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A Novel Control Technique to Enhanced Monitoring and Mitigation Techniques for Power Quality Disturbances in Hybrid Renewable Energy Systems

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Abstract- The proportion of renewable energy sources in the energy system is rapidly rising. Hybrid Renewable Energy Sources, or H.R.E.S., are becoming more widely used in the electrical power system. At the user and consumer levels, there are more Power Quality (P.Q.) problems as a result of the higher percentage of renewable energy sources. Engineers conducting this research will focus on P.Q. disturbances in the electrical system caused by hybrid renewable energy sources, particularly solar and wind. What kind of P.Q. disruptions are introduced during power production will be predicted by the research. A standalone hybrid renewable energy system (H.R.E.S.) will be the study's main emphasis. A Fuzzy Logic (F.L.) algorithm will be developed using the energy system data in order to enhance the mitigation methods and lower P.Q. disruptions. The recommended algorithm examines ongoing and stored data from several sources. In order to control the hardware and execute the necessary mitigation-level steps, data will be gathered and used. A Multiplexer (MUX) and several kinds of filters make up the system's hardware. The filters are selected by the multiplexer's output. The algorithm will increase the effectiveness of the system and assist the designers in enhancing the system's design potential. The monitoring system will assist in anticipating the kinds of P.Q. disturbances that result from utilizing various energy sources to generate power. These P.Q. disturbances are monitored by the proposed system, which also assigns a severity level to each one.

Keywords* — *Harmonic Distortion, Power Quality, Power Quality Mitigation, Power Quality Monitoring, Voltage Disturbances

I. INTRODUCTION

The capacity of the electrical system to generate flawless power with no sinusoidal wave disruptions is referred to as power quality. In the actual world, this is not the case, though. Different types of loads as well as other variables like weather, inverter type, and distance from the power source affect the sinusoidal wave that the power sources create. PQ disturbances are indicated by variations in the waveform caused by these variables. Clean and affordable power is produced via the utilization of renewable energy sources. The idea of integrating renewable energy power systems into the distribution grid or using them independently is becoming more and more relevant. PQ disruptions in the system have increased with the inclusion of renewable sources. Techniques for mitigating and monitoring power quality go hand in hand. Engineers and designers are working on various mitigating strategies as a result of the improvement and increased understanding of PQ difficulties [1]. As a result, issues with power quality are increasingly being considered while designing electrical power networks. The use of renewable energy sources makes monitoring and mitigation even more difficult. The electricity sector uses a variety of renewable energy sources. Among these are solar, wind, bio fuels, and a host of other sources. In order to meet rising power demands, a new trend in stand-alone power production combines two or more renewable energy sources. The term "HRES" refers to the electricity system. These systems are added to the current grid in order to support it, either by supplementing generated power or by acting as a backup for the electrical grid [2].

Together, these energy sources generate the electrical power that is used by both utility companies and end users. Solar and wind energy is the most often used combination. Solar panels are used to capture solar energy, and wind turbines use wind energy to generate electricity. For isolated locations or places where it is expensive to produce electricity using the traditional design of the power grid and substation system, the combination of solar and wind energy is a good source of power [3]. These sources of electrical power generation require monitoring and appropriate mitigation. When the excess energy

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generated by these sources is returned to the grid, the stakes are increased. It becomes critical to examine each individual unit, whether it is a residential or commercial load. These sources generate PQ disturbances that are introduced into the main system, costing utilities and customer's money and power. The various kinds of electrical equipment that are employed in the electrical grid are negatively impacted by these disruptions. Modern electrical machinery is extremely sensitive to variations in power output. Keeping an eye on the variations is crucial for creating more effective mitigating strategies. Furthermore, it will assist the designer in developing more effective predictive and preventative maintenance [2, 4].

PQ disturbances are exacerbated by the issues with the two sources utilized in the hybrid system. The HRES, which consists of a solar photovoltaic panel (PV) and wind turbine (WT), is the subject of the research. There are numerous elements that affect the power output of each source. These variables include wind speed, height inside the wind turbine, temperature, irradiance level, tilt angle in the PV instance, and so on [5].

