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Power Quality Issues on Jordan Wind Farm Connected to Grid System

Malik Khalid *, Baharuddin Ismail *(C.A.), Chanuri Charin*, Arnawan Hasibuan ** and Abd Alazeez Almaleeh*

Abstract: This paper presents a comprehensive research endeavor focused on evaluating the influence of renewable energy, particularly wind power, on power quality within the context of Jordan's electrical grid. The escalating global demand for energy, coupled with the imperative to curb greenhouse gas emissions, has propelled the rapid adoption of renewable energy sources. Against this backdrop, the study aims to meticulously analyze the effects of wind energy projects on power quality parameters such as voltage fluctuations, harmonics, and power factor. Through an extensive methodology comprising data collection, rigorous analysis, and advanced simulation techniques, actionable insights are provided into the seamless integration of renewable energy into existing grid infrastructures. In this work, power quality parameters like Total Harmonic Distortion, flickers, power frequency, Crest factor, and voltage unbalance are measured at Al-Tafilah Governorate, Jordan. The significance of this study lies in its contribution to the development of strategies and guidelines essential for policymakers, engineers, and stakeholders. By fostering a deeper understanding of the interplay between renewable energy and power quality, the findings aim to facilitate the establishment of a sustainable and resilient energy system in Jordan. Beyond mitigating climate change and enhancing energy security, this research underscores the pivotal role of renewable energy in ushering in a greener, cleaner future for generations to come.

Keywords: Wind Power, Power Quality, Total Harmonic Distortion, Grid Integration

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1 Introduction

THE surge in global energy demand has outpaced the capacity of traditional sources, driving the exploration of alternative solutions [1]. Among these, wind power stands out as a sustainable option, leveraging natural elements like wind to generate electricity. Its growth has been propelled by concerns over climate change, the quest for energy diversification, and the pursuit of a reliable energy supply [2] [3]. Technological advancements have significantly bolstered the economic viability of wind power, making it a compelling choice for many regions [4].However, integrating wind power into existing electrical grids, especially in places like Jordan, presents unique challenges, particularly regarding power quality. Power quality encompasses various factors including harmonics distortion, flicker, sag, and swell [5][6][7][8]. Harmonics distortion, for instance, stems from unwanted frequencies in the electrical system, often due to non-linear loads like power electronics [6]. Flicker involves variations in voltage or light output, which can discomfort individuals and affect sensitive equipment. Sags and swells denote short-term voltage deviations from normal levels, caused by faults or load demand changes [9]. Managing these power quality issues is crucial for ensuring the stable operation of the electrical grid [6]. Engineers and operators in Jordan employ advanced monitoring and control systems to address these challenges, ensuring the reliable integration of wind power [10]. By carefully considering power quality, they can enhance system efficiency and reliability, facilitating the seamless incorporation of wind power into the energy mix. In summary, wind

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power presents a promising solution to meet growing energy demands while reducing environmental impacts. However, successful integration requires meticulous attention to power quality, ensuring the smooth functioning of the electrical grid.

1 Power Quality Standards

The power quality standards, with their requirement for data collection over a minimum of one week, serve as a fundamental cornerstone in guaranteeing the reliability and stability of electrical systems [11]. This extended data collection period allows for a comprehensive and in-depth analysis of power quality parameters, offering a robust foundation for evaluating the performance of the power distribution network [12]. By recording measurements at 10-minute intervals throughout week-long period, the standards enable the capture of fluctuations, variations, and transient events that might occur, which may be missed in shorter sampling periods [11]. With a total of 1008 data points per week, this extensive dataset provides a detailed and accurate representation of power quality conditions, facilitating the identification of potential issues, the implementation of corrective actions, and the overall enhancement of the power supply's efficiency and reliability [12]. This meticulous data collection is essential for power quality monitoring and compliance with established standards, ensuring that electrical systems consistently meet the required quality criteria [11].

