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RESEARCH ARTICLE

Analysis of Factors Affecting Electric Power Quality: PLS-SEM and Deep Learning Neural Network Analysis

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ABSTRACT The world today is increasingly dependent directly or indirectly on the power system. Ensuring the quality of power supplied to electrical equipment is essential. The national regulatory framework is for harmonic mitigation in the global power system. This paper discusses the relationship between Efficiency (E), Security (S), and Reliability (R) for Electric Power Quality (EPQ). We measure the harmonic mitigation regulations listed in the IEEE 519 standard. To evaluate the proposed E, S, and R constructs and their relationship to EPQ, a multi-planning approach the method of Partial Least Squares- Structural Equation Modeling (PLS-SEM) and Deep Learning Artificial Neural Network (ANN) analysis were performed. In it, deep Learning Artificial Neural Network (ANN) was performed to complement the PLS-SEM findings and higher prediction accuracy. The study shows that the aspects of efficiency (E), security (S), and reliability (R) have a significant relationship with Electric Power Quality (EPQ). Another result of the study indicates that science, technology, engineering and math (STEM) resource conditions have a significant and positive impact on EPQ.

INDEX TERMS Harmonic mitigation, partial least squares- structural equation modeling, PLS-SEM, artificial neural network (ANN), electric power quality.

I. INTRODUCTION

The study empirically explores the role of the host country's IEEE 519-2022 [1] power quality regulation on harmonic mitigation activities in power systems to improve the quality of power supply and protect electrical equipment from explosions [2], [3]. Previous studies used traditional econometric models and measured the impact of IEEE 519 regulation on power quality assurance. The system of regulations on electricity management applied by Vietnam is in line with the operating standards in the world and there has not been a specific study on the regulations guiding the electricity law on management. To fill in the gaps and expand research directions compared to previous studies, this paper analyzes the influence of different IEEE 519 regulations on harmonic mitigation in power supplies. This paper selects some quantitative representations of regulation and their relationships to EPQ covers IEEE 519, IEC 61000-2-2 [4], IEC 61000-2-4 [5], EN 50160 [6], IEC 61000-3-2 [7] and IEC 61000-3-12 [8]. This paper proposed to follow the partial least squares structural equation modeling method (PLS-SEM) to conduct this analysis.

There are two standards for quality control of the distribution network. First, the EN 50160 Standard specifies the grid characteristics provided by the public distribution network. Second, the IEEE 519 Standard represents a shared usefulness for customers to limit the impact of non-linear loads [9]. Industrial 4.0 is increasingly developing, automatic switching control systems are mostly used in electrical equipment, lighting loads such as LEDs are widely used, and the above devices are the main cause of harmonic generation. Furthermore, these benefits encourage preventive action in terms of

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reduced energy quality values, increased temperatures, and reduced power factor [10], [11], [12]. The main sources of harmonic generation tend to cost clients significantly.

There are many measures to improve electric power quality. Specifically, the goal of solutions is harmonic mitigation. There are three commonly used solutions to reduce harmonics. (1) Carry out corrections in the electrical network. (2) Use special equipment in the supply system and (3) Use harmonic filtering devices. To limit the propagation of harmonics in the distribution network, many different solutions can be used such as creating isolation sources. The transformer is especially connected by the inductor installation method [13]. Select the appropriate grounding system. In case the measures to prevent harmonics mentioned above are still not met, it is necessary to equip the grid with harmonic filtering systems such as passive harmonic filtering, active harmonic filtering, or hybrid harmonic filtering [14].

For decades, the PLS-SEM Model has been accepted by critics and researchers as a multivariate analysis method. Searching in the database system, the results indicate the term ''partial least squares structural equation modeling method (PLS-SEM)'' which has helped the researchers in the experiment to confirm the analysis of the theoretical project such as operations management, supply chain, information systems, business, and many others. This paper takes the first approach to study the interaction between Efficiency (E), Security (S), and Reliability (R) for Electric Power Quality (EPQ) using the PLS-SEM model. Efficiency is the ability to operate profitably and is a measure of the ability of an electrical system to avoid wasting energy, time, and costs. Efficiency is a measure of the actual power supply capacity compared to the original calculation. The higher the efficiency, the more efficiently the power system's ability works. This means less energy, materials, and costs are wasted. Grid security ensures the stable operation of the system and enhances connectivity between power systems in a digitized system safely. Information communication between power distribution networks ensures security for users. The power supply reliability of the distribution grid is the ability of the system to fully and continuously supply power to the power-consuming load with the power quality (voltage and frequency) in accordance with the regulations. The studies of the PLS-EEM model give results on the effects on electric power quality using usage reports with linear relationships between the studied variables and the PLS-SEM model of a research approach for the prediction model. One of the serious shortcomings of the PLS-SEM model (that is, linear relationships) techniques, it simplifies the human decision-making process, which is a complex one.

Artificial Neural Network (ANN) analysis has the benefit of building linear and non-linear models with higher accuracy than the PLS-SEM model. Artificial Neural Networks use interconnected nodes or neurons in a layered structure similar to the human brain. This approach creates an adaptive system used by computers to learn from their mistakes and continuously improve. Artificial Neural Networks aim to solve complex problems. Artificial Neural Networkscan learn and model complex, non-linear relationships between input and output data. Artificial Neural Networks can clearly understand unstructured data and make general comments without specific training. Therefore, the recommendations of the ANN model were followed throughout previous studies. However, the ANN model has a single hidden layer approach in the neural network model.

To fill the gaps in the research, it is proposed to use a deep learning-based ANN model using two or more hidden layers to improve prediction accuracy. The research model aims to specifically evaluate the factors affecting electric power quality by applying a multi-step approach. The first is to use the partial least squares structural equation modeling method (PLS-SEM) model and Artificial Neural Network (ANN) based on training. To further clarify the findings in the research model for management implications, Importance Performance Mapping Analysis (IPMA) evaluates the relationship between the significance of a latent variable and the performance of that latent variable in the model. IPMA can identify which variables in the model are of relatively high importance but with low efficiency. From there, the researchers made accurate assessments of the situation and made improvements. A variable of high importance but low efficiency means that the variable has a strong effect but a low mean. The goals of this study include:

(1) Analysis and clarification of power quality management regulations including standards for harmonic control and power quality-related factors such as IEEE 519, IEC 61000-3-2, EN 61000-3-2, IEC 61000-3-12.

(2) Evaluate the positive and negative effects of potential variables including Efficiency (E), Security (S), and Reliability (R) on power quality (PQ) and proper response to control standards for the quality of power sources operating in Vietnam.

(3) Highlight the role of harmonic management standards in the design of electrical control devices to meet the industrial 4.0 era.

(4) Proving research model PLS-SEM Neural network meets deep and extensive research on power quality management regulations. The PLS-SEM Neural network model provides a complete overview of the elements of harmonic control regulation, bringing practical benefits to researchers and electronics manufacturers in new designs.

This article is structured as follows. Section II presents the theoretical foundations and hypothesis development. Section III presents details of the structure of the methodology. The results and discussion of the study are detailed in Section IV. Section V presents the conclusions.

II. THEORETICAL FOUNDATIONS AND HYPOTHESIS DEVELOPMENT

Power quality strongly affects the performance of power-using equipment [15], [16]. Power quality determines the lifespan of electrical equipment [17]. Previous studies have mainly focused on harmonic mitigation methods using various models and focused on basic traditional theoretical models, and there have been no specific studies analyzing the impact of these effects. Management standards for minimizing harmonics related to power supply quality. Specifically, there are too many electrical equipment fires and explosions due to poor power quality.

Unstable power quality makes equipment unstable or explodes causing economic losses to users [18]. The distortion of the voltage or current waveform causes the power distribution to be noisy and the power quality to be disturbed [19]. Harmonic currents are generated from non-linear loads connected to the distribution network through impedance and distortion of the supply voltage [20].

The source of harmonic generation is from all non-linear devices such as (1) Industrial Equipment: Welding machine, Arc furnace, Electromagnetic induction furnace, and Rectifier. (2) Variable controller asynchronous speed or DC motors. (3) UPS rectifier. (4) Office equipment such as computers, copiers, and fax machines. (5) Magnetic saturation-related equipment such as transformers [21].

Harmonics in the distribution network degrade the quality of the power supply [22]. This causes several negative effects as follows: (1) Overcurrent occurs on the power distribution network due to an increase in the current R.M.S. (2) Overload occurs on the neutral wire due to the cumulative increase of the 3rd harmonic generated by the single-phase loads. (3) Amperage exceeds the allowable levels, electrical fluctuations and shortening of the life of generators, transformers, andmotors such as noise from transformers are increasing. (4) The power factor correction capacitoris overrated current and life reduced. (5) Distortion of the power supply may result in interference with sensitive loads. (6) Causing interference on communication networks and telephone lines [23], [24].

Harmonics is the object of study of standards for compatibility with distribution networks, standards for application generation for devices generating harmonics, recommendations for generated from power companies and can be applied to the grid. To rapidly weaken the effects of harmonics, a three-part system of applicable standards and regulations is used based on the following documents [25], [26]. IEC 61000-2-2 and IEC 61000-2-4 are standards that control the compatibility of distribution networks and products. EN 50160, IEEE 1459 [27], and IEEE 519 are standards for the quality control of power networks. IEC 61000-3-2 and IEC 61000-3-12 are equipment control standards. Figure 1 shows the research model.

Efficiency (E): This means a positive view of technology to improve controllability, flexibility, and efficiency of everyday power quality for technical reasons.

Security (S): This is about trusting technology for privacy and security in power usage control and power quality improvement with industrial 4.0.

Reliability (R): This is meant to provide the best overview of all aspects related to power quality.

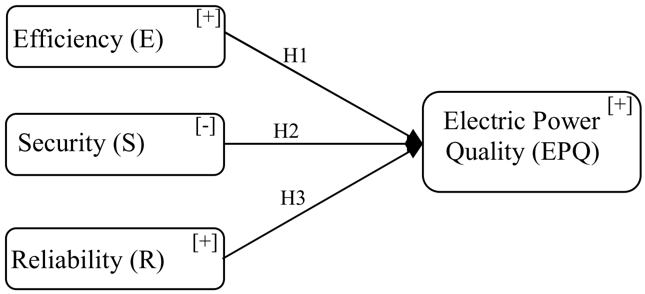

FIGURE 1. Research model.

