	H
DM5	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	DM6	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
V1	VL	L	M	MH	MH	M	L	ML	MH	MH	V1	AL	ML	M	M	M	ML	VL	L	M	M
V2	VL	ML	MH	M	ML	L	ML	L	M	EH	V2	VL	MH	MH	ML	ML	L	ML	L	M	MH
V3	VL	L	H	MH	MH	M	L	ML	MH	MH	V3	L	ML	M	M	M	ML	VL	L	M	M
V4	L	VL	M	MH	MH	M	L	ML	M	H	V4	ML	L	M	M	M	ML	VL	L	M	MH
V5	ML	L	M	MH	MH	M	L	ML	MH	H	V5	M	ML	M	M	M	ML	VL	L	M	MH
V6	M	M	MH	M	ML	AL	ML	VL	M	M	V6	M	MH	H	ML	ML	AL	ML	AL	M	ML
V7	ML	ML	M	M	M	M	L	L	H	EH	V7	ML	M	ML	M	M	ML	VL	L	EH	MH
V8	ML	ML	M	M	M	M	L	L	H	AH	V8	M	M	M	M	M	ML	VL	L	H	M
V9	ML	M	M	M	M	M	L	L	H	EH	V9	M	H	ML	M	M	ML	VL	L	H	MH

[0.099, 0.198), (0.291, 0.395), (0.399, 0.583)] gives the price result's greatest value. The weight of criterion C1 (Price) = (0.047, 0.094), (0.099, 0.381), (0.295, 0.578) gives the 2nd largest value, and the weight value of criterion C10 (Versatile Operating Functions) = (0.016, 0.079), (0.087, 0.119), (0.174,0.501) is the 3rd largest, and the weight value of criterion C2 (Speed response to power quality) = (0.001, 0.000), (0.000, 0.009), (0.011, 0.381) gives the smallest value.

The SAPF filter device was evaluated after calculating the weight values of the criteria. First, evaluate the criteria that have been selected using the observation plan and from the evaluation results of experts using linguistic variables (Tab. 13).

TABLE 14. Initial value of the fuzzy coarse decision matrix for the alternative solution.

	C1	C2	…	C10
AAI	[(4.99,6.89), (6.89,8.01), (7.89,7.89)]	[(5.78,6.67), (6.67,7.57), (8.01,8.56)]	…	[(3.49,5.02), (5.09,6.09), (6.07,7.02)]
V1	[(1.87,2.87), (3.48,4.35), (4.37,6.89)]	[(3.49,4.67), (4.67,5.67), (6.01,7.45)]	…	[(3.98,5.87), (5.47,6.72), (5.87,8.69)]
V2	[(3.01,4.21), (4.02,5.02), (5.39,5.99)]	[(4.67,6.34), (6.12,7.09), (7.09, 8.04)]	…	[(5.57,6.99), (6.89,7.99), (7.89,8.97)]
V3	[(2.67,402), (4.59,5.02), (5.47,6.51)]	[(3.46,4.68), (4.57,6.01), (5.35,6.98)]	…	[(3.89,5.01), (4.89,6.23), (5.89,7.56)]
V4	[(3.39,4.07), (4.21,4.78), (4.89,5.89)]	[(2.48,3.67), (3.67,4.12), (4.78,5.38)]	…	[(5.89,6.87), (7.02,7.68), (7.98,8.56)]
V5	[(4.35,5.34), (5.35,6.03), (5.78,6.98)]	[(3.67,5.49), (5.48,6.25), (6.28,7.23)]	…	[(5.98,6.34), (6.89,7.45), (7.98,8.46)]
V6	[(4.67,6.34), (6.34,7.09), (6.98,8.12)]	[(5.01,6.12), (6.30,7.12), (7.13,8.09)]	…	[(4.01,5.02), (4.99,5.89), (5.89,6.99)]
V7	[(4.26,6.07), (5.92,6.09), (7.23,7.99)]	[(4.01,5.02), (5.02,6.04), (6.30,7.29)]	…	[(6.56,7.45), (7.45,8.34), (8.45,9.03)]
V8	[(5.01,6.23), (6.71,7.46), (7.46,8.78)]	[(4.01,5.49), (5.23,6.04), (6.36,7.47)]	…	[(7.34,8.23), (8.45,9.46), (9.56,9.56)]
V9	[(4.98,6.98), (5.91,7.84), (7.82,7.95)]	[(5.78,6.67), (6.78,7.82), (7.98,8.34)]	…	[(6.34,7.34), (7.34,8.49), (8.45,9.87)]
AI	[(1.89,3.47), (3.49,4.26), (4.69,5.97)]	[(2.49,3.56), (3.67,4.24), (4.67,5.45)]	…	[(7.34,8.49), (8.45,9.23), (9.49,9.59)]

The next step in performing evaluation using the fuzzy-rough SWARA method is to convert the values of the linguistic variables into fuzzy numbers and calculate the upper and lower bound values of the fuzzy numbers using the fuzzy-rough method. The fuzzy values are calculated and given different values based on the membership function of the calculation (Tab. 9). The next step is to calculate the rough fuzzy values using the fuzzy-rough SWARA method to form the initial fuzzy-rough decision matrix. From the analysis results of this matrix table, ideal solutions and anti-ideal solutions are formed and determined (Tab. 14). From the results of this analysis, when evaluating the criteria according to the level of cost significance, follow the criterion that the lower the price alternatives, the better, and conversely, when evaluating according to the benefit level, the lower the price. The value of the alternative should be as large as possible. In addition to the above two cases, the alternative is an anti-ideal plan.

The next step is to normalize the rough fuzzy decision matrix using the fuzzy-rough SWARA method. Depending on each type of criterion, different standardization processes are performed to meet the cost or benefit criteria (Eq. 23 and Eq. 24). Performing normalization for criterion C1 minimizes the value of criterion C1 according to the cost criterion and creates the value C1 = (1.9, 3.5) (3.5, 4.5) (4.5, 6.2) divide the value of criterion V1 by this value and produce the normalized value of n_{ij} = [(0.24, 0.78), (0.78, 1.28), (1.28, 3.28)], and perform normalization for all other values following the same formula for other criteria and alternatives. The weight of the normalized matrix is calculated by multiplying the number with the normalized values of the raw fuzzy decision matrix: raw fuzzy value C1 = [(0.24, 0.78), (0.78, 1.28), (1.28, 3.28)] × [(0.06, 0.15), (0.17, 0.34), (0.37, 0.63)] = [(0.01, 0.12), (0.13, 0.43), (0.47, 2.05)].