2 Measurement Procedure

The meticulous selection of primary measurement instruments, namely the Sonel PQM-701Z and Fluke 435 devices, is pivotal within the measurement procedure, significantly enhancing the comprehensive evaluation of power quality parameters [13]. Renowned for their precision and reliability in power quality monitoring, the Sonel PQM-701Z and Fluke 435 devices boast advanced and versatile features critical to this assessment [13]. Their notable attributes encompass multiple inputs for both voltage and current, facilitating the simultaneous capture of a diverse range of data [14]. This multi-input capability enables the measurement of crucial parameters such as voltage levels, current waveforms, harmonic distortions, flicker, and unbalances, all essential for a thorough comprehension of power quality dynamics [15]

Moreover, these instruments are equipped with advanced data logging and analysis capabilities, empowering the recording and interpretation of data over extended periods [16]. This longitudinal data collection proves invaluable in identifying trends, irregularities, and disturbances that may manifest over time [16]. Such insights facilitate proactive measures such as preventive maintenance, troubleshooting, and quality enhancement within the electrical distribution system [16]. In terms of connection methods, the power quality devices feature five inputs for voltage and five inputs for current, enabling the concurrent measurement of multiple parameters, as depicted in Figure 1. These inputs are strategically linked at the Point of Common Coupling (PCC), the juncture where the electric utility and customer interface occurs.

By adhering to this meticulous measurement procedure, the effectively assess power quality, monitor the impact of renewable energy integration, and ensure compliance with power quality standards. This concerted effort contributes to the establishment of a stable and reliable electrical grid system. In this work, the power quality parameter like Total Harmonic Distortion, flickers, power frequency, Crest factor and voltage unbalance are measure at Al-Tafilah Governorate, Jordan.

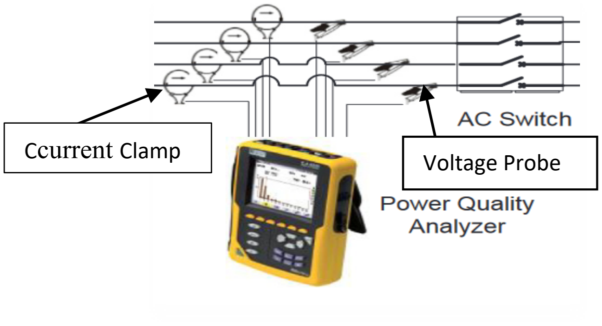

Fig. 1 Power quality device connections at the Point of Common Coupling (PCC).

3 Results and Discussion

3.1 Relationship between Wind Speed and Actual Active Power

Wind energy has emerged as a significant and indispensable contributor to the landscape of renewable electricity generation. Within this realm, wind farms occupy a pivotal position, serving as catalysts for tapping into wind's vast potential. An essential facet underpinning wind turbine performance optimization lies in the intricate relationship between wind speed and actual active power. This connection is pivotal for understanding the mechanics of wind turbine operation and for enhancing the overall efficiency of wind energy systems[17][18][19].

The relationship can be observed through the graphical as shown in Figure 2. It represent data collected from wind turbines in the Al-Tafilah Governorate, Jordan, where high wind speeds are prevalent. Understanding how wind turbine speed directly affects actual active power generation is of utmost importance. As wind speed increases, the kinetic energy available to the wind turbine rises, resulting in higher rotational speeds of the turbine blades. Consequently, this increased rotational speed leads to the generation of more active power, thereby contributing to greater electricity production.

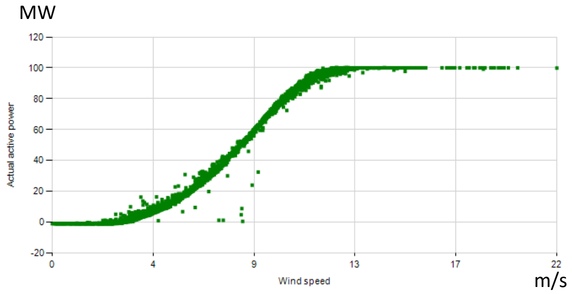

Fig. 2 Relationship between Wind Speed and Actual Active Power for Optimizing Wind Farm Performance.