TABLE 1. Voltage harmonic distortion (Source: IEEE 519-2022, pp. 17).

Bus voltage (V) at PCC	Total Harmonic Distortion	Individual harmonics
$V \leq 1.0kV$	$\leq 8.0\%$	$\leq 5.0\%$
$1.0kV \leq V \leq 69kV$	$\leq 5.0\%$	$\leq 3.0\%$
$69kV < V \leq 161kV$	$\leq 2.5\%$	$\leq 1.5\%$
$69kV < V$	$\leq 1.5\%$	$\leq 1.0\%$

Efficiency (E) of power supply for electrical equipment has always been interest to electricity users [12]. Harmonic control in IEEE 915 and prevention of explosions due to overload is necessary [28], [29]. The total voltage harmonic distortion at all connection points shall not exceed the limits specified in Table 1 as follows.

Design measures to reduce harmonic loss and provide suitable operating solutions for users to improve the operating efficiency of electrical equipment such as: replacing damaged equipment, using AC reactors or coils resistance, DC for inverter, 12-pulse rectifier solution, using an inverter with low harmonics, using filter [11], [30].

Proper and appropriate use of sub-harmonic suppressors will result in a reduction of harmonic currents of up to the 50th order (2500 Hz), user-selectable harmonic frequencies filtered for greater efficiency, restore unbalanced current consumption between phases of the power system and compensate reactive power in an inductive or capacitive fashion [31]. These filters provide configurable preference functionality for optimal use of filter capabilities according to installation needs. In case the power supply requires high-quality filtering, the 8 filters are coupled in parallel and the filters must have the same power. Depending on the specific environment, the harmonic reduction filter is designed to be suitable such as automation factories, hotels, cinemas, hospitals, or airports [10], [32]. The above arguments lead to our first hypothesis.

Hypothesis H1: The operational efficiency (E) of the power system has a positive relationship with the Power Supply Quality (EPQ).

Grid security is the goal of providing solutions to make the control system more secure and the benefits of digitization increasingly stable. Connectivity is a cybersecurity challenge for surveillance automation and telecommunications infrastructure. In case, the power grid is compromised endangering the users and reducing the reliability of the system [33]. The power supplier ensures the continuity of power system operations with a comprehensive network of highly secure systems. At its core is to provide a method of reducing risk and enhancing network security from the sensor level to the application level [34].

Attacking the national power grid is considered the most dangerous model when critical infrastructure and essential services of the power supply system cease to function [35]. Specifically, Power Consumption Tracking Utilities are commanded by grid operators to turn off equipment via radio frequency when excess power is consumed. These signals are not encrypted and can be interfered with by stronger transmitters that hackers can use tomanipulate the electrical system [36]. In case, all power systems are activated during peak hours, the electricity network of the whole area will be severely affected and Hackers can take control remotely and change the current, attack the power grid, and cause damage, animbalance between supply and demand, generating overload leading to power failure [37]. In the past few years, malicious attacks on electrical systems have begun to appear in some parts of the world. The alarming thing here is that the grid control protocols were designed decades ago and have a lot of vulnerabilities for malicious attacks. Hackers broke into the power grid, paralyzing substations and switches, causing power outages that happened in December 2015 [38]. Hence, we propose the next hypothesis.

Hypothesis H2: Grid security (S) of thepower supply system has a negative relationship (-) to Power Supply Quality (EPQ).

Reliability (R) of the power supply system includes supply reliability, service quality, voltage quality, current quality, supply quality, and consumption quality. Supply reliability and quality of supply are when the power system is working. There will be a problem with the frequency depending on the quality of the equipment, the operating method of the system, and objective factors. System response is related to the distribution system's ability to provide power to users [39]. Existing techniques for calculating the reliability of power systems are all within the standard range [40]. Improve power supply reliability by measures including quickly finding and fixing problems, using short-circuit fault reporting devices, equipment to detect underground cable problems, establishing professional trouble-shooting teams, or constructing hotlines using the hotline system in repairing and maintaining high-, medium- and low-voltage lines. Porcelain washers effectively clean insulation with high-pressure water [41]. Hot oil filter improves transmission transformer oil quality without power cut.

Power quality (PQ) includes voltage quality and current quality which are factors that directly affect the operating quality of electrical equipment. The best quality power supply will be provided with a sine waveform whose amplitude, frequency, or specifications meet the national standard system combined with zero ohm impedance at all frequencies [42]. Low power quality causes problems such as overvoltage, equipment flickering, power consumption and reduced lifespan of electrical equipment, louder motor, vibration, high temperature, anddamage tothegearbox. Capacitors have the phenomenon of overheating, overvoltage, andcapacitor explosion. The transformer emits loud noise, large vibrations, high temperature, higherflammabilityandexplosion risk. Power transmission lines generate heat on the lines, which burns the conductors. Electronic equipment is damaged or short-circuited. The measuring device affects the accuracy of the measurement [43]. Metallurgical furnaces that smelt metals for a long time use a lot of electricity, increasing electricity costs, and at the same time increasing operating costs in production. The power grid has reduced transmission capacity [44]. The power quality assessment criteria are used to evaluate the operating efficiency of the power system. The power quality assessment criteria can be based on the provisions of Circular 39/2015/TT-BCT. You can refer to it below. IEEE 519-2022 is the standard for current and voltage harmonics. You can refer to the specified table below (Tab. 2).

The nominal voltage level for the distribution power system will include voltage levels: 110kV, 35kV, 22kV, 15kV, 10kV, 6kV, and 0.4kV. Under normal circumstances, the permissible power fluctuations such as residential load capacity will not exceed ±5%, power plants will not exceed +10% and -5%. For single-power system failures, a tolerance of +5% and -10% will be required. For serious faults, a tolerance of ±10% will be required. The rated frequency level is 50Hz, andthe permissible frequency oscillation will be specified with the following level: Under normal conditions, the given oscillation frequency is ±2%. When the system condition is not stable, the allowed oscillation frequency is ±5% (see figure.2). Figure 2 shows that the power fluctuation of the power supply when a serious fault occurs has a tolerance of +/-10% and is up to 5% larger than when a minor fault occurs. This proves that the risk of a major incident is more and more likely to arise. The oscillation frequency in the event of a fault occurs with an allowable tolerance of +/-5% compared to a normal state of +/-2% which is up to 6% higher. This proves that the risk of impact affects the quality of equipment using electricity. Verification of tolerance domains for power and frequency fluctuations in the event of an electrical fault to improve the quality of power supply and performance of electrical equipment is a promising research topic. In the case of the connector and power-down voltage supply up to 10kW, the value of high-harmonic current should not exceed 5A for 1 phase, 14A 3 phases. In the case of the connector from a power supply medium voltage or connector with a capacity from 10kW to 50kW, the value of high-order current must not exceed 20% of the load. In the case of a high-voltage input terminal with a capacity greater than 500kW, the harmonic current value will not overload 12% of the load. When the

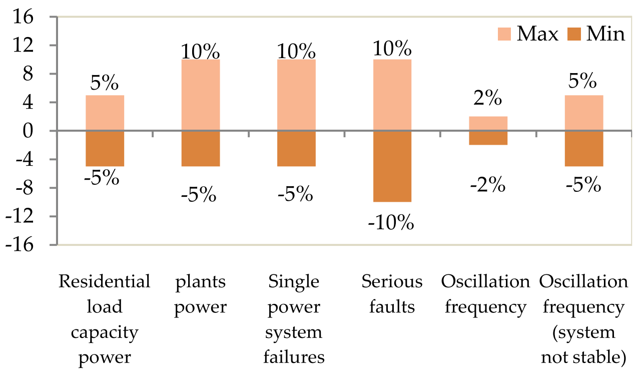

FIGURE 2. **Distribution power system management standards.**

phase balance is atthe stable operating level, the reverse order component of the phase-breaking power level will not be more than 3% of the nominal voltage at the110kV voltage level. At the same time, the phase voltage will also not be more than 5% at themedium voltage and low voltage levels.

Service Quality and Consumption Quality are a function of the failure intensity of electrical equipment. Damage intensity is usually expressed as the number of failures per kilometer of length in a year. Electricity service providers for electricity users always monitor and measure the following information to provide quality services to electricity users [45], [46]. Specifically, indexes such as System Average Interruption Frequency Index, System Average Interruption Duration Index, Customer Average Interruption Frequency Index, Customer Average Interruption Duration Index, Average Service Availability Index, Average System Interruption frequency index, Average System Interruption Duration index, Energy Not Supplied, Average Energy Not Supplied, Momentary Average Interruption Frequency index and Only for blackout in case of long term failure. A large part of failures are transient, self-healing, for example lightning; birds, rats, snakes; electric arcs. Devices that allow self-closing are: reclose and circuit breakers equipped with RELAY 79 and minimize the number of customers who lose power. Using devices with fault isolation and segmentation functions such as FCO, DS, LBS, and reclose. Combine with the source transfer operation method [47], [48]. Thus, we hypothesize that:

Hypothesis H3: Reliability (R) of thepower supply system has a positive relationship with Power Supply Quality (EPQ).

III. RAW MATERIAL AND RESEARCH METHODOLOGY

Use of electronic components such as motor speed regulators and control rectifiers have greatly increased the problem of harmonics in the power supply system [49], [50]. Harmonics have been around since the beginning of theindustry, mainly due to the nonlinear reactance of magnetized circuits of transformers, reactors, arc furnaces,and fluorescent lamp ballasts. Harmonics in a symmetric 3-phase system usually have odd orders of order like 3, 5, 7, and9 and their amplitude decreases as their order increases [51], [52]. Completeelimination of harmonics is not possible and it is not the subject of research in harmonic control standards and regulations [53].