The decision matrix has similar calculated parameters for the weights of the alternatives and other criteria. The usefulness value of the criteria in the decision matrix is also determined specifically (Tab. 15). The total alternatives include both ideal alternatives and counter-ideal alternatives for the values of the criteria in the decision matrix. Equation 26 is applied to calculate the total value of ideal alternatives with utility value levels for ideal alternatives, and math equation 27 is applied to calculate the sum of utility level values application of the criteria of anti-ideal alternatives. Criterion C1 calculated the utility values of the alternatives, giving the result as K1 = [(0.022, 0.348), (0.414, 4.261), (5.062, 86.962)], K11 = [(0.012, 0.224), (0.267, 2.678), (3.189, 50.773)].

The values of the fuzzy-rough MARCOS method are calculated when all parameters in the decision matrix have been completely calculated using equation 29 to perform the conversion of values to fuzzy-rough numbers. These calculated values are performed in the form of simple arithmetic averaging, that is, performing the calculation of the average value of the criteria of individual elements of fuzzy-rough arithmetic. Then, the fuzzy-rough MARCOS method is used to calculate the fuzzy values of the criteria (Tab. 16). From this analysis result, which is arranged in order according to the best ranking, experts evaluate SAPF equipment from different manufacturers according to the corresponding criteria. The results show that criterion V1 (Schneider Electronic) gives the best value, followed by criterion V6 (ABB Group), and the criterion with the lowest rank is criterion V9 (TDK Corporation).

Researchers often apply the method of comparing the performance levels of different methods to evaluate and compare the methods with each other. The research results of the methods are used as a tool for comparison. Compare the methods with each other. Different MCDM methods are used for comparison; specifically, the fuzzy-rough method is implemented with specific names such as the Simple Additive Weighting Method, the Additive Ratio Assessment Method, and the Weighted Product Method. This research article compares the evaluation results on criteria related to SAPF equipment using the fuzzy-rough MARCOS method, and the research results have been confirmed using the fuzzy-rough MABAC method, which gives the most skewed results in the ordered rankings (Fig. 2). These methods implement normalization approaches and calculate different

TABLE 15. Evaluate the level and functionality of the MARCOS method.

	$\overline{\overline{K_i^-}}$	$\overline{\overline{K_i^+}}$
V1	[(0.019,0.289), (0.394,4.209), (5.013,85.945)]	[(0.009,0.131), (0.194,1.987), (3.091,59.987)]
V2	[(0.019,0.376), (0.399,4.092), (4.879,77.891)]	[(0.009,0.241), (0.243,2.519), (3.019,45.891)]
V3	[(0.019,0.314), (0.395,4.057), (4.912,79.421)]	[(0.014,0.198), (0.198,2.478), (3.106,46.023)]
V4	[(0.019,0.299), (0.399,4.099), (4.895,77.903)]	[(0.014,0.209), (0.256,2.601), (3.091,45.398)]
V5	[(0.019,0.308), (0.289,3.896), (4.598,71.983)]	[(0.011,0.097), (0.231,2.417), (2.983,42.091)]
V6	[(0.019,0.289), (0.398,4.039), (4.891,80.237)]	[(0.016,0.213), (0.256,2.612), (3.012,46.231)]
V7	[(0.017,0.289), (0.289,3.587), (4.389,70.981)]	[(0.009,0.176), (0.231,2.309), (2.661,40.997)]
V8	[(0.017,0.289), (0.358,3.689), (4.389,71.256)]	[(0.009,0.183), (0.219,2.401), (2.905,40.934)]
V9	[(0.017,0.198), (0.341,3.503), (4.187,70.012)]	[(0.009,0.082), (0.209,2.209), (2.589,41.001)]
	$\overline{\overline{f(K_i^-)}}$	$\overline{\overline{f(K_i^+)}}$
V1	[(0.000,0.008), (0.009,0.102), (0.116,1.905)]	[(0.001,0.009), (0.014,0.015), (0.164,3.289)]
V2	[(0.001,0.008), (0.009,0.099), (0.089,1.688)]	[(0.001,0.013), (0.015,0.149), (0.099,3.099)]
V3	[(0.000,0.009), (0.009,0.097), (0.109,1.784)]	[(0.001,0.009), (0.009,0.152), (0.197,3.103)]
V4	[(0.001,0.007), (0.009,0.099), (0.092,1.698)]	[(0.000,0.009), (0.013,0.158), (0.109,3.023)]
V5	[(0.000,0.008), (0.008,0.089), (0.099,1.583)]	[(0.001,0.009), (0.009,0.134), (0.198,2.809)]
V6	[(0.000,0.008), (0.009,0.089), (0.092,1.732)]	[(0.001,0.009), (0.013,0.192), (0.157,3091)]
V7	[(0.000,0.006), (0.008,0.079), (0.091,1.509)]	[(0.001,0.009), (0.009,0.139), (0.092,2.692)]
V8	[(0.000,0.007) (0.008,0.009), (0.009,1.591)]	[(0.001,0.011), (0.009,0.139), (0.069,2.691)]
V9	[(0.000,0.008), (0.007,0.009), (0.091,1.409)]	[(0.001,0.009), (0.012,0.091), (0.158,2.590)]

TABLE 16. Analytical results using the Fuzzy-rough MARCOS method.

	K_i^-	K_i^+	$f(K_i^-)$	$f(K_i^+)$	$f(K_i)$	Rank
V1	15.921	9.491	0.291	0.5981	8.012	1
V2	14.391	8.901	0.329	0.601	6.621	4
V3	15.012	8.691	0.339	0.603	6.798	3
V4	13.701	7.998	0.329	0.601	6.241	5
V5	12.991	7.891	0.299	0.546	5.998	6
V6	14.989	8.819	0.381	0.601	7.001	2
V7	13.291	8.029	0.401	0.602	5.021	8
V8	13.290	8.102	0.291	0.521	5.109	7
V9	13.012	7.831	0.301	0.499	4.561	9

weights with different criteria in the normalized decision matrices. Because the weights of the criteria are different, the rankings of the methods are also arranged differently. However, the analytical results of the MARCOS method give similar results to the other methods, but there is no decisive sign at all. Although they give different analysis results and rankings, the difference is not too large, and only the fuzzy-rough MABAC method gives different analysis results compared to other methods. The analysis results show that the biggest difference is criterion V2 (Siemens) and criterion V6 (ABB Group) because these 2 manufacturers give different results of 4 formulas according to 6 methods used to evaluate and compare. Comparing the results, the remaining manufacturers gave almost identical rankings. Based on the results of using the fuzzy-rough method MACOS in analysis and giving acceptable results because the research results of the fuzzy-rough methods are different and can be applied. Sensitivity analysis is used to analyze the criteria and evaluate which criteria directly impact the degree of change in the rankings of the alternatives.