Analysing the data from the wind turbines in Al-Tafilah Governorate empowers researchers and energy experts to identify the optimal wind speeds at which the turbines achieve peak performance. The results shows that the optimal output occurs at wind speed more than 13 m/s. This knowledge maximizes the conversion of wind energy into usable electricity. Moreover, such information is invaluable for wind farm operators and energy planners as it enables them to predict and manage energy output based on prevailing wind speeds in the region.

A clear understanding of the relationship between wind turbine speed and active power facilitates the development and implementation of more efficient and cost-effective wind energy systems. By harnessing the power of high wind speeds in regions like Al-Tafilah, Jordan, the country can enhance its renewable energy capacity, reduce reliance on fossil fuels, and move closer towards a more sustainable and environmentally friendly energy future.

3.2 Relationship between Wind Speed and Total Harmonic Distortion (THD)

The relationship between wind turbine speed and Total Harmonic Distortion (THD) is of great significance in the study of wind energy systems. Understanding the correlation between wind turbine speed and THD is critical as it directly impacts the quality of the electricity generated. THD refers to the presence of harmonic frequencies in the electrical system, which can lead to undesirable effects such as reduced power quality, equipment overheating, and interference with other electrical devices.

Analyzing the data from the wind turbines in Al-Tafilah Governorate enables researchers and energy experts to pinpoint specific wind speeds at which THD levels are at their lowest. This indicates improved power quality and system performance. Such knowledge is invaluable for wind farm operators and energy planners as it helps them comprehend the conditions under which wind turbines operate most efficiently, generating high-quality electricity.

Furthermore, the results in Figure 3 demonstrate that for the lowest wind speeds, which correspond to low power references, the Total Harmonic Distortion (THD) is high. This can be justified by the fact that the fundamental current is low, and its ripple becomes more pronounced due to its amplitude, contributing to increased harmonic distortion [20].

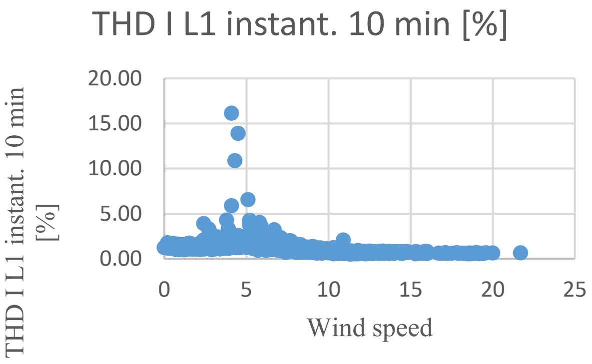

Fig. 3 Relationship between Wind Speed and THD from measurement values for Optimizing Wind Farm Performance.

Having a clear understanding of the relationship between wind turbine speed and THD enables the development of strategies to mitigate harmonic distortions and enhance the overall performance of wind energy systems. By optimizing wind turbine operations based on this relationship, it becomes feasible to harness the full potential of high wind speeds in regions like Al-Tafilah, Jordan, while ensuring the reliable and stable generation of electricity with minimal harmonic distortions. Ultimately, this contributes to the broader goal of promoting sustainable and environmentally friendly energy solutions.

3.3 Short-Term and Long-Term Flicker

Within the domain of power quality assessment, flicker—the rapid and repetitive variation in voltage—can significantly impact both grid stability and the performance of connected devices. Two distinct concepts capture different time scales of this phenomenon: short-term flicker for 10 minutes (Pst) and long-term flicker (Plt).

In this pursuit of understanding power quality challenges within the context of renewable energy integration, the assessment of flicker—voltage variations occurring over short periods—holds particular significance. Table 1 and Figure 4 provide the results of short-term flicker (Pst) measurements across different phases (L1, L2, and L3) of the electrical system. The values of extreme flicker and average flicker are compared against a defined threshold of 0.8, representing an acceptable limit for short-term flicker.

Table 1 Short-term flicker.