A. SOURCES AND MEASURES

In this study, to test the proposed hypotheses, alternative reliable secondary data sources were used including standards for power quality management. We have collected metrics from standards that control compatibility between distribution networks and products such as Standard IEC 61000-2-2 for public low-voltage power supply systems and Standard IEC 61000-2-4 for low and medium-voltage industrial power grids. The standards of distribution network power quality control such as the standard EN 50160 which specifies the grid properties provided by the public distribution network and the IEEE 519 standardand IEEE 1459standardrepresent a general approach to controlling harmonics that are caused by non-linear loads on electrical equipment such as IEC 61000-3-2 or EN 61000-3-2 for low voltage electrical equipment with rated current below 16A and Standard IEC 61000-3-12 for low voltage electrical equipment with rated current between higher than 16A and lower than 75A. Table 3 summarizes the structure and scale of each source.

Power quality is the core factor for electronic and electrical components in theoperation, longevity, and accuracy of electrical equipment [54]. This study shows that the complexity and variety of sources affect power quality. Power quality requires a lot of relatedknowledge such as engineering, management knowledge, and even related knowledge to ensure information security for the power system [55]. Looking at the economy with the explosion of smart electronic components and with the development of smart systems such as smart homes, andsmart factories, along with industry 4.0 and the need to use a lot of control switches control and this is the main source of harmonic generation in the power supply [56]. It is from the importance of power quality assurance and specifically harmonic mitigation that we analyze the current power quality control standards that organizations are using and applying (Tab. 3)

B. CONSTRUCTS AND INDICATORS

From the mentioned sources, we select specific indicators related to the meaning of the proposed structures. In Table 4, we describe the composition of each structure and show the descriptions of the indicators.

C. SAMPLING METHOD TO COLLECT DATA

In this study, a convenient sampling method was used to collect data. Students and staff of the Faculty of Electrical and IT Engineering, Van Lang University, and staff of the power company in Ho Chi Minh City, Vietnam, were invited to participate in the survey in May 2022. We use the random sampling method (convenience sampling and a random sample ensure equal chances of selection [57]) because it is easily accessible to the participants and willing to participate. In addition, the research lab of the control equipment of the

TABLE 2. Current distortion limits for systems rated 120 V to 69 Kv (IEEE 519-2022, pg.19).

I_{sc}/I_L	Harmonic limits a,b					TDD Required
	$2 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

a: For $h \le 6$, even harmonics are below to 50% of the harmonic limit; b: Current distortion has result in a dc offset; I_{sc}: Maximum short circuit current at PCC; I_L: Maximum demand load current at PCC under normal operating conditions.

TABLE 3. Data sources and scales.

Index	Categories/Pillars	Indicators	Scale	
			High	Low
IEC 61000-2-2 and IEC 61000-2-4	Basic requirements	Electromagnetic compatibility (EMC); Specification for radio disturbance and immunity measuring apparatus and methods;	10	1
	Basic Rules	Harmonics; Total Harmonic Distortion (THD); Signals from mains communicating systems; Ripple control systems	10	1
	Technical environment	Sources of inter-harmonic currents and voltages; Effects of the inter-harmonic voltages;	10	1
EN 50160, IEEE 1459 and IEEE 519	Basic requirements	Engineering Perspective; Business Perspective; Recommended harmonic limits	10	1
	Basic Rules	Very short time harmonic measurements; Short time harmonic measurements; Individual responsibilities;	10	1
	Technical environment	Harmonic Voltage Limits; Current Distortion Limits; Emphasis of Phase-Shifting Transformer & "Multi-pulse" Converter;	10	1
IEC 61000-3-2 or EN 61000-3-2 and IEC 61000-3-12	Basic requirements	Harmonic line current reduction techniques; Limits for harmonic current emissions; Requirements and limits for equipment;	10	1
	Basic Rules	Harmonic current limits; Harmonic current measurement; Illustration of limits for harmonic currents;	10	1
	Technical environment	Measurement circuit and supply source; Test conditions; Test observation;	10	1

Source: Author's elaboration based on the respective source

electrical-computer department requires the quality of the power supply to be stable and free of interference to ensure the correct operation of the equipment. HCMC Power Company provides uninterrupted power and ensures stable power supply quality. The criteria are select participants is to have basic knowledge, understanding, and awareness of electricity and electrical equipment. A survey (closed questionnaire) in English and Vietnamese using a 5-point Likert scale to collect data. The questionnaire was sent to 3 experienced researchers in electricity at Van Lang University, and the questionnaire was re-completed according to the suggestions of those 3 researchers. Measure each of thespecific content in the standards to ensure the validity and reliability of the research.

A total of 600 responses were collected and after removal 45 answers are missing or incomplete, possibly because participants did not read the question carefully and did not understand the content of the question or answered without noticing that the content was missing, 555 answers yes can be used for data analysis. 95% of survey respondents are male and 5% are female. All survey participants had knowledge and experience in electricity and electrical equipment for 2 years or more and were well aware of electrical engineering and well understood that harmonics affecting power quality. 45% of the participants enrolled in the Bachelor of Electrical Science. 10% have registered to study Master of Information Technology. 10% of the participants were Ph.Dstudents, 10% were staff of the Faculty of Electronics and Communication and 25% of the participants were officers of apower company in Ho Chi Minh City, Vietnam.

This study performed data analysis using a multi-step approach like that of PLS-SEM and deep learning neural network analysis. Deep learning neural network analysis yielded useful results inadjusting complex linear and non-linear relationships with a high degree of predictive accuracy compared toSEM method [58], [59]. However, the PLS-SEM model is

TABLE 4. Indicators and constructs.

Indicator		Description	Construct		Source
e-le	X_1	Limits for emission			IEC 61000-3-12
e-pd	X_2	Product documentation			IEC 61000-3-12
e-tp	X_3	Transitional periods	E	Y_1	EN 61000-3-2
e-vc	X_4	Voltage characteristics			EN 50160
e-nr	X_5	Normative references			IEC-61000-2-2
s-dm	X_6	Direct measurement			IEC 61000-3-12
s-ts	X_7	Test and Simulation			IEC 61000-3-12
s-mm	X_8	Measuring methods			EN 50160
s-dvw	X_9	Deterioration of voltage wave	S	Y_2	IEC-61000-2-4
s-cs	X_{10}	Communicating systems			IEC-61000-2-2
s-ds	X_{11}	Distribution systems			IEC-61000-2-2
r-lhc	X_{12}	Limits for harmonic currents			IEC 61000-3-12
r-lhv	X_{13}	Limits for harmonic voltages			IEC 61000-3-12
r-ems	X_{14}	Electro Magnetic Susceptibility	R	Y_3	IEC 61000-3-2
r-emi	X_{15}	Electro-magnetic Interference			IEC 61000-3-2
epq	X_{16}	Electric Power Quality	EPQ	Y_4	IEEE 519-2022

Source: Author's elaboration

a preferred analytical method in applied research technology. ANNs are useful for research content where the theory is weak or theunderstanding of the underlying relationships is limited.

In this study, thePartial Least Squares Structural Equations Modeling (PLS-SEM) model is deployed and analyzed first. Dash et al. [60], [61] recommend implementing the PLS-SEM model, as it performs better under the condition of asmall sample size and does not include normality and no distributional assumptions. In addition, Leong et al. [62] stated that PLS-SEM analysis is a more efficient approach than CB-SEM in the results of a real model and Lee et al. [63] have made a detailed comparison of PLS-SEM and CB-SEM.

In the secondary analysis step of this study, we propose to use deep learning-based Artificial Neural Network (ANN) analysis to complement the PLS-SEM results. Deep learning ANN analysis is performed using two hidden layers in ANN modeling, which is considered to be a more accurate approach than one hidden layer methods [64], [65]. The details of PLS-SEM and ANN deep learning are presented in the following sections.

D. PLS-SEM METHODOLOGY

In this study, we chose the structural equation model (SEM) [58] because of the ability to model all the paths at the same time. In addition, this study proposed apartial least squares method (PLS-SEM) instead of based on covariance (CB-SEM) for the following purposes: (1) PLS model has minimal limitations on measurement of scale, sample size, and residual distribution, (2) Analysis using the PLS model does not assume truly independent variables, leading to more reliable results, and (3) the PLS model performs robustly and effectively can resist data bias and ignore an independent variable [63].

The normative literature on power quality management shows an increasing complexity in the issues and this research model is made of observations due to the correlation between established theoretical quantities and data availability. The PLS-SEM model can be considered as one of the most innovative approaches in the field of evaluating very complex problems [60], [61]. This method has proved particularly valuable for exploratory purposes and is considered suitable for explaining complex relationships, such as those arising from institutions, standards, and quality assurance amount of power supply.

Data were evaluated using Smart-PLS to help identify relationships between latent variables E, S, and R as indicators of institutional quality and their impact on EPQ.

The variables were modeled as reflective constructs since the indices were expected to cooperate. The indicators have the same theme in the mirroring pattern. Therefore, indicators must have the same premises and consequences.

Model Specification:

Our research model has set technical points including 16 indicators (X_1, X_2, X_3,. .n., X_{16}) and 4 latent variables (Y_1, Y_2, Y_3, Y_4). The latent variables Y_1, Y_2, Y_3 affect Y_4 and the measurement model is as follows:

$$X_1 = Y_1C_1 + \varepsilon_1$$
$$X_2 = Y_2C_2 + \varepsilon_2$$
$$X_3 = Y_3C_3 + \varepsilon_3$$
$$X_4 = Y_4C_4 + \varepsilon_4$$
$$X_5 = Y_5C_5 + \varepsilon_5$$
$$X_6 = Y_6C_6 + \varepsilon_6$$
$$X_7 = Y_7C_7 + \varepsilon_7$$
$$X_8 = Y_8C_8 + \varepsilon_8$$
$$X_9 = Y_9C_9 + \varepsilon_9$$
$$X_{10} = Y_{10}C_{10} + \varepsilon_{10}$$
$$X_{11} = Y_{11}C_{11} + \varepsilon_{11}$$

$$X_{12} = Y_{12}C_{12} + \varepsilon_{12}$$
$$X_{13} = Y_{13}C_{13} + \varepsilon_{13}$$
$$X_{14} = Y_{14}C_{14} + \varepsilon_{14}$$
$$X_{15} = Y_{15}C_{15} + \varepsilon_{15}$$
$$X_{16} = Y_{16}C_{16} + \varepsilon_{16}$$

In our study, X is called the indices, Y is called the latent variables, C is called the loads relating the latent variables to the indicators, and is called the residual of the variables. Our measurement model is represented by the analytic indicators and each is assumed to affect the corresponding latent variable. As a result of the study, all endogenous variables were observed.