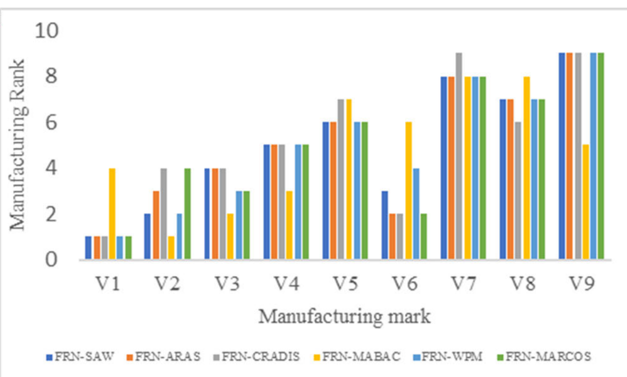

FIGURE 2. Evaluate and confirm analytical results.

Sensitivity analysis to evaluate the effectiveness of analysis and application of models or research methods in the MCDM method is necessary. The purpose of sensitivity analysis is to evaluate the influence of the weights of impact criteria on the change in ranking of alternatives, and this case study is the SAPF device. If the sensitivity analysis for this study was designed according to values of 5%, 15%, 25%, and 95% for 10 scenarios of 10 criteria, the results are realistic. Currently, we are analyzing 100 scenarios. Evaluate and determine that if the weight of one criterion is reduced, it is necessary to consider and increase the weight of another criterion with a corresponding reduction, which is done using formula 44.

$$W_{n\beta} = (1 - W_{n\alpha}) \times \frac{W_\beta}{(1 - W_n)} \tag{44}$$

From the results of the sensitivity analysis, the result of criterion V9 (TDK Corporation) is that the ranking position is unchanged for all scenarios, which confirms that this manufacturer is the bottom choice (Fig. 2). However, for all other SAPF equipment manufacturers, when the rankings change, the weights of the criteria change accordingly. This proves that criterion V1 shows sensitivity to changes in the numbers of criteria C1 (price). In all scenarios used as a perspective, the sensitivity product was performed, and the result was that criterion V6 (ABB Group) took first place in the ranking and showed that criterion V6 met the greatest level of sensitivity for changing the weights of the criteria and proving that criterion V6 is still in the penultimate position. Do the same for all remaining criteria, and the analysis results are shown in Figure 3.

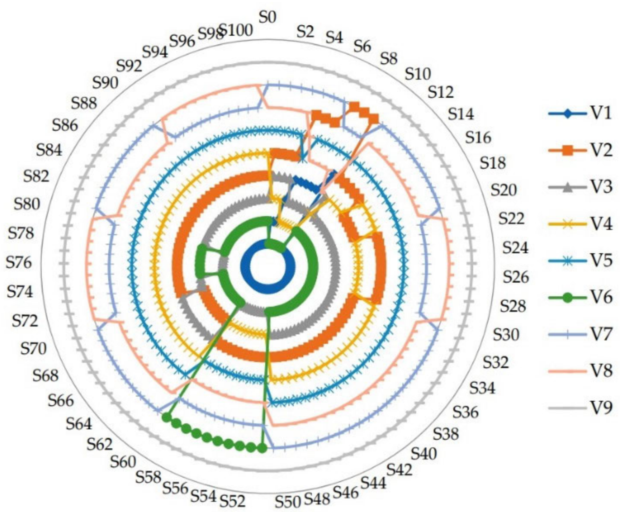

FIGURE 3. Results of sensitivity analysis of the criteria.

VI. DISCUSSION AND EXPERIMENTAL IMPLEMENTATION

A. DISCUSSION

Devices using IOT technology or Industry 4.0 technology's structure use a lot of high-frequency circuits, and these IoT devices are used in large quantities and connected directly to the power grid distribution. With a high switching function, the operation generates harmonics in the power source and causes power loss due to the harmonic currents distorting the sinusoidal shape of the power source signal, causing energy loss in the process of electricity transmission and distribution. Satisfactory power quality means that the THD value in the power source does not meet IEEE 519:2022 standards, causing phenomena such as fire, explosion, and heating of the equipment.

The difference between APF shunts in Industry 4.0 and previous infrastructures mainly lies in the integration of digital technology, integration with smart network systems, application of artificial intelligence and machine learning, as well as greater flexibility and interoperability. This improves performance, saves energy, and increases the flexibility of the APF shunt in the grid system. Modern APF devices can be connected to the energy management system via communication protocols such as Modbus, Profibus, or Ethernet, allowing remote monitoring and control. In addition, APF shunts can also integrate with smart power systems and artificial intelligence to optimize operations and improve performance. Using APF shunts in Industry 4.0 helps improve power quality, minimize harmonics, and protect other electrical equipment in the system. This simultaneously creates a stable and efficient production environment that meets the requirements of Industry 4.0.

However, APF is a technology widely used globally to reduce electrical noise and improve power quality in power systems. APF is an electronic device used to reduce electrical noise such as voltage noise, unnecessary current noise, and phenomena that distort electrical waves. It works by detecting electrical disturbances and generating an out-of-phase current whose phase is opposite to the electrical disturbance. When this current is incorporated into the system, it helps reduce interference and maintain stable power quality. APF's applications are very diverse, from industrial power systems to home power systems. The use of APF in Vietnam may depend on the specific needs and requirements of local industries and power systems. In recent times, Vietnam has increased investment and development in the power system, especially in the field of renewable energy. This could lead to the use of technology such as APF to improve efficiency and power quality in renewable energy projects, such as wind or solar power.

The study mistakenly evaluated the selection of SAPF equipment provided to the electricity distribution market in Vietnam by Electricity Measurement and Testing Company Limited. This company is one of the companies providing and measuring equipment for power quality in Vietnam. Electricity Measurement and Testing Company Limited has many branches distributed throughout Vietnam and provides the design, installation, testing, and operation of SAPF equipment in Vietnam. Mistakenly improving the efficiency of using SAPF equipment to improve the quality of power supply for equipment used in manufacturing companies that have been using distributed power sources in Vietnam, Electricity Measurement and Testing Company Limited must make the correct selection of SAPF equipment from manufacturers and appropriately evaluate the features of SAPF equipment specifically and accurately. Experts evaluate the criteria for the devices in general and confirm the limitations and benefits of SAPF devices to meet the quality status of distributed power sources in Vietnam. The criteria related to costs and benefits are considered specifically for each criterion. The selected SAPF devices need to meet the requirements of Vietnam's national power source testing center and comply with the requirements for power quality management. The subjects of this study were 9 SAPF equipment manufacturers in the world that were conducted.