II. LITERATURE REVIEW

The goal of the research and design teams is to understand the causes and effects of these PQ disturbances. The PQ disturbances of HRES vary based on the electrical power sources utilized. Different kinds of PQ disturbances could be introduced into the system by the other components. These variables include the synchronization of two renewable energy sources to produce power, types of loads, and metrological shifts. There are various potential causes for PQ disruptions in a hybrid renewable energy system that combines wind and solar power. It is necessary to keep an eye on and look into these disruptions further [6]. The major PQ disturbances observed in an HRES are related to

- Voltage changes
- Frequency changes
- Harmonics

A. Power Quality Disturbances

There are numerous reasons why the system's voltage fluctuates. The voltage variations may be transients, sags, or brief power outages. Harmonic distortion in voltage and current can happen simultaneously. As a result, one significant kind of PQ disruption in the HRES is frequency fluctuations [7]. The PQ disruptions in HRES are caused by numerous sources. The system's electrical equipment and naturally existing materials are to blame for these issues [8].

PQ disruptions in HRES are mostly caused by three factors:

- Integration of various renewable energy sources
- Modifications to the Metrological
- Choice and type of electrical equipment used in the HRES

The reduction or minimization of voltage variance is known as synchronization. Phase angle and frequency of the various renewable energy sources that feed the system with electricity. Prior to entering the electricity grid, the voltage needs to be synced [9]. An optimal synchronization strategy ought to be capable of [10]:

- Able to detect frequency variations
- Effectively monitor changes in harmonics and other disturbances
- Capable of tracking phase angle changes in the power grid

The imbalanced supply and demand lead to problems with grid frequency synchronization. The frequency of the grid is altered if surplus power is produced by renewable energy sources (RES). If the RES generates less power than the grid needs, the opposite will occur. Electrical equipment connected to the grid experiences issues as a result of frequency variations [11]. One of the main causes of synchronization issues is fluctuating voltage and frequency.

Furthermore, the wind speed is erratic and subject to change at any time, which could lead to variations in the voltage and frequency of the system, an uneven power supply, and different frequencies [12]. Synchronization issues arise from the unique problems associated with solar electricity. Depending on how well the solar panels are producing power, solar power can have varying power outputs. The power grid experiences frequency fluctuations and harmonic problems as a result of these power oscillations. The frequency and voltage of the system are affected by the inclusion of backup batteries [13].

Voltage dips or sags are introduced by the RES grid synchronization. Dips in voltage are possible when the grid is synchronizing. The voltage differential between the grid and the RES is what causes these dips. Voltage dips in the electricity generated by WT are caused by the reactive power that DFIG draws. Voltage swells occur after voltage sags in HRES [14].

The power generated by HRES is significantly influenced by the metrological conditions. Different effects of these conditions are seen by wind and solar power. When it comes to solar energy, various weather conditions have an impact on the power generated. For instance, a higher voltage will result from strong sun intensity. On the other side, a cloudy day will result in the solar setup producing less power. The grid's energy demand varies with the weather. PQ disruptions are caused by the increased demand for power in a stand-alone system. Low magnitude transients are indicated by voltage fluctuations, and variations in the solar insulation frequency deviation result in variations in current and voltage harmonics [15].

Variable power is produced by temperature and airspeed variations. The electricity grid must maintain a balance between the variations in power generated and consumed.

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Let's say that the metrological conditions are not appropriately observed. When HRES penetration increases, they could result in significant power losses for the grid [16]. The HRES will flicker and have voltage fluctuations due to the change in wind speed. As wind energy permeates more areas, the transient magnitude, flicker, voltage, and current harmonics all rise. These disruptions will result in significant system losses if they are not tracked and appropriate mitigation measures are not implemented [17–20].