The measurement model of this study is expressed through formula (1).

$$X = C'Y + \varepsilon \tag{1}$$

In the measurement model of this study, X is called vector J according to 1 of all indicators, Y is called P according to 1 vector of all latent variables, C is called a P according to the matrix J of the loads related to the latent variables P to J indices, and is called the vector J according to 1 remainder of all Indicators. In our research model, J and P are indicated by 16 (indicator) and 4 (latent variable), respectively.

The structural (internal) model of this study is proposed to show the relationship between latent variables and is expressed by the following formula:

$$Y_4 = Y_1\beta_1 + Y_2\beta_2 + Y_3\beta_3 + \tau_4$$

This is where β is called the path coefficient relating one latent variable to other latent variables and is called the residual of the latent variable not explained by the corresponding exogenous latent variable. In the model, Y1, Y2, and Y3 are called exogenous latent variables, while Y4 are called endogenous latent variables.

The above research model is expressed by formula (2).

$$Y = B'Y + \tau \tag{2}$$

In the structural model of this study, B is called the P-by-P matrix of the path coefficients relating P the latent variables to each other and is called a vector P times 1 of the residuals of all latent variables. The weight relationship for the proposed model is as follows:

$$Y_1 = X_1\omega_1 + X_2\omega_2 + X_3\omega_3 + X_4\omega_4 + X_5\omega_5$$
$$Y_2 = X_6\omega_6 + X_7\omega_7 + X_8\omega_8 + X_9\omega_9 + X_{10}\omega_{10} + X_{11}\omega_{11}$$
$$Y_3 = X_{12}\omega_{12} + X_{13}\omega_{13} + X_{14}\omega_{14} + X_{15}\omega_{15}$$
$$Y_4 = X_{16}\omega_{16}$$

In the weighted relational model of this study, W is called a J because the weight matrix P assigns J indices, thus, leading to latent variables P. Expressed by formula (3).

$$Y = \omega'X \tag{3}$$

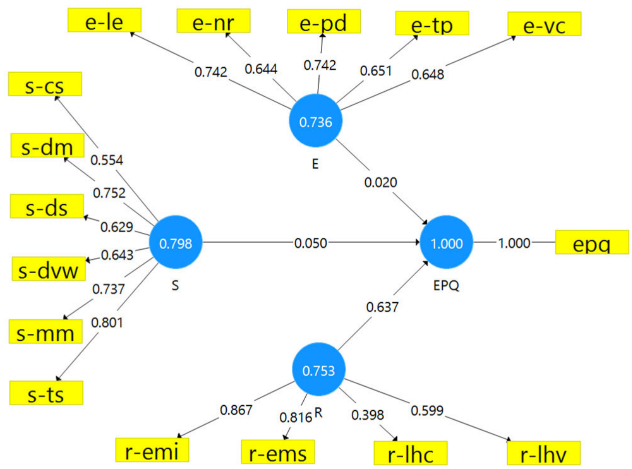

FIGURE 3. Indicator loadings. Source: Results from Smart-PLS software 3.3.3.

TABLE 5. Construct validity and reliability.

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
E	0.809	0.805	0.871	0.508
S	0.858	0.902	0.912	0.568
R	0.823	0.876	0.921	0.632

TABLE 6. Discriminant validity-HTMT.

	E	S	R
E	0.308		
S	0.424	0.648	
R	0.589	0.627	0.423

Source: Results from Smart-PLS software 3.3.3

In a nutshell, general, structured component analysis involves three sub-models that take the form of the following general formula:

$$\text{Measurement model}: X = C'Y + \varepsilon$$
$$\text{Structural model}: Y = B'Y + \tau$$
$$\text{Weighted model}: Y = \omega'X$$

where:

X is a J by 1 vector of indicators
Y is a P by 1 vector of latent variables
C is a P by J matrix of loadings
B is a P by P matrix of path coefficients
W is a J by P matrix of component weights
ε is a J by 1 vector of the residuals of indicators
ζ is a P by 1 vector of the residuals of latent variables

TABLE 7. Hypothesis results.

	Hypothesis	Coefficient	Standard deviation	T statistics	p-value	VIF	F Square	CI 2.5% Lower	CI 97.5% Upper
H1	E -> EPQ	-0.215	0.051	3.491	0.000	4.019	0.012	-0.239	-0.142
H2	S -> EPQ	0.308	0.049	6.810	0.000	3.390	0.102	0.298	0.449
H3	R -> EPQ	-0.479	0.051	11.393	0.000	2.319	0.201	-0.809	-0.698

Source: Results from Smart-PLS software 3.3.3

E. ASSESSMENT OF THE MEASUREMENT MODEL

Run bootstrapping in smart-PLS of the PLS-SEM model to evaluate the statistical significance of this research model. Figure 3 shows the analysis results of the PLS-SEM model. The reliability and measurement values of the model are similar and have been tested on the PLS-SEM model. All indicators are highly correlated with their intended structure. The obtained indices are almost all higher than the threshold of 0.70, which proves that all indicators represent the structural model of this study.

To evaluate the internal consistency of this research model, we use Cronbach's alpha index and Heterotrait-Monotrait Ratio (HTMT) composite reliability, to perform the assessment. The Cronbach's Alpha coefficient has results ranging from 0.891 to 1,000 and all of these values are greater than the minimum score of 0.7. The composite reliability value index is more than 0.7 and exceeds the full-level minimum. This proves that the data used for this study are consistent and responsive to the PLS-SEM model analysis. The result of the extracted mean variance (AVE) is greater than the recommended minimum of 0.5 (see Table 5).

In this study, we tested the discriminant validity of structural indices using the HeterotraitMonotrait Ratio (HTMT). Values below 0.83 indicate adequate discriminant, (see Table 6).

Additional information about the measurement model of this study is presented in Table 12: Descriptive Statistics, Table 13: Mean, STDEV (Standard Deviation), T-value, P-value, interval confidence, Table 14: Outer-Average Load, STDEV, T-Value, P-Value, Confidence Interval, Table 15: Outer VIF value and Table 16: Indicator Correlation.

F. ASSESSMENT OF THE STRUCTURAL MODEL

For the structural model of this study, the internal VIF (Variable Inflation Factor) value indices are examined. The results of the VIF indicators are below the recommended threshold of 5.0. In addition, the path coefficient is statistically significant at the 95% level.

In this study, the indicators of predictive accuracy, the coefficient of determination (R2), andexogenous structural factors (E, S R) explaining 41% of the endogenous structure (EPQ), were considered as tissues. This study model has a regulatory effect. This criterion recommends that the conceptual model predicts latent structures endogenously. In our model, the value for EPQ is 0.504, values greater than

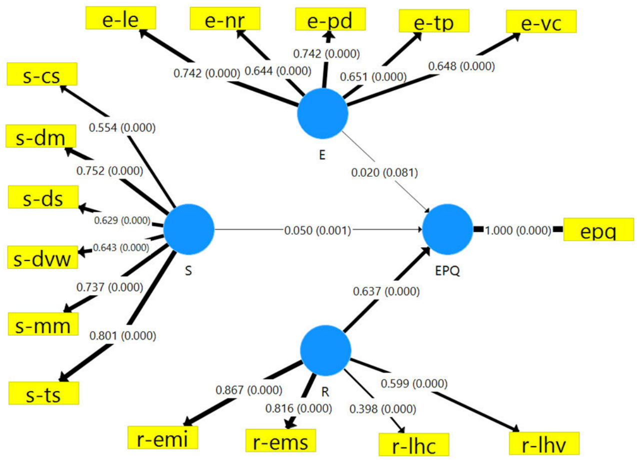

FIGURE 4. Model results (Source: Results from SmartPLS software 3.3.3.

0 suggest that a specific endogenous structure is considered relevant. Evaluatingthe effectiveness size (f2) shows that the effect size of E(0.019) is small, S(0.144) is moderate and R(0.203) is significant, see Table 6.

G. DISCUSSION OF FINDINGS

In this study, the path model used to evaluate is important based on the estimated path coefficients as valid and the significance levels of the path coefficients in the model analysis. P-values analyzed from the bootstrapping analysis results of the PLS-SEM model were used as this evaluation index of the different paths in the research model. The results of thecard analysis are shown in Table 7 and Figure 3.

This study shows the results of the external model on the indices of the load factor and the index of p-values, and the internal model in the indices of the path coefficients and the index of the p-values (see figure 4). Arrows represent the absolute value of each path in the research model. As discussed above, this index is very important for the path model of this study (see table 6)

In this study, we found that thereliability factor (R) positively affects power quality (EPQ) [21]. The long-term and safe operation of electronic components is completely dependent on the quality of the power source. Supply reliability and service quality factors bring stability to the operation of electronic components. The factor of voltage quality and current quality affects the operating properties of electronic components and equipment, it makes electrical equipment

TABLE 8. PLS Prediction results.

	RMSE		MAE		MAPE		Q2	
	LM	PLS-SEM	LM	PLS-SEM	LM	PLS-SEM	LM	PLS-SEM
EPQ1	1.57	1.41	1.24	1.06	45.03	35.97	0.08	0.18
EPQ2	1.62	1.54	1.45	1.37	63.37	61.94	0.07	0.14
EPQ3	1.60	1.35	1.16	1.04	41.68	40.03	0.02	0.21
EPQ	-	0.508	-	0.426	-	-	-	0.309

Notes: EPQ: Electric Power Quality; LM: Linear Model; Q2>0; MAPE: Mean Absolute Percentage Error; RMSE: Root Mean Square Error; MAE: Mean Absolute Error

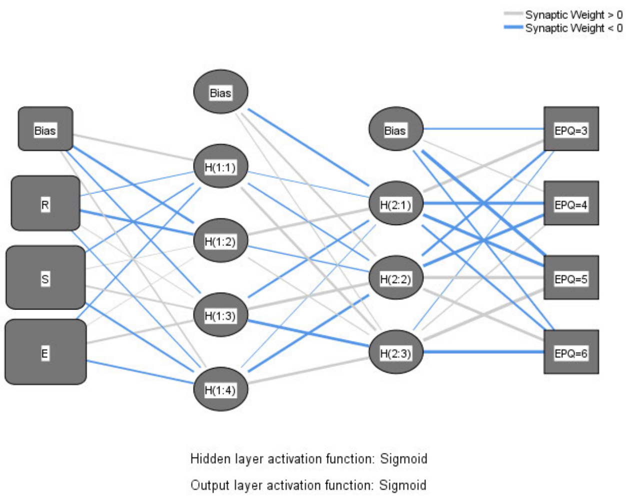

FIGURE 5. ANN model.