When evaluating and deploying SAPF equipment in Vietnam, there are some limitations, such as high initial investment costs, a lack of maintenance equipment in the Vietnamese market, and insufficient human resources. The level of operation, maintenance, and upkeep of SAPF equipment and the knowledge of decision-makers in the company about SAPF equipment are not enough. These limitations are one of the things that prevent the development of SAPF equipment in Vietnam. These limitations are common to other countries and industries around the world that require SAPF equipment manufacturers to plan for improvement. Businesses in developing countries like Vietnam are mostly small and medium-sized companies, so the issue of initial investment costs is always a huge obstacle for decision-makers at companies. Therefore, small and medium-sized companies often have low-level human resources, making it difficult to operate SAPF equipment effectively.

Experts in this study have selected criteria to evaluate and make decisions on choosing SAPF equipment from a manufacturer that is suitable for the power quality situation in Vietnam. After specifying the criteria, experts proceed to evaluate the importance of each criterion, and the fuzzy-rough SWARA method is used by experts in this research to evaluate the importance of each criterion. The importance of each SAPF's equipment is selection criterion. From the research results, it turns out that criterion V1 (Schneider Electronic) is the company with SAPF equipment that most appropriately meets the power quality situation in Vietnam and the accompanying criteria to determine suitability. The suitability of the SAPF device above is arranged in the following order: the first is criterion C1 (price), the second position of suitability is criterion C3 (solution response), and the third-ranked position is criterion C10 (Versatile operating functions). The importance of each criterion is important in evaluating and ranking the alternatives. The above results show that SAPF equipment from manufacturer Schneider Electronic has a price suitable for small and medium-sized companies in Vietnam that they can consider for initial investment, meeting their needs for the costs or financial resources of the company. In addition, Schneider Electronics' SAPF can respond to much different frequency ranges at different voltage levels and filter noise signals in power sources with many fluctuations in the quality of distributed power sources in Vietnam, and especially SAPF equipment from manufacturer Schneider Electronic fully complies with the power quality requirements that Vietnam regulates and fully complies with all world power quality requirements. Another notable point is that Schneider Electronic Company has built and is operating an electrical component factory in a high-tech park in District 9, Ho Chi Minh City, Vietnam. Because of this, Schneider Electronics can quickly and fully provide replacement equipment or system maintenance services for SAPF equipment. In case customer companies need training to improve operating capacity for SAPF equipment, Schneider Electronic also has training courses to improve skills for employees of customer companies.

According to the results of the sensitivity analysis, the weights of the criteria have a strong impact on the ranking positions of the alternatives in deciding to select SAPF equipment from Electricity Measurement and Testing Company Limited. Analysis results using the fuzzy-rough MARCOS method in this study show that SAPF equipment from manufacturer Schneider Electronic is chosen for deployment in Vietnam because it has the best properties. Second place is the choice of SAPF equipment from the ABB Group, and this result is based on the results of analysis and sensitivity determination. This study not only conducts experimental research on each type of method in MCDM but also compares the results of the studies with each other to choose which type of method is most suitable for the evaluation criteria price and selection of SAPF equipment in the Vietnamese market. From the comparison results of the methods, different methods give different results, and the accuracy of the research results depends on each step of each method. The MABAC method gives the most different results from the research results of the other methods. The reason is that the MABAC method standardizes the data in the decision matrix and uses the average value to calculate and rank the results. Alternative criteria and the weighting process of criteria in the decision matrix also affect the results of the MABAC method.

The research method is applied to a new research environment, so it is necessary to compare research results with different methods to compare and evaluate the level of effectiveness. Decision-makers rely on different relevant information, so a different procedure and evaluation method are needed to compare and evaluate the effectiveness of each method, and the fuzzy-rough approach is used in this study. A more comprehensive study is needed to compare the results of the fuzzy-rough method with the results of other research methods in the future to evaluate the strengths and disadvantages of the fuzzy-rough method. One benefit of the fuzzy-rough method in this study is that it performs a combination of the fuzzy method and the rough method to fully exploit their strengths. Incorporating the fuzzy-rough method is into the MARCOS method to perform decision-making in uncertain environments. However, the fuzzy-rough MARCOS combination method has the limitation that the model is complex and determines the values that determine the limit levels for the fuzzy-rough parameters in the decision matrix for each individual criterion of the parameters. Different methods are used for shaping the unselected results, and the alternative options are also different. All methods have their advantages and disadvantages, and researchers and decision-makers need to identify and consider ways to improve the disadvantages and enhance them. The benefits of each option are an urgent need. All methods use expert opinions to make decisions. The implementation method has a general process, but to improve the effectiveness of the research model, it is possible to improve, modify, and update the criteria and alternative solutions.

B. EXPERIMENTAL IMPLEMENTATION

The study presents in detail the results of the installation and measurement of power quality after installing an SAPF device manufactured by Schneider Electronics at a manufacturing company in Vietnam and brings satisfactory results. Highly effective in improving the quality of power supplied to manufacturing plants.

A general introduction is about the project. Currently, the electrical system at ABC Factory is provided by 03 MSBs located in the main electrical room. To ensure stable operation of the electrical system and improve power quality, as well as meet the harmonic requirements of the Ministry of Industry and Trade, ABC Factory installed PCS+ harmonic filters for 01 banks electrical cabinet in the main electrical room, with the following harmonic filter capacity: MSB 03: Use Schneider Electric harmonic filters.

Organizational chart of SAPF installation project implementation is at ABC Company. Construction site supervisors are responsible for drawing up plans and performing construction direction tasks such as surveying the site and drawing up appropriate construction plans, proposing construction measures and progress, and adjusting construction plans are reasonable. Propose technical construction solutions, guide workers to execute construction items according to technical requirements and standards, check construction quality and construction workers are the direct construction department items are responsible for performing well the assigned tasks according to the approved design, according to the instructions of the supervising engineer as well as the supervising consultant.