FLICKER SHORT TERM (Plt)	EXTREME	AVERAGE	THRESHOLD
L3	1.14	1.14	0.8
L1	0.87	0.87	0.8
L1	2.224	2.22	0.8
L2	2.126	2.126	0.8
L3	1.85	1.85	0.8
L1	0.898	0.8980	0.8
L2	0.9227	0.9227	0.8
L3	0.9303	0.9303	0.8
L3	1.212	1.121	0.8
L2	0.8388	0.838	0.8

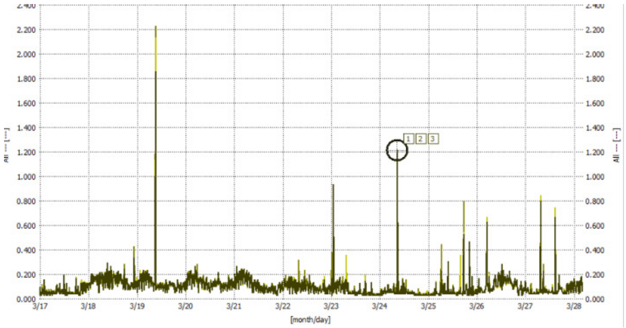

Fig. 4 Short-Term Flicker Analysis: Extreme and Average Values across Phases.

Observations from the presented data are as follows:

Phase L3: In numerous instances, the extreme flicker value for phase L3 exceeds the threshold of 0.8. This indicates that flicker levels in this phase occasionally surpass the acceptable limit, potentially leading to discomfort or disturbances in connected equipment. The corresponding average flicker values mirror these trends.

Phase L1 and L2: Similar trends are observed in phases L1 and L2, with various instances of extreme flicker values exceeding the threshold. Both phases display fluctuations that might impact power quality, as reflected in their average flicker values.

These results spotlight the dynamic nature of short-term flicker and its potential implications for grid stability and consumer equipment. The values exceeding the acceptable threshold underscore the need for advanced monitoring and control systems, as discussed earlier, to effectively manage and mitigate short-term flicker in real-time.

In summary, the examination of short-term flicker values reinforces the importance of addressing power quality challenges within the broader context of renewable energy integration. The insights gained from these results further emphasize the significance of ongoing research and proactive measures to ensure optimal grid performance in the presence of intermittent renewable sources.

In the context of power quality analysis for renewable energy integration, the assessment of flicker—particularly long-term flicker (Plt)—is essential to understand the potential impact of renewable energy sources on grid stability and quality. Flicker, characterized by rapid and repetitive variations in voltage levels, can lead to discomfort and operational challenges in sensitive devices. Table 2 and Figure 5 presents the results of long-term flicker (Plt) measurements across different phases (L1, L2, and L3) of the electrical system. The values of extreme flicker and average flicker are compared against a predefined threshold of 0.6, which represents an acceptable level of flicker within the grid. The following observations can be made from the provided data:

Phase L1: The extreme flicker value is measured at 0.9720, which is higher than the threshold of 0.6. This suggests that during certain periods, the flicker level in phase L1 exceeds the acceptable limit, potentially causing discomfort or disruptions in sensitive equipment. The average flicker value for phase L1 is 0.97, also indicating a relatively high level of flicker.

Phase L2: The extreme flicker value for phase L2 is measured at 0.9290, which is again above the defined threshold. Similar to phase L1, this suggests that the flicker levels in phase L2 can occasionally reach levels that may impact power quality. The average flicker value of 0.92 further supports this observation.

Phase L3: Phase L3 exhibits an extreme flicker value of 0.808, which exceeds the threshold, and an average flicker value of 0.80. While these values are lower compared to phases L1 and L2, they still suggest the presence of flicker that may require attention to maintain power quality.

Table 2 Flicker long term.

FLICKER LONG TERM (Plt)	EXTREME	AVERAGE	THRESHOLD
L1	0.9720	0.97	0.6
L2	09290	0.92	0.6
L3	0808	0.80	0.6

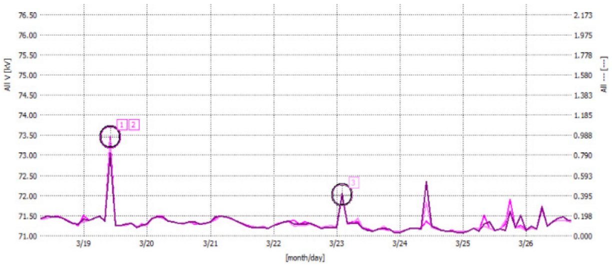

Fig. 5 Long-Term Flicker Analysis: Extreme and Average Values across Phases.