TABLE 9. ANN model RMSE values.

Output: Electric Power Quality				
ANN	Training (70% of 555data samples)		Testing (30% of 555data samples)	
	MSE	**RMSE**	**MSE**	**RMSE**
ANN1	0.126	0.019	0.111	0.089
ANN2	0.121	0.021	0.108	0.089
ANN3	0.128	0.018	0.118	0.098
ANN4	0.132	0.020	0.127	0.089
ANN5	0.120	0.022	0.108	0.086
ANN6	0.113	0.021	0.118	0.097
ANN7	0.114	0.024	0.117	0.096
ANN8	0.111	0.031	0.109	0.093
ANN9	0.121	0.023	0.121	0.089
ANN10	0.132	0.030	0.119	0.089
	Mean	0.031	**Mean**	0.089

TABLE 10. Input predictor relative importance.

Output: EPQ	Average relative importance	Normalized relative importance (%)	Ranking
Reliability (R)	0.398	100	First
Security (S)	0.355	84.59%	Second
Efficiency (E)	0.240	54.89%	Third

TABLE 11. Summary of ranking importance.

Output: Electric power quality	PLS-SEM	IPMA	ANN sensitivity ranking
Reliability (R)	1	1	1
Security (S)	2	2	2
Efficiency (E)	3	3	3

stable or not, In case harmonic interference occurs in the power supply, the power supplier sends out warnings and requires users to comply with electrical safety measures, so it determines the life of the electrical equipment. For the case of security factor (S), all the metrics in the PLS-SEM model are suitable, but the individual user or operator of the power system is relatively in compliance with the requirements for ensuring the use of loads in the power system [26]. Promotional activities for research to improve the quality of power system operation such as financing for research and training services, FDI and technology transfer, programs to improve system quality of education, programs to improve the quality of research and scientific institutions, and to strengthen university-company partnerships. Regarding the efficiency factor (E), the measurement indicators in the study are appropriate, which proves that the users and operators have sufficient knowledge about operation and control actions in electricity use as well as in the use of electricity such as using electrical equipment [26].Ensuring power quality and prolonging the life of electrical equipment and at the same time ensuring the transmission system of electrical equipment is free from interference is a complex issue.

Furthermore, this study is used to evaluate the predictive relevance ofthe cross-validated redundancy assurance measure, the index of the Stone-Geisser criterion Q2 is also used by theblindfold method [66]. The index of the Q2 value (i.e., Electric Power Quality (EPQ) = 0.356) exceeds the threshold value of 0, which demonstrates that the predicted association is strong. Moreover, this study also uses thePLS-prediction algorithm to analyze and prove the predictive relationship of PLS model performance for Latent Variables (LV) and Visible Variables (MV) [67]. The PLS-predict

TABLE 12. Indicators descriptive statistics.

	Mean	Median	Min	Max	Standard deviation	Excess Kurtosis	Skewness	Number of Observations
epq	0.122	0.133	-1.968	1.768	0.845	0.299	-0.213	555
r-lhc	43.157	39.965	5.023	90.321	16.986	0.211	0.365	555
r-lhv	5.443	5.361	2.367	7.998	1.623	-0.923	0.132	555
r-ems	6.211	6.448	1.021	10.287	2.142	-0.923	-0.324	555
r-emi	6.253	6.378	3.021	10.021	1.635	-0.989	0.201	555
e-le	6.275	6.531	1.598	9.357	1.781	-0.706	-0.299	555
e-pd	4.222	4.267	2.2267	6.142	0.526	0.709	-0.143	555
e-tp	3.179	3.234	1.198	6.598	0.905	1.432	1.094	555
e-nv	4.536	4.687	2.489	6.145	0.592	0.245	-0.421	555
e-nr	3.552	3.639	1.732	6.093	0.978	0.321	0.523	555
s-dm	3.522	3.663	2.056	5.793	0.709	0.265	0.498	555
s-ts	3.876	4.235	1.869	6.035	0.879	-0.735	-0.267	555
s-mm	3.984	3.768	2.245	5.879	0.623	-006	0.367	555
s-dvw	3.544	3.587	2.059	5.378	0.616	0.269	0.469	555
s-cs	2.327	2.631	0.400	4.578	0.589	1.056	0.478	555
s-ds	3.556	4.050	1.001	5.002	1.036	-0.789	-0.361	555

TABLE 13. Mean, STDEV, T-Values, p-Values, confidence intervals.

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	p Values	CI 2.5%	CI 97.5%
						Lower	Upper
E -> EPQ	-0.177	-0.142	0.037	3.046	0.001	-0.179	-0.024
S -> EPQ	0.268	0.319	0.029	7.089	0.000	0.267	0.428
R -> EPQ	-0.479	-0.479	0.039	13.011	0.001	-0.570	-0.454

TABLE 14. Outer Loadings: Mean, STDEV, T-Values, p-Values, confidence intervals.

	Original Sample (O)	Sample Mean (M)	Standard Deviation	T Statistics	p Values	CI 2.5%	CI 97.5%
						Lower	Upper
epq<- EPQ	1.000	1.000	0.0	-	-	1.000	1.000
r-lhc<-R	0.758	0.749	0.046	60.038	0.000	0.738	0.809
r-lhv<-R	0.739	0.722	0.028	38.041	0.001	0.710	0.768
r-ems<-R	0.849	0.860	0.019	120.112	0.000	0.891	0.934
r-emi<-R	0.728	0.829	0.011	75.783	0.001	0.866	0899
e-le<-E	0.768	0.849	0.019	106.069	0.001	0.748	0.897
e-pd<-E	0.849	0.874	0.025	64.039	0.001	0.831	0.879
e-tp<-E	0.638	0.792	0.029	22.070	0.000	0.677	0.798
e-nv<-E	0.671	0.538	0.035	13.032	0.000	0.443	0.606
e-nr<-E	0.731	0.859	0.031	31.0452	0.000	0.745	0.798
s-dm<-S	0.751	0.732	0.017	32.047	0.000	0.735	0.789
s-ts<-S	0.628	0.773	0.031	23.867	0.001	0.728	0.784
s-mm<-S	0.859	0.866	0.019	118.074	0.001	0.866	0.912
s-dvw<-S	0.824	0.883	0.027	57.061	0.000	0.879	0.863
s-cs<-S	0.773	0.731	0.026	24.186	0.000	0.621	0.736
s-ds<-S	0.628	0.659	0.029	24.234	0.001	0.597	0.706

method includes linear model predictions (LM) and Q2 mean indices to measure prediction quality by Mean Absolute Error (MAE), Mean Root Mean Square Error (RMSE)) and Mean Absolute Percent Error (MAPE) of the PLS path model estimates. Table 8 shows the potential PLS-predict performance of the structure (Used for Electric Power Quality) and its three display factors (E, S, and R). The findings showed that the PLS-SEM value was lower than that of the simple linear model (LM) value and that the Q2 value was also higher than 0 indicating higher predictive power [68].

H. DEEP LEARNING ARTIFICIAL NEURAL NETWORK (ANN) METHODOLOGY

In this study, the second analysis step using the ANN model is an additional analysis step for the analysis results of the PLS-SEM model and the goal is to highlight each predictor of

TABLE 15. Outer VIF values.

	VIF
epq	1.732
r-lhc	2.724
r-lhv	1.262
r-ems	4.851
r-emi	4.324
e-le	2.846
e-pd	3.371
e-tp	5.212
e-nv	3.971
e-nr	1.541
s-dm	5.967
s-ts	4.342
s-mm	3.536
s-dvw	4.876
s-cs	3.427
s-ds	4.843

TABLE 16. Indicator correlation.

	epq	r-lhc	r-lhv	r-ems	r-emi	e-le	e-pd	e-tp	e-nv	e-nr	s-dm	s-ts	s-mm	s-dvw	s-cs	s-ds
epq	1.000															
r-lhc	0.913	1.000														
r-lhv	0.915	0.863	1.000													
r-ems	0.947	0.826	0.829	1.000												
r-emi	0.958	0.837	0.820	0.983	1.000											
e-le	0.819	0.746	0.740	0.867	0.752	1.000										
e-pd	0.942	0.945	0.868	0.920	0.920	0.812	1.000									
e-tp	0.953	0.885	0.838	0.849	0.850	0.871	0.931	1.000								
e-nv	0.661	0.686	0.548	0.679	0.660	0.549	0.675	0.546	1.000							
e-nr	0.884	0.720	0.728	0.751	0.737	0.779	0.832	0.733	0.560	1.000						
s-dm	0.726	0.760	0.762	0.776	0.795	0.690	0.738	0.761	0.596	0.662	1.000					
s-ts	0.915	0.838	0.841	0.942	0.839	0.727	0.968	0.820	0.643	0.751	0.735	1.000				
s-mm	0.925	0.819	0.872	0.923	0.854	0.841	0.978	0.840	0.657	0.744	0.727	0.832	1.000			
s-dvw	0.826	0.874	0.832	0.875	0.870	0.726	0.829	0.888	0.631	0.756	0.777	0.863	0.823	1.000		
s-cs	0.877	0.798	0.782	0.858	0.880	0.750	0.880	0.834	0.675	0.774	0.630	0.835	0.854	0.742	1.000	
s-ds	0.985	0.839	0.822	0.932	0.855	0.865	0.916	0.840	0.686	0.749	0.755	0.920	0.920	0.820	0.854	1.000

related importance. Analysis results of theANN model have higher prediction accuracy than PLS-SEM models because they are capable of evaluating data sets that have linear or non-linear relationships [68]. Analysis by ANN model using Multilayer Perceptron Method (MLP) modeled with SPSS v22. MLP analysis includes inputs, hidden layers, and outputs [59], [69]. In this study, the recommended ANN model with deep learning uses two hidden layers in ANN [64], [65]. The benefit of using two hidden layers in the ANN model is to enable deeper learning on the output neuron node [64]. The ANN learning model uses the sigmoid function for both the hidden layer and the output layer of neurons and serves as the activation function. Furthermore, the ranges between 0.1 and 1 for both input and output neurons are normalized to enhance the performance of the ANN deep learning model. The ANN model has 3 inputs: Efficiency, Securityand Reliability, and the output: Electric Power Quality. Figure 5 shows the deep learning ANN model.