The values measured with the Class A standard meter, Fluke 435, show harmonic currents exceeding the threshold according to Circular 30/2019/TT-BCT. It is recommended to install a harmonic filter to ensure safe and stable operation of the system.

TABLE 17. Maximum allowable harmonic currents distortion for electrical load.

Voltage level	THD (%)	Individual deformation
110 kV	4%	3.5%
Central Voltage	8%	7%
Lower Voltage	12% (Load >=50kW) 20% (Load <50kW)	10% (Load >=50kW) 15% (Load <50kW)

Effect of filter: The "Active Harmonic Filtering" project to bring power quality (harmonic currents) will comply with IEEE 519:2022 and TCVN standards (Circulars 39 and 30, Ministry of Industry and Trade of Vietnam), but it also brings many other outstanding economic values. Improves power reliability and productivity (energy management): Reducing peak current frees up system capacity, limits harmonic currents distortion, eliminates the effects of harmonic currents, prevents damage to equipment or reduces equipment life (asset management), reduces excessive heat production by reducing harmonic currents, prevents errors that can lead to downtime, improves equipment life, improves financial performance (cost management), reduces energy-related penalties, and contributes to plant power consumption savings.

Materials needed to prepare to install SAPF equipment include main equipment (Tab. 18) and auxiliary equipment (Tab. 19). Choosing the correct and complete main and auxiliary equipment to meet the requirements in the SAPF equipment shed is an urgent requirement; the equipment needs to meet the criteria of cost, quality, and level of performance. Correct installation of SAPF equipment.

To design a layout for installing active filtration equipment, you need to consider the following factors: (1) Installation location is to determine the location of the active filtration equipment on the system. This may depend on the system's requirements and intended use, but it is usually located near a clean water source or in front of other equipment in the system. (2) Size and space consider the size of the active filtration equipment and ensure that you have enough space to install it. If space is limited, you may need to consider options such as installing an active filter along a wall or using a compact active filter. (3) Flow guidelines are used to design the layout so that the water flow in the system is reasonable and does not cause restrictions on the active filtration equipment. Make sure that no active filtration equipment is installed above or below the water level in the system to avoid pressure imbalances and impacts on equipment performance. (4) Pipe connections are used to determine how to connect the active filtration equipment to the main duct system. Make sure that there is enough space and convenience to install suitable fittings and valves. (5) Maintenance convenience is used to design the layout so that maintenance and replacement of active filter equipment is easy and convenient. Make sure you have enough space and access to perform the necessary maintenance activities. (6) The support system considers other elements in the system, such as water pumps, control valves, and electrical systems. Design the layout so that these components have a reasonable interaction and do not cause conflict with the active filter device (Fig. 4).

The filter electrical connection diagram follows some basic principles to ensure correct and safe operation. Here are some important principles: (1) The power source must be supplied with the correct voltage and frequency required for the filter. The power source should be connected correctly to ensure safety. (2) The filter device's inlets and outlets must be properly connected. This ensures that the input signal is filtered, and the output signal has been processed. (3)

TABLE 18. List of main equipment.

No.	Equipment names	Technology parameter	Q'ty	Note
1	Harmonics filter	PCS+ 300A	1 set	
2	Harmonics filter	PCS+ 120A	1 set	
3	Temperature monitoring cabinet	EcoStruxure Asset Advisor	1 set	
4	MCCB 200A	Used for 120A filter	1 set	Busbar processing
5	MCCB 400A	Used for 300A filter	1 set	Busbar processing
6	Dynamic cable	+Cu/XLPE/PVC: 185mm2	45m	3 strands x15m
7	Dynamic cable	+Cu/XLPE/PVC: 70mm2	45m	3 strands x15m
8	Current variance	4000/5A	6 sets	Class 1

TABLE 19. List of auxiliary equipment.

No.	Equipment names	Technology parameter	Q'ty	Note
1	Control cable	CV-4×2.5mm2 (4 cores)	45m	
2	Earthing wire	CV-1×25mm2	25m	Red - Yellow - Blue
3	Ethernet cable	CAT7 SSTP 5m	1 wire	
4	Busbar	60x8mm	10m	
5	Busbar	30x8mm	5m	
6	Heat shrink busbar	Red - Yellow - Blue	1 Lot	
7	Wire tube			
8	Cosse heads of all kinds			

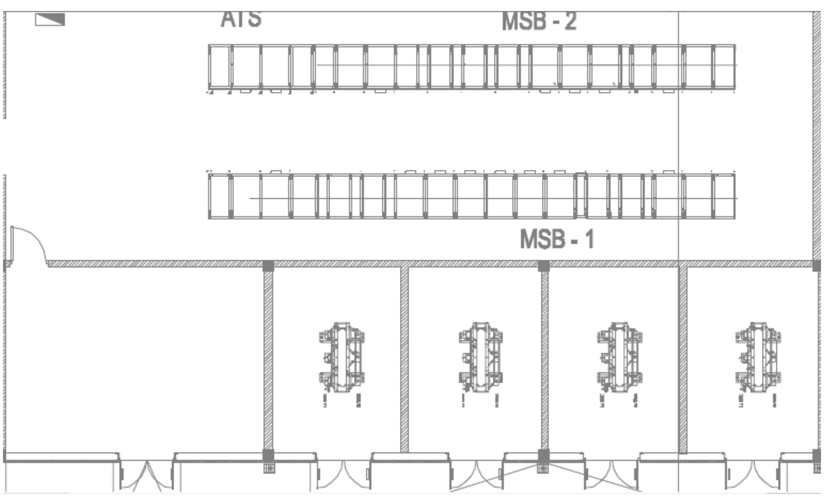

FIGURE 4. Proposed electrical room floor plan.

The control equipment is properly connected to the control equipment to control the operation of the filter. This includes control signals from the controller to the filter device and feedback signals from the filter device to the controller. (4) The sensor must be connected according to the correct principle to collect information from the environment or system. Sensors can provide input to control or regulate filter operation. (5) An amplifier (if any) must be connected to enhance the signal or adjust the output level. Make sure that the signal passing through the amplifier is free from distortion or noise. (6) The controller and communication unit connect the controller and communicate with other components in the system. This allows control, management, and interaction with the filter through interfaces and control signals. (7) Load control is the load control connection (if any) to regulate and control the operation of the load or device being filtered. (8) The user interface is connected to the user interface to allow the user to interact and adjust the settings and functions of the filter. Through the electrical connection diagram, the above principles are demonstrated through the correct connection of components and appropriate electrical signals to ensure stable and effective operation of the filter (Fig. 5).