The results highlight the significance of long-term flicker analysis in renewable energy integration. The values exceeding the acceptable threshold underscore the potential challenges associated with maintaining optimal power quality. These findings emphasize the need for comprehensive studies, as discussed in the literature review, to further investigate the specific impacts of power quality disturbances caused by renewable energy sources. Furthermore, the development of advanced monitoring and control systems, as discussed in the literature review, becomes imperative to effectively detect and mitigate flicker disturbances in real-time. Such systems can play a vital role in managing the intermittent and variable nature of renewable energy sources while ensuring grid stability and reliability. In conclusion, the results presented in the table shed light on the presence of long-term flicker and its potential implications for power quality. Addressing the identified challenges and research gaps is crucial to pave the way for a resilient and stable energy future amidst the integration of renewable energy sources.

4 Power Frequency

In the realm of this research methodology, the power frequency of alternating current (AC) oscillation to be of paramount significance within the intricate workings of an electric power grid. This fundamental frequency represents the precise rate at which the lifeblood of electrical energy flows from its generation hubs to the countless endpoints where it powers in modern world. Typically, this frequency adheres to the widely adopted standards of 50 or 60 Hz, denoting the number of cycles per second [21]. It's imperative to note that these frequencies are not arbitrary; rather, they are subject to stringent regulations, particularly within High Voltage (HV) systems.

This study, conducted in the context of Jordan, aligns with the national standards as delineated in the National Transmission Grid Code [22]. Figure 6 shows a visual representation of these standards, providing a clear window into the defined parameters for different operational scenarios: Under the banner of normal operation and when interconnected with other systems, the power frequencies within the range of 49.95 Hz to 50.05 Hz are deemed well within the bounds of acceptability.

However, when the operational scenario shifts to normal operation without interconnection to external systems, the acceptable frequency range remains steadfast, maintaining a steady span from 49.95 Hz to 50.05 Hz. In instances of system stress, when the grid contends with various pressures and demands, a broader but still well-defined frequency spectrum of 48.75 Hz to 51.25 Hz is considered acceptable. This range accommodates the dynamic nature of such scenarios while ensuring the stable and reliable operation of the grid. Conversely, during periods of extreme system fault conditions, when the electrical grid faces unprecedented challenges, a more rigorous protocol comes into play. In these dire situations, all generating units are mandated to disconnect immediately if frequencies venture beyond predefined thresholds, either surging too high or plunging too low. Any exceptions to this disconnection protocol must be documented in writing and require approval from the Transmission System Operator (TSO). Specifically, these disconnection limits are set at: Frequency disconnection occurs when the level equals or exceeds 51.5 Hz. Frequency disconnection transpires when the level equals or falls below 47.5 Hz. Adherence to these precise power frequency standards is not just a formality but a cornerstone of ensuring the dependable and robust operation of electrical systems, safeguarding that power flows within secure and efficient limits.

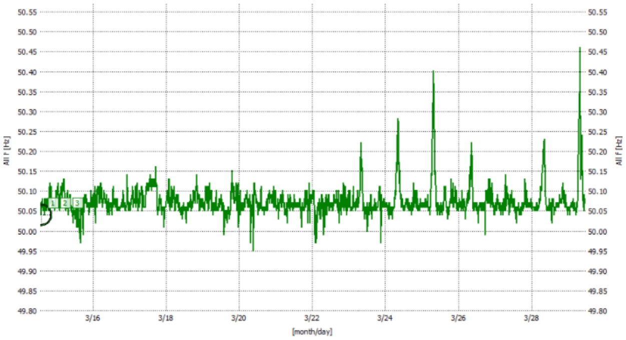

Fig. 6 Statics analysis for measurements for Power Frequency.