A converter's primary job is to change generated DC power into AC power. The grid configuration is used to categorize the inverters. The efficiency standards established by various grid standards serve as the foundation for the inverter technology. PQ disruptions are caused by the kind of electrical equipment that connects the HRES to the grid. PQ disturbances to the electrical grid will be increased by the interior structure. They are going to introduce power factors, current distortion, and harmonics into the grid. PQ disturbances are largely dependent on the topology of these converters [21]. Furthermore, PQ disturbances may be exacerbated by the bidirectional power transmission between the user and the grid. PQ in the integrated grid will be impacted by these modifications [22]. While making sure that the power quality is kept at a consistent level, the monitoring system should be able to manage these variations. The most significant component of these modifications that increase PQ disturbances is the inverters and converters[23]. As such, the material that goes into making these inverters is essential. These inverters are mostly constructed of various semiconductor materials, and PQ disturbances may arise throughout the inverter production process [24].

B. Power Quality Monitoring Methods

The interface between the grid and the RE sources is when the PQ disruptions start. Any PQ monitoring system's primary components are the disturbances' identification and classification. The methods based on hardware, software, or a hybrid system with both hardware and software tools are used to address these PQ disturbances [15]. Data from PQ monitoring is crucial for enhancing PQ. It will take some time to evaluate the vast amount of data that the PQ monitoring system gathers. Regulatory organizations' approved standards are compared with the gathered data. PQ disruptions in HRES are monitored using a variety of techniques.

PQ in the renewable system is monitored using the Fourier transform technique. Using Fourier transforms, Bracewell's work presents several approaches to monitoring PQ disturbance in the RE system [25]. Scientific equations for handling the intricate computational scenarios pertaining to PQ monitoring are provided by Kaman filters [26]. The signal's frequency spectrum is utilized to track flickers and forecast when they might happen [27]. Fuzzy Logic (FL), Artificial Neural Networks (ANN), and Expert Systems (ES) are the other intelligent techniques that are utilized to detect PQ disruptions. Papers describe the many methods for detecting power quality issues [28–32]. The HRES makes use of certain monitoring techniques. Monitoring power quality is thought to be a costly procedure. It is not possible to install the power quality analyzer on every node [33]. The practice of placing a PQ analyzer at various nodes is becoming more popular, and it may be an affordable way to examine PQ disturbances in the HRES [34]. There is an issue with HRES's current and voltage signal measurement. A greater degree of accuracy is needed in their measurement. At the moment, ordinary transducers are unable to reliably measure these parameters. To monitor at least the 40th harmonic, more modern voltage and current transducers are required [35]. A study of a few Power quality monitoring systems is provided [36–38].

C. Mitigation of Power Quality Disturbances

Numerous techniques are employed to alleviate the various forms of PQ disruptions. PQ disturbances have been impacted by the rise in the usage of sensitive technology in commercial, industrial, and residential applications. The majority of these disruptions fall under the category of voltage and current quality issues. Depending on the needs of the electrical grid, various devices such as Unified Power Quality Conditioners (UPQCs), Distribution Static Compensators (DSTATCOMs), Dynamic Voltage Restorers (DVRs), and Custom Power Devices (CPDs) are employed to reduce some of the PQ disturbances. To lessen disruptions connected to current, CPD and DSTATCOM are employed. Variations in the current and voltage harmonic values cause an increase in PQ disturbances. To lessen these harmonics, active shunt filters are employed [39]. Using proportional integral differential (PID) controllers or multilayer inverters (MI) is another way to mitigate PQ issues. PID controllers are less efficient than other controllers, according to research. The investigator has resorted to Artificial Intelligence (AI) techniques in order to track and minimize disruptions in electricity quality. AI gives the machine the ability to reason and make decisions much like people do. To make more crucial improvements in the electrical system, the AI aids in enhancing stability, dependability, and other aspects. Artificial Intelligence (AI) facilitates the electrical system by offering additional features including data security, maintenance, and optimization. The discovery and diagnosis of PQ issues are aided by the Artificial Neural Network (ANN). Engineers and researchers can create patterns for input and output data as well as compare the values of the output data to the initial parameter values with the use of artificial neural networks (ANN) [40–42]. Filters of the Infinite Impulse Response (IIR) type are utilized because they can output varying amounts of power at night. A fixed power mode is used to send the continuous power to the electrical grid [43]. Effective voltage stability, demand management, energy