The ANN model was calculated using the root mean square of error (RMSE) for the test data (30%) and the training (70%) set [58]. Table 9 shows the analysis results of the ANN model and the lower RMSE value indicates higher prediction accuracy [59], [69].

Furthermore, this studyhas sensitivity analysis performed to find the relative importance of each input predictor such as Efficiency (E), Confidentiality (S), andReliability (R). Table 10 shows the detailed analysis results of the model. In this study, the finding of relative importance shows that reliability is the first predictor of electric power quality assurance, followed by security as an important predictor in

TABLE 17. List of proposed indicators.

Variable	Measurement index	Literature source
Reliability [R]	[R-EMI]: Make sure to prevent the generation of electromagnetic interference in the power supply that meets IEC 61000-3-2 for safe operation of electrical equipment.	[7]
	[R-EMS]: Ensures electrical field sensitivity response of the power supply to IEC 61000-3-2 for improved power supply quality uncertainty	[7]
	[R-LHC]: Harmonic current control in the power supply complies with IEEE 519-2022 and IEC 61000-3-12 standards to improve the quality of the power supply.	[8]
	[R-LHC]: Ensure that the harmonic voltage in the power supply meets IEEE 519-2022 and IEC 61000-3-12 standards to help ensure safe operation of electrical equipment.	[1], [8]
Security [S]	[S-CS]: Ensure the provision of power quality management system information in accordance with IEC 61000-2-2 to help improve the quality of power supply.	[4]
	[S-DM]: Ensure that the measurement results of direct power quality characteristics at the source meet IEC 61000-3-12 standards to help ensure the quality of the power supply.	[8]
	[S-DS]: Ensuring a stable power distribution system in compliance with IEC 61000-2-2 improves reliability and customer satisfaction.	[4]
	[S-VDW]: The voltage wave attenuation does not meet the IEC 61000-2-4 standard, destabilizing the power quality in power transmission and distribution.	[4]
	[S-TS]: Ensure good testing and simulation of power supply operations according to IEC 61000-3-12 to improve the quality of power distribution.	[8]
	[S-MM]: Make sure to use the correct measurement method for each object of the power characteristics in accordance with IEEE 519-2022 and EN 50160 standards to help ensure the quality of the power supply.	[1], [5]
Efficiency [E]	[E-LE]: Ensuring emissions in the power supply are within the limits of IEEE 519-2022 and IEC 61000-3-12 standards to minimize power quality loss of the power supply.	[1], [8]
	[E-VC]: Ensure all voltage source characteristics meet IEEE 519-2022 and EN 50160 standards to improve stability in power distribution transmission.	[1], [5]
	[E-TP]: Ensuring the correct relay safety as required for each power source to be relayed in the distribution network according to EN 61000-3-2 standard helps to ensure the safe operation of electrical equipment.	[7]
	[E-PD]: Ensure to provide adequate documents, standards and guidelines on power supply system management according to IEC 61000-3-12 standards to help improve the quality of power supply.	[7]
	[E-NR]: Ensuring full compliance with the use of the electrical system operating manual when supplying power in accordance with IEC 61000-2-2 improves the stability of power distribution.	[4]

TABLE 18. List of abbreviations.

Abb.	Full name	Abb.	Full name
AC	Alternating Current	IEEE	Institute of Electrical and Electronics Engineers
ANN	Deep Learning Artificial Neural Network	IPMA	Importance Performance Mapping Analysis
CB-SEM	Covariance-based Structural Equation Modeling	LBS	Load Break Switch
CI	Confidence Interval	LV	Latent Variables
DC	Direct Current	LM	linear model predictions
DS	Disconnectors Switches	MAE	Mean Absolute Error
EMC	Electromagnetic compatibility	MAPE	Mean Absolute Percent Error
EN	European Norm	PhD	Doctor of physolophy
EPQ	Electric Power Quality	PLS-SEM	Partial Least Squares- Structural Equation Modeling
E	Efficiency	RMSE	Mean Root Mean Square Error
FCO	Fuse Cutout	R	Reliability
FDI	Foreign Direct Investment	S	Security
HCMC	Ho Chi Minh City	STDEV	Standard Deviation
HTMT	Heterotrait-Monotrait Ratio	THD	Total Distortion Harmonic
IT	Information Technology	UPS	Uninterruptible Power Supply
Indi. Harm.	Individual Harmonic	Volt.	Voltage
IEC	International Electrotechnical Commission	VIF	Variable Inflation Factor
PCC	Point of Common Coupling	TDD	Total Demand Distortion

second. However, the efficiency factor has the weakest effect of all. This proves that the measurement indicates users and operators have sufficient knowledge of operation and control actions in electricity use and electricity use.

IV. RESULT AND DISCUSSION

This study conducted extensive research on electric power quality with neural network methods based on deep learning. This study was carried out following a multi-step approach using the PLS-SEM model and deep learning artificial neural network (ANN). A method of displaying useful information regarding electric power quality by predicting the relative importance of inputs such as Efficiency (E), Security (S), and Reliability (R). The results of the PLS-SEM model analysis show that Reliability (R) has P- Value = 0.000 and F-Square = 0.201 (Table. 7) which proves that R has a strong impact on power quality (PQ).). Next, the Security factor (S) has P-Value = 0.000 and F-Square = 0.102, and Efficiency (E) has P-Value = 0.000 and F-Square = 0.012 proving that the S and E factors are affected PQ with the following 2nd and 3rd. At the same time, the analysis results of the ANN Model show the average relative importance of the Reliability factor (R) = 0.398, followed by the average relative importance of the Security factor (S) and the Efficiency factor (E) = 0.355 and 0.240. This proves that factor R has a strong effect on PQ, and the second and third positions are followed by the S factor and the E factor. Both PLS-SEM and ANN analysis gave analytical results indicating that Reliability (R), Security (S), and Efficiency (E) impact PQ as 1st, 2nd, and 3rd respectively.

The results of the analysis of the PLS-SEM model by smart-PLS show the results of the Performance-Importance Map Analysis (IPMA) [70] to build further findings on the significance of the model. The IPMA findings include two dimensions of interest, namely performance and significance [70], [71]. Performance metrics are typically rated on a scale of 0 to 100. Performance-importance map analysis involves identifying an objective in the PLS path model, that is, in the field. Our case is electric power quality. The strong effect of the Reliability factor (R) which has great significance for increasing acceptance of electric power quality. The Security Factor (S) has the second highest importance and the Efficiency Factor (E) has the lowest importance.

Table 11 summarizes the results for the relative importance of PLS-SEM, ANN, and IPMA. The analysis results of the PLS-SEM model and the IPMA analysis chart show the relative importance ranking of predictive variables such as Reliability, Security, and Efficiency. At the same time, the analysis results of the ANN model also show that Reliability is the most important predictive input for electric power quality, followed by Security and Efficiency factors.

V. CONCLUSION

In summary, the results of this study reveal that the Reliability factor (R) has the strongest impact on Electric Power Quality (EPQ), the factors related to Reliability (R) include supply reliability, service quality, voltage quality, current quality, quality of supply, and quality of consumption improve the quality of power sources in the industrial 4.0 period, the period when electronic switches are used to control switch and are the place where harmonics are generated, causing instability to the power quality. There are many methods implemented for harmonic mitigation. However, at present, soft computing methods in shunt active power filtering by mathematical models of meta-heuristic optimization are being interested and implemented by many researchers.

Limitations of this study include data collection, it was only based on students and employees of power companies in Ho Chi Minh City, Vietnam. Therefore, the results are less likely to generalize. Future studies should extend the study to other countries. In addition, it is proposed to use the same data set to perform the comparison of shallow ANN and deep ANN methods. This study only stops at data analysis and survey and proposes to use soft computing methods in harmonic mitigation with shunt active power filters using real models. Build a power network control system with tools in Lab-view software and save data in real-time with the goal of controlling the real-time power usage that users need.

APPENDIX A

See Tables 12–16.

APPENDIX B

See Table 17.

APPENDIX C

See Table 18.

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REFERENCES

[1] *IEEE Standard for Harmonic Control in Electric Power Systems. Transmission and Distribution Committee of the IEEE Power and Energy Society*, The Institute of Electrical and Electronics Engineers, New York, NY, USA, IEEE Standard 519-2022, 2022, pp. 1–31, doi: 10.1109/IEEESTD.2022.9848440.

[2] Y. Hoon, R. Mohd, M. A. Mohd, and M. Zawawi, "Shunt active power filter: A review on phase synchronization control techniques," *Electronics*, vol. 8, no. 7, pp. 1–28, 2019, doi: 10.3390/electronics8070791.

[3] Y. Zhan, Y. Guo, J. Zhu, B. Yang, and B. Liang, "A review on mitigation technologies of low frequency current ripple injected into fuel cell and a case study," *Int. J. Hydrogen Energy*, vol. 1, pp. 1–13, Sep. 2020, doi: 10.1016/j.ijhydene.2020.06.204.

[4] *Electromagnetic Compatibility (EMC)—Part 2-2: Environment—Compatibility Levels for Low-Frequency Conducted Disturbances and Signaling in Public Low-Voltage Power Supply Systems, Edition 2.0*, document IEC 61000-2-2, 2017.

[5] The Technical Article, *AFQevo Multifunction Active Filter Harmonics: Today's Problems and Its Solution, Technology for Energy Efficiency*. [Online]. Available: https://www.circutor.com

[6] H. Markiewicz and A. Klajn, "Standard EN 50160—Voltage characteristics in public distribution systems, copper development association," Wroclaw Univ. Technol., Wroclaw, Poland, Tech. Rep., Jul. 2004, pp. 1–19.