When installing an active power filter (APF), you need the following consumables and related equipment: (1) Frame and

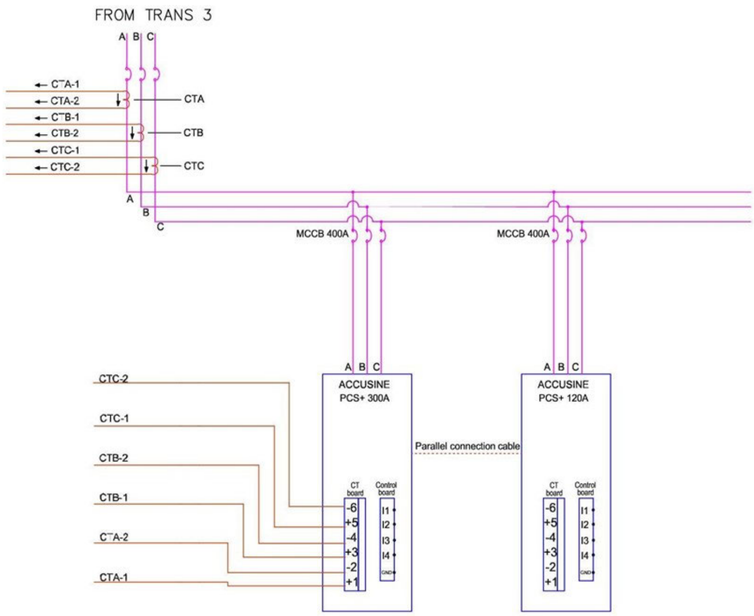

FIGURE 5. **SAPF filter wiring diagram.**

mechanical device APF filters require a load-bearing frame and other components mechanical device to hold system components. This includes suspension systems, navigation systems, struts, and other mechanical components. (2) An electronic circuit is an APF filter that uses electronic circuits to analyze and control current. This includes electronic components such as microcontrollers, sensors, power supplies, capacitors, inductors, and other components. (3) The voltage converter is an APF filter that requires a voltage converter to produce a phase voltage equivalent to the target voltage. Voltage converters may include transformers, inverters, and other electronic components to regulate and maintain the output voltage. (4) The sensor is an APF filter that uses sensors to monitor electrical parameters such as current, voltage, and frequency. These sensors provide information to the control system to adjust filter operation. (5) The control and communication system are the control and communication system used to manage the operation of the APF filter. This includes automatic controllers, human-machine interfaces, and control software to adjust and monitor filter performance. (6) The power system is an APF filter that requires a power source to power its operation. This can be AC or DC power, depending on the specific requirements of the filter. The process of installing APF equipment is detailed in Table. 20.

If the active power filter has not been activated, the power quality condition does not meet IEEE 519:2022 standards. Electric current can be distorted in certain situations and with certain factors (Fig. 7a). Here are some common situations that can lead to current distortion: (1) Electrical noise is the presence of unwanted signals in an electrical current. Electrical interference can originate from other electronic devices in the same system, from external power sources such as household electrical appliances, or from environmental influences. If electrical noise is too strong or occurs at a frequency close to the main signal, it can cause current distortion. (2) Resistors in a circuit are resistive components in a circuit such as wires, resistors, and capacitors that can cause current distortion. Resistors cause voltage loss and reduce the efficiency of current transmission in the circuit. Phenomena such as thermal resistance and frequency resistance can distort the current. (3) Non-linear components are present. In some cases, the components in the circuit may not obey Ohm's linear law, causing current distortion. For example, semiconductor devices such as transistors and amplifier circuits can create current distortion when operating at high signal levels. (4) The opening angle of the thyristor is because the thyristor is a type of electronic device that can control the current in the circuit. When the thyristor is in an off state, the current is not allowed to pass through. When the thyristor is open in its state, the current is controlled and flows through the device. However, when the thyristor switches from off to on or vice versa, a brief current distortion may occur.

High harmonic currents at orders 5 and 7 do not arise directly from power quality. Instead, it is often an undesirable phenomenon or can have a negative effect on power quality and power system performance. In an electrical system, voltage and current waves typically have the form of sine waves, with the fundamental frequency being that of the power source (e.g., 50 Hz or 60 Hz). However, power systems can be affected by factors such as non-linear loads, voltage variations, electrical noise, and interactions between different electronic devices. When these factors are present, harmonic components may appear in the power quality. Harmonic currents can have different orders, and

TABLE 20. Sequence of installation and operation of SAPF filter.

Step No.	Explain Step by Step
Step 1	Prepare before the implementation session
Step 1.1	Notify relevant parties
Step 1.2	Transport equipment and auxiliary supplies
Step 1.3	Isolate the work area with barricades and barriers, place a sign on where you are working, and the manager's name and phone number.
Step 1.4	Install lights in appropriate locations
Step 1.5	Run the generator to power lights and construction machinery.
Step 2	Cut off power and check
Step 2.1	Cut off power to the transformers and generators supplying power to the MSB 02 cabinet
Step 2.2	Rack out and LOTO again VCB supplies power through transformer, Incoming ACB, and Generator ACB if any.
Step 2.3	Recheck the voltage on the headlight indicators
Step 2.4	Remove the rear cover at the Incoming compartment and use the probe to retest the busbar system voltage.
Step 2.5	Ground the bus bar.
Step 3	Laying dynamic cables
Step 3.1	Remove the baseplate to reveal the cable compartment.
Step 3.2	Open the cable tray cover.
Step 3.3	Insert the power wire with control wire from the location of the MCCB mounting cabinet to the intended location of installing the PCS+ according to the current cable tray.
Step 3.4	Wrap with insulating glue and isolate cable ends in a waiting position under the cable tunnel.
Step 4	Attach 2 MCCBs to the two prepared compartments
Step 4.1	Remove the cabinet panel from the current installation position on the cabinet
Step 4.2	Drill holes to mount MCCB.
Step 4.3	Cut the groove for the busbar.
Step 4.4	Attach the MCCB to the panel and reattach the panel to the cabinet.
Step 5	Machining and creating holes on the main busbar
Step 5.1	Observe the installation position of the busbar that needs to be removed
Step 5.2	Remove the busbar from the current link position
Step 5.3	Measure and punch holes to attach the split bus to the bottom
Step 5.4	Attach the newly machined busbar bars to the original connection position and tighten again.
Step 6	Mount the prepared busbar to the new location
Step 6.1	Check the installation location for the new busbar.
Step 6.2	Attach the brackets and ceramic supports.
Step 6.3	Attach the 3 mains 60 x 8mm busbars to the cabinet.
Step 6.4	Bend corners and punch mounting holes for 6 30x8 busbars from the 3 newly mounted 60x8mm busbars to connect to the 2 MCCBs just attached to the cabinet panel to suit the actual size.
Step 6.5	Wrap the insulating jacket and heat it so that the insulating layer hugs the bus tightly.
Step 6.6	Securely attach the busbars to the cabinet.
Step 7	Attach the previously pulled power cables to the 2 MCCBs
Step 7.1	Observe the position of bringing the rope up
Step 7.2	Press the code end for the cable
Step 7.3	Insert the wire and attach it to the prepared MCCB in the correct order and tighten it.
Step 8	Attach the CT to the busbars to be measured
Step 8.1	Observe the CT installation location
Step 8.2	Install CT onto the bus
Step 8.3	Connect the secondary wire and bring it to the control compartment of the cabinet
Step 8.4	Connect the rest of the second wire in the control cabinet
Step 8.5	Jump the CT wire ends together at Terminal Block
Step 8.6	Connect the second CT wire on the signal side through the 2 PCS cabinets previously prepared in step 2.3.3. Side part of ACB cabinet.
Step 9	Return the operating status for the ACB cabinets that have just been operated, and the working area status
Step 9.1	Observe that all connection positions are tightened. The waiting point settings for PCS have been placed in the correct position. Check that electrical locations in the cabinet are clean and that the equipment has been completely removed.