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efficiency, power quality improvement, and voltage and current harmonic abatement have all been achieved with the help of Flexible AC Transmission System (FACTS) technology [44]. Power electronics devices have emerged as a result of the increased use of RE sources in distributed generation, which increase the power grid's reliability [45]. The HRES makes use of FCATS-based devices. These gadgets reduce PQ disruptions at homes, businesses, and HRES. Through the addition of active power filters and a STATCOM interface for large HRES, the FCATS are employed to increase the system's efficiency [46]. The remaining HRES mitigation strategies are covered in [47–51]. The industry monitors and reduces PQ disruptions using a variety of techniques. Among these approaches are experimental system-based Power Quality analysis, classification of Power quality disturbances, and optimization techniques for optimal features [52]. These approaches include active power filters, passive filters, current quality enhancement, energy conversion optimization, customer power devices, energy storage systems, and voltage improvement techniques. It describes the many mitigating and monitoring techniques employed by the sector. The study confirms the effectiveness of various techniques employed in the real estate sector.

The paper will outline a two-pronged approach. The system will first gather site-specific PQ monitoring data, from which a mitigation strategy will be chosen. There are numerous mitigating strategies employed in the sector. Compared to others, some of them are utilized more frequently. The percentage of mitigating techniques that are used is shown in Figure 1 [49].

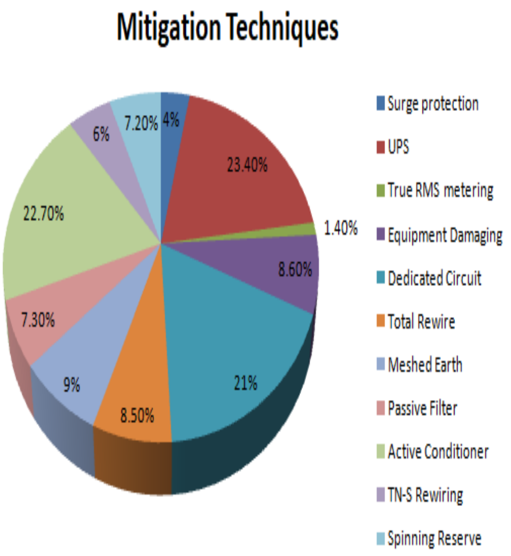

Fig. 1 Percentage of various mitigating strategies [53]

III. METHODOLOGY

The approach for monitoring and mitigating strategies for an HRES will be suggested in this study. The suggested approach is predicated on the analysis of real-time data and the selection of the appropriate mitigating equipment. Data on PQ disruptions is gathered and stored in a database. The FL procedure that produced the FL algorithm is depicted in Figure 2. The system will examine the gathered data using fuzzy logic, or FL. The system inputs are converted into fuzzy sets by the FL.

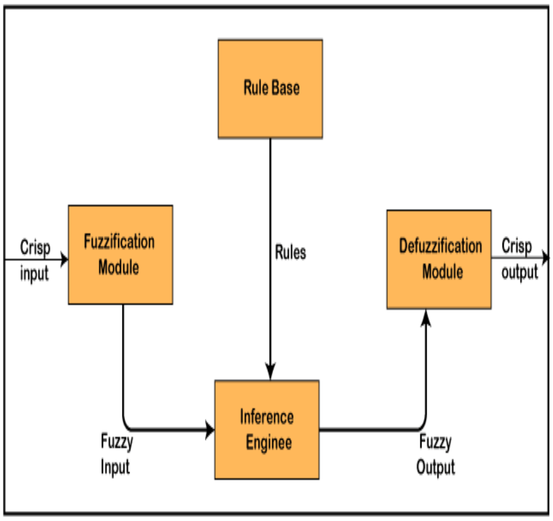

Fig. 2 Fuzzy Logic Process

The ANN algorithm is used to simplify the data. The algorithm is initialized with the sigmoid function.