[7] *Electromagnetic Compatibility (EMC)—Part 3-2: Limits—Limits for Harmonic Current Emissions (Equipment Input Current ≤ 16 A Per Phase)*, Edition 5.0, document IEC 61000-3-2, 2018.

[8] *Electromagnetic Compatibility (EMC)—Part 3-12: Limits—Limits for Harmonic Currents Produced by Equipment Connected to Public Low-Voltage Systems With Input Current >16 A and ≤75 A Per Phase*, Edition 2.0, document IEC 61000-3-12, 2011.

[9] W. Tareen, M. Aamir, S. Mekhilef, M. Nakaoka, M. Seyedmahmoudian, B. Horan, M. A. Memon, and N. A. Baig, "Mitigation of power quality issues due to high penetration of renewable energy sources in electric grid systems using three-phase APF/STATCOM technologies: A review," *Energies*, vol. 11, no. 6, p. 1491, 2018, doi: 10.3390/en11061491.

[10] D. Lumbreras, E. G. lvez, A. Collado, and J. Zaragoza, "Trends in power quality, harmonic mitigation and standards for light and heavy industries: A review," *Energies*, vol. 13, no. 21, p. 5792, 2020, doi: 10.3390/en13215792.

[11] S. Mohammadi, A. Mahmoudi, S. Kahourzade, A. Yazdani, and G. Shafiullah, "Decaying DC offset current mitigation in phasor estimation applications: A review," *Energies*, vol. 15, no. 14, p. 5260, 2022, doi: 10.3390/en15145260.

[12] R. Ali and T. O'Donnell, "Analysis and mitigation of harmonic resonances in multi–parallel grid–connected inverters: A review," *Energies*, vol. 15, p. 5438, Jul. 2022, doi: 10.3390/en15155438.

[13] H. Hu, Y. Zhou, X. Li, and K. Lei, "Low-frequency oscillation in electric railway depot: A comprehensive review," *IEEE Trans. Power Electron.*, vol. 36, no. 1, pp. 295–314, Jan. 2020, doi: 10.1109/TPEL.2020.2998702.

[14] R. Martinek, J. Vanus, P. Bilik, T. Stratil, and J. Zidek, "An efficient control method of shunt active power filter using ADALINE," *IFAC-PapersOnLine*, vol. 49, no. 25, pp. 352–357, 2016, doi: 10.1016/j.ifacol.2016.12.064.

[15] A. Haroon, I. S. Javed, H. R. Baig, and A. Nasir, "Modeling, control and placement of FACTS devices: A review," *Mehran Univ. Res. J. Eng. Technol.*, vol. 39, no. 4, pp. 719–733, Oct. 2020, doi: 10.22581/muet1982.2004.04.

[16] R. Jaros, R. Byrtus, J. Dohnal, L. Danys, J. Baros, J. Koziorek, P. Zmij, and R. Martinek, ''Advanced signal processing methods for condition monitoring,'' *Arch. Comput. Methods Eng.*, vol. 1, pp. 1553–1577, Oct. 2022, doi: 10.1007/s11831-022-09834-4.

[17] M. T. L. Gayatri, A. M. Parimi, and A. V. Pavan Kumar, ''A review of reactive power compensation techniques in microgrids,'' *Renew. Sustain. Energy Rev.*, vol. 81, pp. 1030–1036, Jan. 2018, doi: 10.1016/j.rser.2017.08.006.

[18] Z. Zhang, Y. Hu, X. Chen, G. W. Jewell, and H. Li, ''A review on conductive common-mode EMI suppression methods in inverter fed motor drives,'' *IEEE Access*, vol. 9, pp. 18345–18360, 2021, doi: 10.1109/access.2021.3054514.

[19] A. Kalair, N. Abas, A. R. Kalair, Z. Saleem, and N. Khan, ''Review of harmonic analysis, modeling and mitigation techniques,'' *Renew. Sustain. Energy Rev.*, vol. 78, pp. 1152–1187, Oct. 2017, doi: 10.1016/j.rser.2017.04.121.

[20] R. Martinek, J. Rzidky, R. Jaros, P. Bilik, and M. Ladrova, ''Least mean squares and recursive least squares algorithms for total harmonic distortion reduction using shunt active power filter control,'' *Energies*, vol. 12, no. 8, p. 1545, 2019, doi: 10.3390/en12081545.

[21] M. T. Benchouia, I. Ghadbane, A. Golea, K. Srairi, and M. E. H. Benbouzid, ''Implementation of adaptive fuzzy logic and PI controllers to regulate the DC bus voltage of shunt active power filter,'' *Appl. Soft Comput.*, vol. 28, pp. 125–131, Mar. 2015, doi: 10.1016/j.asoc.2014.10.043.

[22] R. Martinek, P. Bilik, J. Baros, J. Brablik, R. Kahankova, R. Jaros, L. Danys, J. Rzidky, and H. Wen, ''Design of a measuring system for electricity quality monitoring within the SMART street lighting test polygon: Pilot study on adaptive current control strategy for three-phase shunt active power filters,'' *Sensors*, vol. 20, no. 6, p. 1718, 2020, doi: 10.3390/s20061718.

[23] A. Sannino, J. Svensson, and T. Larsson, ''Power-electronic solutions to power quality problems,'' *Electr. Power Syst. Res.*, vol. 66, no. 1, pp. 71–82, 2003, doi: 10.1016/s0378-7796(03)00073-7.

[24] J. Baros, V. Sotola, P. Bilik, R. Martinek, R. Jaros, L. Danys, and P. Simonik, ''Review of fundamental active current extraction techniques for SAPF,'' *Sensors*, vol. 22, p. 7985, Oct. 2022, doi: 10.3390/s22207985.

[25] R. Martinek, R. Jaros, J. Baros, L. Danys, A. Kawala-Sterniuk, J. Nedoma, Z. Machacek, and J. Koziorek, ''Noise reduction in industry based on virtual instrumentation,'' *Comput., Mater. Continua*, vol. 69, no. 1, pp. 1073–1096, 2021.

[26] C. Yin, X. Xie, S. Xu, and C. Zou, ''Review of oscillations in VSC-HVDC systems caused by control interactions,'' *J. Eng.*, vol. 2019, no. 16, pp. 1204–1207, Mar. 2019, doi: 10.1049/joe.2018.8634.

[27] *IEEE Standard Definition for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions*, IEEE Power & Energy Society, The Institute of Electrical and Electronics Engineers, New York, NY, USA, IEEE Standard 1459-2000, 2000, pp. 1–52.

[28] S. Das, K. Ray, A. Sahoo, S. Ramasubbareddy, T. Babu, M. Kumar, and M. Elavarasan, ''A comprehensive survey on different control strategies and applications of active power filters for power quality improvement,'' *Energies*, vol. 14, p. 4589, Jun. 2021, doi: 10.3390/en14154589.

[29] L. Pantoli, G. Leuzzi, F. Deborgies, P. Jankovic, and F. Vitulli, ''A survey of MMIC active filters,'' *Electronics*, vol. 10, p. 1680, May 2021, doi: 10.3390/electronics10141680.

[30] R. Pal and S. Gupta, ''Topologies and control strategies implicated in dynamic voltage restorer (DVR) for power quality improvement,'' *Iranian J. Sci. Technol., Trans. Electr. Eng.*, vol. 44, no. 2, pp. 581–603, Jun. 2020, doi: 10.1007/s40998-019-00287-3.

[31] B. Adineh, R. Keypour, P. Davari, and F. Blaabjerg, ''Review of harmonic mitigation methods in microgrid: From a hierarchical control perspective,'' *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 9, no. 3, pp. 3044–3060, Jun. 2020, doi: 10.1109/JESTPE.2020.3001971.

[32] Y. Hoon, M. Radzi, M. Hassan, and F. Mailah, ''Control algorithms of shunt active power filter for harmonics mitigation: A review,'' *Energies*, vol. 10, p. 2038, Sep. 2017, doi: 10.3390/en10122038.

[33] A. R. Gautam, D. M. Fulwani, R. R. Makineni, A. K. Rathore, and D. Singh, ''Control strategies and power decoupling topologies to mitigate 2ω-ripple in single-phase inverters: A review and open challenges,'' *IEEE Access*, vol. 8, pp. 147533–147559, 2020, doi: 10.1109/ACCESS.2020.3015315.

[34] A. Mboving, Z. Hanzelka, and A. Firlit, ''Analysis of the factors having an influence on the LC passive harmonic filter work efficiency,'' *Energies*, vol. 15, p. 1894, Feb. 2022, doi: 10.3390/en15051894.

[35] T. Jing, A. Maklakov, A. Radionov, V. Gasiyarov, and Y. Liang, ''Formulations, solving algorithms, existing problems and future challenges of pre-programmed PWM techniques for high-power AFE converters: A comprehensive review,'' *Energies*, vol. 15, p. 1696, Feb. 2022, doi: 10.3390/en15051696.

[36] A. Eisenmann, T. Streubel, and K. Rudion, ''Power quality mitigation via smart demand-side management based on a genetic algorithm,'' *Energies*, vol. 15, p. 1492, Dec. 2022, doi: 10.3390/en15041492.

[37] L. Michalec, M. J. Ski, T. Sikorski, Z. Leonowicz, L. J. Ski, and V. Suresh, ''Impact of harmonic currents of nonlinear loads on power quality of a low voltage network-review and case study,'' *Energies*, vol. 14, p. 3665, May 2021, doi: 10.3390/en14123665.

[38] B. Park, J. Lee, H. Yoo, and G. Jang, ''Harmonic mitigation using passive harmonic filters: Case study in a steel mill power system,'' *Energies*, vol. 14, p. 2278, Apr. 2021, doi: 10.3390/en14082278.

[39] A. Abbas, R. El-Sehiemy, A. El-Ela, S. Ali, K. Mahmoud, M. Lehtonen, and F. Darwish, ''Optimal harmonic mitigation in distribution systems with inverter based distributed generation,'' *Appl. Sci.*, vol. 11, p. 774, Dec. 2021, doi: 10.3390/app11020774.