TABLE 20. ***(Continued.)*** **Sequence of installation and operation of SAPF filter.**

Step 9.2	Remove the previously installed busbar ground
Step 9.3	Reinstall the previously removed covers
Step 10	Return electricity to the factory
Step 10.1	Notify relevant parties
Step 10.2	Remove the previously installed LOTOs except for the 2 MCCBs that are in the standby position for the 2 harmonic filters.
Step 10.3	Remove the previously installed LOTOs except for the 2 MCCBs that are in the standby position for the 2 harmonic filters.
Step 10.4	Return the original state to the cutters.
Step 10.5	Turn off the generator and clean up the lights
Step 10.6	Clean up the original barriers and return the factory to its original operating state.

FIGURE 6. **Actual set up SAPF.**

the frequency is n times the fundamental frequency, where n is an integer (e.g., 5th order, 7th order). However, high harmonic currents at these levels often cause noise and variations in power quality. It can cause phenomena such as wave shape variation, voltage variation, and current variation, create system imbalances, and causes other problems related to device performance and stability of electricity (Fig. 7b). Therefore, in power systems, reducing harmonic currents and maintaining power quality are important factors to ensure the stable and efficient operation of electrical equipment and systems.

After applying the filter, the current waveform can be improved and closer to the standard sine waveform. Filters are used to remove or minimize unwanted components in the electrical current, such as harmonic currents and noise (Fig. 8a). Filters are often designed to have high efficiency at the frequencies to be filtered and to minimize harmonic currents distortion. When current passes through the filter, it undergoes processing to remove unwanted components and allow only the desired frequency components to pass through. As a result, after passing through the filter, the current waveform will be rounded and closer to a standard

Filter STOP Filter STOP

a)The current is distorted due to the influence of harmonics b)High harmonics at levels 5 and 7

FIGURE 7. **Filter stops status.**

sine wave. This helps improve power quality and ensure the stable operation of electrical equipment and electrical systems. However, it is worth noting that the effectiveness of a filter depends on its design and construction, as well as other factors in the electrical system. Sophisticated and high-quality filters can remove unwanted components and produce a nearly standard waveform.

During the process of applying a filter to remove harmonics, the total distortion and amplitude of stepwise harmonics often decrease sharply compared to the original. This results from the process of eliminating or minimizing unwanted components in the electrical signal (Fig. 8b). Harmonics are often represented by components with different amplitudes compared to the fundamental wave. When applying a filter, harmonic components can be eliminated or significantly reduced in the electrical signal. As a result, the total distortion of the signal is reduced, and the step-harmonic amplitude is also sharply reduced. Reducing total distortion and harmonic amplitude can provide many benefits in power systems. It helps improve power quality, reduce noise and distortion in signals, and ensure stable and efficient operation of electrical devices and systems. However, it should be noted that the degree of reduction in total distortion and harmonic amplitude depends on the performance and design of the filter used. High-quality and sophisticated filters can remove harmonics more effectively and reduce distortion significantly.