$$f(z) = \frac{1}{1 + \exp(-z)} \qquad (1)$$

The weighted input for the node would be

$$X_1W_1 + X_2W_2 + X_3W_3 + b \qquad (2)$$

The weight is wi, and the bias is +1 in b. The input layer is layer one, the hidden layer is layer two, and the output layer is layer three of the suggested ANN network. Using Equation 6, the layers' output was computed.

$$h_1^2 = f(w_{11}^1 x_1 + w_{12}^1 x_1 + w_{13}^1 x_1 + b_1^1) \qquad (3)$$
$$h_2^2 = f(w_{21}^1 x_1 + w_{22}^1 x_1 + w_{23}^1 x_1 + b_2^1) \qquad (4)$$
$$h_3^2 = f(w_{31}^1 x_1 + w_{32}^1 x_1 + w_{33}^1 x_1 + b_3^1) \qquad (5)$$

The output of the last layer is given by Eq 6

$$h_{w,b}(x) = h_1^3 = f(w_{11}^2 h_1^3 + w_{12}^2 h_2^3 + w_{13}^2 h_3^3 + b_1^{31}) \qquad (6)$$

Equation 7 provides the algorithm's matrix representation.

$$W^1 = \begin{pmatrix} W_{11}^1 & W_{12}^1 & W_{13}^1 \\ W_{21}^1 & W_{22}^1 & W_{23}^1 \\ W_{31}^1 & W_{23}^1 & W_{33}^1 \end{pmatrix} \qquad (7)$$

Equation was used to create the random number.

$$Z_1 = A_o w_1 + b \qquad (8)$$

The learning rate was calculated by using Gradient Desent Method

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$$a := a - \propto \frac{dL(w)}{da} \qquad (9)$$

a: Alpha is the name of a learning rate.

The derivative of the overall weight loss is d(w).

The derivative of alpha is w d(a).

Through experimentation, the learning rate of 0.05 was determined.

Figure 3 depicts the proposed algorithm's tiered architecture. Three layers make up the suggested network. The input layer is layer 1, the hidden layer is layer 2, and the output layer is layer 3.

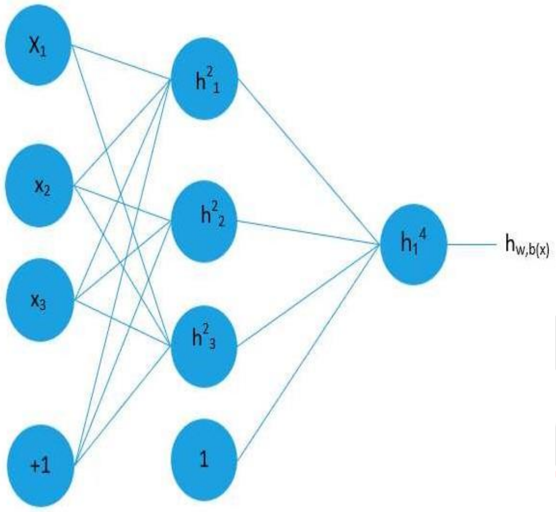

Fig. 3 Three-layer Neural Network

A PQ analyzer made by HIOKI is used to get the data. HIOKI 3198 was the model utilized for the collection. The 4-1 MUX is connected to the program output, and it is the MUX that selects the mitigation devices to lessen PQ disturbances. The system has a variety of mitigation equipment options. When low voltage and current conditions arise, the system will select either IIR to reduce disturbances or FACT to reduce higher voltage and current harmonics. Mixed PQ disturbances will be handled by the hybrid filters. Figure 4 depicts the data flow diagram, which explains how the program will be utilized to collect, process, and send the output to the 4-1 Mux. The MUX is made with Matlab code. Four inputs will be handled by the MUX, and it will output one. This output will be used to link the filter to various kinds of mitigation equipment. It is connected to the filter's selection input.