[40] A. Almohaimeed and M. Abdel-Akher, ''Power quality issues and mitigation for electric grids with wind power penetration,'' *Appl. Sci.*, vol. 10, p. 8852, Oct. 2020, doi: 10.3390/app10248852.

[41] A. Piana and B. Roozen, ''On the control of low-frequency audible noise from electrical substations: A case study,'' *Appl. Sci.*, vol. 10, p. 637, Dec. 2020, doi: 10.3390/app10020637.

[42] E. Skjong, J. A. Suul, A. Rygg, T. A. Johansen, and M. Molinas, ''System-wide harmonic mitigation in a diesel-electric ship by model predictive control,'' *IEEE Trans. Ind. Electron.*, vol. 63, no. 7, pp. 4008–4019, Jul. 2016, doi: 10.1109/TIE.2016.2532845.

[43] B. Xie, L. Zhou, and M. Mao, ''Analysis of resonance and harmonic amplification for grid-connected inverters,'' *IET Gener., Transmiss. Distrib.*, vol. 2, pp. 1–28, May 2019, doi: 10.1049/iet-gtd.2018.6499.

[44] E. Kontos, G. Tsolaridis, R. Teodorescu, and P. Bauer, ''High order voltage and current harmonic mitigation using the modular multilevel converter STATCOM,'' *IEEE Access*, vol. 5, pp. 16684–16692, 2017, doi: 10.1109/ACCESS.2017.2749119.

[45] J. Zhao, H. Yang, X. Ma, and F. Xu, ''Evaluation of harmonic contributions for multi harmonic sources system based on mixed entropy screening and an improved independent component analysis method,'' *Entropy*, vol. 22, p. 323, Feb. 2020, doi: 10.3390/e22030323.

[46] A. Shaqsi, K. Sopian, and A. Al-Hinai, ''Review of energy storage services, applications, limitations, and benefits,'' *Energy Rep.*, vol. 1, pp. 288–306, Dec. 2020, doi: 10.1016/j.egyr.2020.07.028.

[47] J. Mueller, A. Bensmann, B. Bensmann, T. Fischer, T. Kadyk, G. Narjes, F. Kauth, and B. Ponick, ''Design considerations for the electrical power supply of future civil aircraft with active high-lift systems,'' *Energies*, vol. 11, no. 1, p. 179, 2018, doi: 10.3390/en11010179.

[48] L. Zhang, S. Ji, S. Gu, X. Huang, J. E. Palmer, W. Giewont, F. F. Wang, and L. M. Tolbert, ''Design considerations for high-voltage-insulated gate drive power supply for 10-kV SiC MOSFET applied in medium-voltage converter,'' *IEEE Trans. Ind. Electron.*, vol. 68, no. 7, pp. 5712–5724, Jul. 2020, doi: 10.1109/TIE.2020.3000131.

[49] L. Chng, L. Orel, M. Starikovskaia, and V. Adamovich, ''Electric field induced second harmonic (E-FISH) generation for characterization of fast ionization wave discharges at moderate and low pressures,'' *Plasma Sources Sci. Technol.*, vol. .1, no. 4, 2019, Art. no. 045004, doi: 10.1088/1361-6595/ab0b22.

[50] O. Neufeld, D. Ayuso, P. Decleva, M. Y. Ivanov, O. Smirnova, and O. Cohen, ''Ultrasensitive chiral spectroscopy by dynamical symmetry breaking in high harmonic generation,'' *Phys. Rev. X*, vol. 9, no. 3, pp. 1–15, Jul. 2019, doi: 10.1103/physrevx.9.031002.

[51] F. Irannezhad, H. Heydari, and F. Faghihi, ''Precise appraisement of the harmonic loads impact on hysteresis losses in a 3-phase HTS transformer,'' *Int. J. Electr. Power Energy Syst.*, vol. 133, Dec. 2021, Art. no. 107199, doi: 10.1016/j.ijepes.2021.107199.

[52] D. K. Patel, D. Kumar, P. Swarnakar, and R. K. Singh, ''A novel 3-phase symmetric/asymmetric reduced device count multilevel inverter for electric drive applications,'' in *Proc. IEEE 2nd Int. Conf. Electr. Power Energy Syst. (ICEPES)*, Bhopal, India, Dec. 2021, pp. 1–6, doi: 10.1109/ICEPES52894.2021.9699501.

[53] S. Ahmad, M. Meraj, A. Iqbal, and I. Ashraf, "Selective harmonics elimination in multilevel inverter by a derivative-free iterative method under varying voltage condition," *ISA Trans.*, vol. 92, pp. 241–256, Sep. 2019, doi: 10.1016/j.isatra.2019.02.015.
[54] S. Masoum and F. Fuchs, *Power Quality In Power System and Electrical Machine*, vol. 1, 2nd ed. San Diego, CA, USA: Elsevier, 2015, pp. 681–778.
[55] R. Singh, S. Yash, and C. Shubham, "IoT embedded cloud-based intelligent power quality monitoring system for industrial drive application," *Future Gener. Comput. Syst.*, vol. 112, pp. 884–898, Nov. 2020, doi: 10.1016/j.future.2020.06.032.
[56] A. Çiçek, K. Erenoğlu, O. Erdinç, A. Bozkurt, A. Taşcıkaraoğlu, and S. Catalão, "Implementing a demand side management strategy for harmonics mitigation in a smart home using real measurements of household appliances," *Int. J. Electr. Power Energy Syst.*, vol. 125, no. 106528, pp. 1–10, 2020, doi: 10.1016/j.ijepes.2020.106528.
[57] H. Aoyama, "A study of the stratified random sampling," *Ann. Inst. Stat. Math.*, vol. 6, no. 1, pp. 1–36, Dec. 1954, doi: 10.1007/bf02960514.
[58] S. S. Zabukovsek, Z. Kalinic, S. Bobek, and P. Tominc, "SEM–ANN based research of factors' impact on extended use of ERP systems," *Central Eur. J. Oper. Res.*, vol. 27, no. 3, pp. 703–735, Sep. 2019.
[59] C. J. Pannucci, A. M. Prazak, and M. Scheefer, "Utility of anti-factor Xa monitoring in surgical patients receiving prophylactic doses of enoxaparin for venous thromboembolism prophylaxis," *Amer. J. Surgery*, vol. 213, no. 6, pp. 1143–1152, Jun. 2017, doi: 10.1016/j.amjsurg.2016.08.010.
[60] G. Dash and J. Paul, "CB-SEM vs PLS-SEM methods for research in social sciences and technology forecasting," *Technol. Forecasting Social Change*, vol. 173, Dec. 2021, Art. no. 121092, doi: 10.1016/j.techfore.2021.121092.
[61] O. Sohaib, W. Hussain, M. Asif, M. Ahmad, and M. Mazzara, "A PLS-SEM neural network approach for understanding cryptocurrency adoption," *IEEE Access*, vol. 8, pp. 1315–13138, 2018.
[62] L.-Y. Leong, T.-S. Hew, V.-H. Lee, and K.-B. Ooi, "An SEM–artificial-neural-network analysis of the relationships between SERVPERF, customer satisfaction and loyalty among low-cost and full-service airline," *Exp. Syst. Appl.*, vol. 42, no. 19, pp. 6620–6634, Nov. 2015.
[63] H. Lee, J. Hew, Y. Leong, H. Tan, and B. Ooi, "Wearable payment: A deep learning-based dual-stage SEM-ANN analysis," *Exp. Syst. Appl.*, vol. 157, Nov. 2020, Art. no. 113477.
[64] W. Guoqiang, T. Garry, Y. Yunpeng, B. Keng, and D. Yogesh, "Revisiting TAM2 in behavioral targeting advertising: A deep learning-based dual-stage SEM-ANN analysis," *Technol. Forecasting Social Change*, vol. .175, Feb. 2022, Art. no. 121345, doi: 10.1016/j.techfore.2021.121345.
[65] N. Zeng, Y. Liu, P. Gong, M. Hertogh, and M. König, "Do right PLS and do PLS right: A critical review of the application of PLS-SEM in construction management research," *Frontiers Eng. Manage.*, vol. 8, no. 3, pp. 356–369, Sep. 2021, doi: 10.1007/s42524-021-0153-5.
[66] J.-G. Wang, Z.-D. Cao, B.-H. Yang, S.-W. Ma, M.-R. Fei, H. Wang, Y. Yao, T. Chen, and X.-F. Wang, "A mothed of improving identification accuracy via deep learning algorithm under condition of deficient labeled data," in *Proc. 36th Chin. Control Conf. (CCC)*, Jul. 2017, pp. 2281–2286.
[67] F. Hair, J. S. Marko, H. Lucas, and G. K. Volker, "Partial least squares structural equation modeling (PLS-SEM) an emerging tool in business research," *Eur. Bus. Rev.*, vol. 26, no. 2, pp. 106–121, 2014.
[68] J. F. Hair, L. M. Matthews, R. L. Matthews, and M. Sarstedt, "PLS-SEM or CB-SEM: Updated guidelines on which method to use," *Int. J. Multivariate Data Anal.*, vol. 1, no. 2, pp. 107–123, 2017.
[69] J. Henseler, T. K. Dijkstra, M. Sarstedt, C. M. Ringle, A. Diamantopoulos, D. W. Straub, D. J. Ketchen, J. F. Hair, G. T. M. Hult, and R. J. Calantone, "Common beliefs and reality about PLS: Comments on Rönkkö and Evermann (2013)," *Organizational Res. Methods*, vol. 17, no. 2, pp. 182–209, Apr. 2014.
[70] W. Reinartz, M. Haenlein, and J. Henseler, "An empirical comparison of the efficacy of covariance-based and variance-based SEM," *Int. J. Res. Marketing*, vol. 26, no. 4, pp. 332–344, 2009.
[71] P.-Y. Foo, V.-H. Lee, G. W.-H. Tan, and K.-B. Ooi, "A gateway to realising sustainability performance via green supply chain management practices: A PLS-ANN approach," *Exp. Syst. Appl.*, vol. 107, pp. 1–14, Oct. 2018.

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