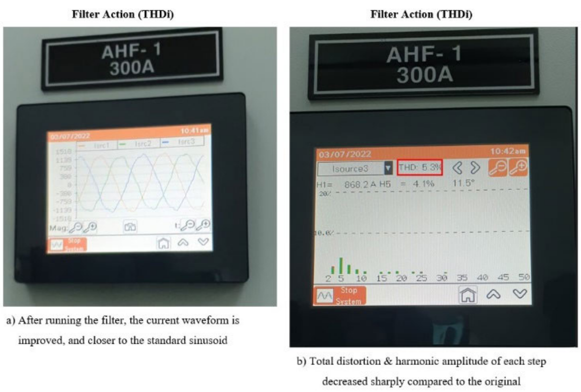

FIGURE 8. **Filter active status.**

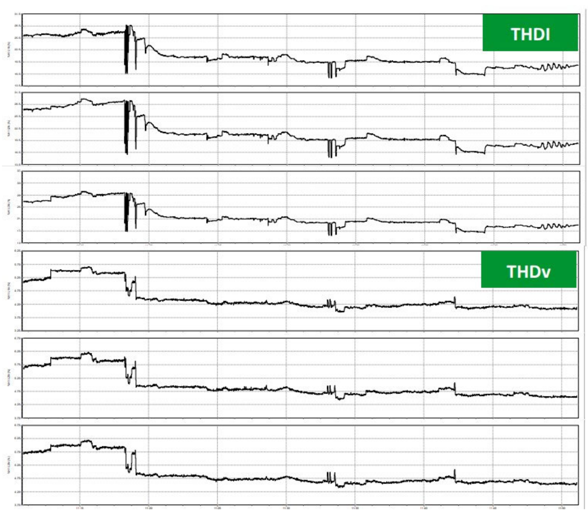

FIGURE 9. **Result of real-time THD measurement.**

Circular 30/2019/TT-BCT (Circular of the Ministry of Industry and Trade) has other requirements on power quality in addition to the requirement of a total harmonic value (THDi) below 12%. Below are some of the main requirements in this circular: (1) Voltage and Frequency the circular stipulates that the voltage and frequency values of electricity must be within an acceptable range. For example, the supply voltage must be within ±10% of the rated value, and the frequency must be within ±0.5% of the rated value. (2) The circular quality of electric current sets out requirements for voltage and current waveform distortion, including noise amplitude, wave shape distortion, and number of harmonics. For example, the voltage fluctuation value must not exceed 10%, the noise amplitude must not exceed 3%, and the number of harmonics must not exceed the specified limit. (3) Voltage drop and recovery time: the circular sets requirements on limits and recovery time when there is a voltage drop in the electrical system. For example, the pressure drop limit must not exceed 10% in a certain time, and the recovery time must satisfy the regulations. (4) The circular regulates the power factor requirements of the electrical system and electrical equipment. For example, the power factor of the load cannot be lower than a certain value. (5) Other requirements stipulated in the circular include measuring, recording, and reporting electricity quality; protecting and checking electricity quality; handling mechanisms when violating regulations; and other regulations related to power quality.

To control in real time the quality of the power supply, the company requires the use of a Fluke 435 instrument to continuously measure twice on an 8-hour shift. The company is working in a 3-shift mode and measures each time for 1 hour, performed by the company's electrical engineer. The measurement results are saved in real-time and saved into the company's SQL database system (Fig. 9). These measurement results are used in the company's weekly reports, monthly reports, quarterly reports, and annual reports. Decision-makers can easily recognize the effectiveness of applying the APF system to improve the quality of power sources at the company.

VII. CONCLUSION

A SAPF device is a modern device used to harmonics filters and other types of noise arising in the power signal to meet the requirements of improving power quality compared to other methods of using noise filters during the period of using Industry 4.0 technology devices. This paper conducts an overall evaluation study of SAPF devices from different manufacturers around the world to meet the needs of users in Vietnam with a distribution source with fluctuations in power quality status at Electricity Measurement and Testing Company Limited. The research method used in this study is the fuzzy-rough method to apply linguistic variables and perform in an uncertain environment to make decisions on selecting SAPF equipment. The fuzzy-rough method makes decisions based on the opinions of experts and adjusts the decision-making results based on the decision-makers. The results of this study show that the choice of SAPF equipment by Electricity Measurement and Testing Company Limited follows three main criteria when implementing a V1 (Schneider Electronic) SAPF device: price, solution response, and versatile operating functions.

From the research results of comparing the results of fuzzy-rough methods on evaluating and ranking positions of SAPF devices, different methods give results of analysis and placement. The rankings of the alternatives also differ. In each MCDM method, there is an implementation process, but the steps in that general process are performed differently for each different method, so the rankings of the alternatives of the methods are, and according to the analysis results of the fuzzy-rough MABAC method, the V2 (Siemens) criterion gives the best ranking results. Because of the differences in the ranking results of these alternative plans, researchers need to compare the research results and evaluate the research results of the different alternatives of different methods to help them choose the appropriate research method when conducting decision-making research for a complex problem in an uncertain environment. The research's sensitivity analysis shows that cost criteria are always the top priority factor considered by decision-makers. Sensitivity analysis shows how interaction and weighting influence the ranking order of SAPF device alternatives.

The harmonic currents value THDi displayed in the field after installing the harmonic filter is respectively THDi1 = 5%, THDi2 = 6%, and THDi3 = 5%, it meets the regulations of Circular 30/2019/TT-BCT. According to this circular, the requirement for total harmonic value (THDi) is below 12%. With THDi1, THDi2, and THDi3 values all below 12%, this indicates that the harmonic filter was effective in reducing harmonics in the power system. These values meet regulatory requirements and show that power quality has improved after the filter is installed. This means that the electrical system meets harmonic standards and complies with the electricity quality regulations of Circular 30/2019/TT-BCT.

The study also demonstrates some limitations that need to be addressed by future researchers. Firstly, the fuzzy-rough method is very complex, and the user needs to have access to the basic background knowledge of the previous method, which requires the user to have a certain understanding of the fuzzy-rough method. Computer software is needed to deal with the complexity of the fuzzy-rough method. The decision-maker must rely on the criteria and the order of the weights of each alternative to decide; however, if there is computer software, it will be simpler for the decision-maker. Second, the MCDM Method implements the same process, but at each specific individual step, it requires decision-makers to consider and identify each specific step to evaluate the decision-making results. This is also a limitation in the decision-making process of the fuzzy-rough method. Third, the compatibility level of SAPF equipment with the power quality status in Vietnam is always an open issue for individuals to consider when making decisions on choosing SAPF equipment. There are many SAPF equipment manufacturers in the world with different structures and operating functions. Choosing SAPF equipment from a manufacturer suitable for the production and business markets in Vietnam brings efficiency. High efficiency in production and business is a challenge.

The fuzzy-rough method brings high efficiency to solving the advantages of fuzzy arithmetic and rough numbers in decision-making techniques. The fuzzy-rough method is considered one of the methods used to solve complex problems that require decision-making in an uncertain environment. However, to further improve the effectiveness of fuzzy-rough methods, it is necessary to improve the steps of the method wall in the decision-making process according to MCDM to improve the sensitivity analysis process and improve the efficiency of fuzzy-rough methods the level of confidence in the decision-making results of the decision-maker. However, the research and decision-making results of the fuzzy-rough method have the benefit of eliminating bias from experts' opinions, helping to improve the reliability of decision-making results.

In future research, it is necessary to research more modern optimization methods applied to SAPF devices to improve efficiency when applying SAPF devices to improve power quality in all situation's different conditions in the Vietnamese market. However, the price of investing in deploying SAPF equipment also needs to be considered and improved to suit the conditions of SMEs in Vietnam and other developing countries in the world. The Vietnamese market is developing renewable energy sources, and there is a great need for a suitable SAPF device to eliminate signal interference in power sources and improve power quality. This is an open research direction with many discoveries and capabilities for researchers and SAPF equipment manufacturers. Research and apply many other methods to conduct research, such as the fuzzy-TOPSIS method, the APH method, or the VIKOR method. In addition, research on modern optimization methods, such as bio-inspired optimization on SAPF filter control, to select an appropriate compensation current to restore power lost due to harmonic currents.

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AUTHOR CONTRIBUTIONS

Minh Ly Duc and Petr Bilik: Conceptualization and validation. Minh Ly Duc: methodology, software, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, and visualization. Petr Bilik and Radek Martinek: supervision, project administration, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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