5 Crest Factor

In accordance with the information presented in Figure 7, the gathered data illustrates three Crest Factors of 1.414. This measurement holds significant relevance within the outlined methodology, as it precisely delineates the proportion between the instantaneous peak value and the Root Mean Square (RMS) value of a voltage or current waveform. This dimensionless numerical quantity stands as a pivotal metric for delineating waveform configurations. Notably, a conventional sinusoidal waveform aligns with a Crest Factor of 1.414 [23].

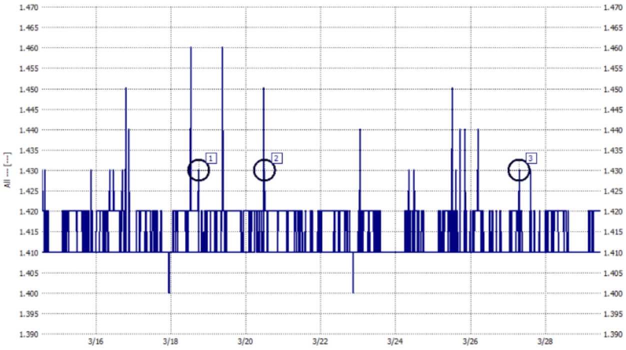

Fig. 7 Crest Factors Analysis for Voltage and Current Waveforms.

6 Voltage Unbalance (Imbalance)

Voltage unbalance, also known as imbalance, stands as a significant factor. It is defined by the ratio of the negative or zero sequence component to the positive sequence component within a power system's voltage. In this research, negative and zero sequence voltages are explored as outcomes of unbalanced loads [24][25].

These aspects collectively contribute to this research methodology by providing insights into the intricacies of power frequency, waveform characteristics, and voltage imbalances that impact the power quality of the system.

In Figure 8, the representation illustrates a balanced three-phase electrical system where the magnitudes of the voltages in the three phases are equal, and the phase angles are 120 degrees apart. This balance is essential for the efficient and reliable operation of the electrical system.

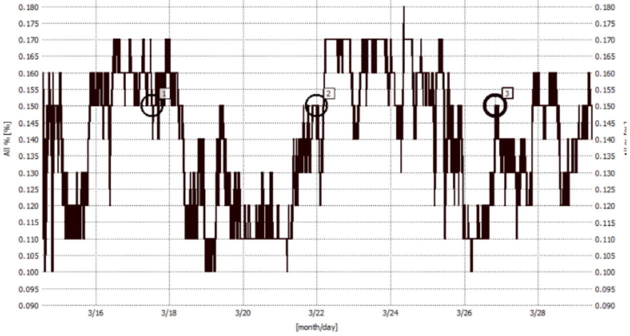

Fig. 8 Voltage Unbalance Analysis for Voltage and Current Waveforms.

The figure visually demonstrates the concept of voltage unbalance. When the voltages in the three phases are not of equal magnitude or not 120 degrees apart in phase, it indicates voltage unbalance. This unbalance can fluctuate with the power frequency.

By examining the data and trends in this figure, one can gain insights into the degree of voltage imbalance and its variations concerning the power frequency. This understanding helps identify potential challenges and areas of concern within the electrical system. It also allows for data-driven decisions and recommendations aimed at improving power quality and enhancing system stability. Ultimately, these actions contribute to the reliable delivery of electrical energy to end-users.

7 Conclusion

In summary, the research highlights the crucial link between renewable energy, particularly wind power, and the existing electrical grid. The impact of wind energy projects on power quality is examined, with proposed solutions for seamless integration while maintaining reliability standards. Insights from Al-Tafilah Governorate, Jordan, underscore the significance of wind speed in enhancing energy output and the need for effective management of harmonic distortions. Strategies such as advanced filtering and power conditioning, alongside voltage regulation techniques, are identified as essential for ensuring grid stability. Collaboration among stakeholders, continuous research, and adherence to standards are emphasized for successful renewable energy integration. By translating these findings into practical solutions, conducting real-world testing, and implementing advanced monitoring, the full potential of renewable energy sources can be harnessed for a sustainable future.

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