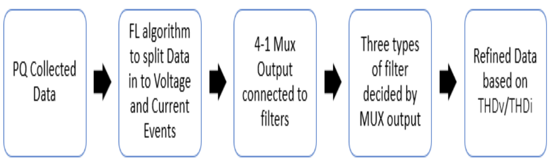

Fig. 4 Software Data flow

The suggested system's AI algorithm is depicted in Figure 5.

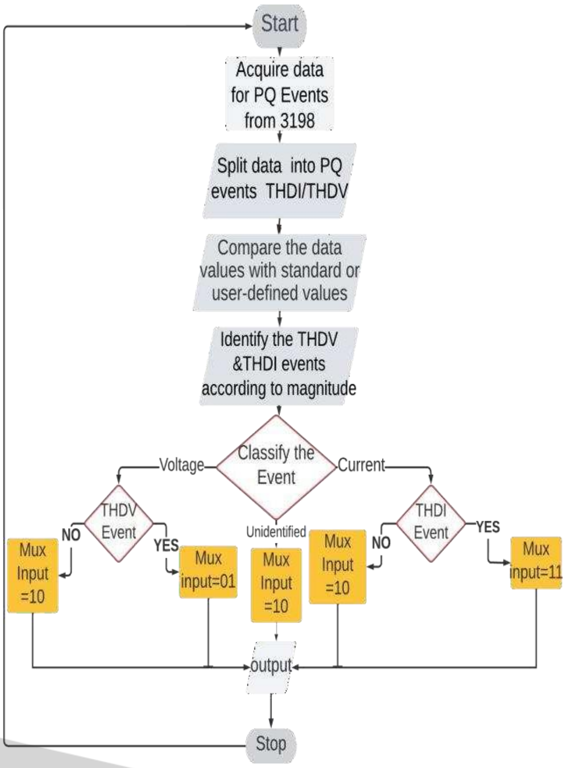

Fig. 5 Artificial Intelligence Algorithm chart

MATLAB was used to simulate the system. C++ was used to extract the data. The spreadsheet file contained the output file. The output of the code is displayed in the excel file. The THD value in current and voltage will be displayed in the excel file. The data was divided into voltage and current values using the FL method. If the value did not fall between the defined values, it was labeled as an undefined value. These values were sent to the 4-1 Mux that was linked. Mathlab was used to design the MUX. The MUX's output was linked to the kind of filter that was employed in the simulation. The outcomes of the simulation were gathered. It is possible to change the code to extract other relevant values. The MUX will receive these values. The Mux will decide which kind of filter is best. The many PQ disturbance types that occurred in the system are displayed in the simulation table. These disruptions were described in terms of the kinds and quantities of the occurrences. Table 1 displays the outcomes of the simulation. The findings demonstrate that the system selected the filter with accuracy in order to reduce the PQ disturbances that were identified within the system.

Table 1 Simulation Results

Type ofEvent	Number of occurrences	Values	Type of filter chosen	Accuracy
THD (voltage)	700	Low	IIR	98%
THD (Current)	900	Low	IIIR	97%
THD (voltage)	800	High	FACT	94%

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THD (Current)	1200	High	FACT	94%
Unidentfied	2500	Mixed	Hybrid	96%

IV. CONCLUSION

The outcomes demonstrate the system's node-level functionality. The information gathered from various nodes will assist the designers in pinpointing trouble spots and enhancing mitigation strategies. The data on PQ disturbances will be obtained by the researchers by minor code modifications. Real-time data collection and mitigation of disturbances are carried out. Because the system is expandable, it would be possible to monitor larger industrial and residential loads in a suburb or city by adding additional functions. It can help the designers determine the kind of PQ disturbances that every grid node produces. The system will assist the designers in understanding how various loads utilized in the grid may affect the power quality of the electrical grid. Utilizing the system as a predictive tool could help the grid avoid serious issues. With the help of this instrument, engineers and designers may more effectively access data and use it to lower expenses and equipment losses.

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