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***Research Article***

# THD Reduction and Power Quality Enhancement in Solar-Wind Hybrid Systems: A Comprehensive Review

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## Abstract

The rising demand for sustainable and efficient energy sources has accelerated the adoption of hybrid renewable energy systems (HRES), particularly those combining solar photovoltaic (PV) and wind power. These systems enhance reliability and energy security but also introduce significant power quality (PQ) challenges most notably, Total Harmonic Distortion (THD). This review explores the key sources of PQ issues in solar-wind hybrids, emphasizing THD origins and impacts. It details system configurations, control strategies, and the role of power electronic converters such as inverters, rectifiers, and MPPT controllers. Various THD mitigation methods are analyzed, including passive/active filters, advanced control techniques (PWM, SVM), and AI-based optimization (fuzzy logic, neural networks, genetic algorithms). Standards from IEEE/IEC are referenced for performance benchmarks. Emerging solutions like UPQC, DVR, smart inverters, and IoT-based monitoring are also discussed, offering a comprehensive outlook on enhancing PQ in modern grid-connected hybrid systems.

**Keywords:** ***Power Quality, Solar-Wind Hybrid System, Harmonic Distortion, Tension Stability, Renewable Energy.***

## 1. Introduction

A Solar-Wind Hybrid System is a renewable electricity system that mixes the strength era capabilities of both sun photovoltaic (PV) panels and wind mills to provide power in a more reliable and green manner [1-3]. The key gain of this hybrid technique lies within the complementary nature of the 2 energy resources sun electricity is generally greater abundant during the day and in sunny seasons, even as wind electricity is frequently available at night or at some point of cloudy and stormy weather. By integrating each, the device guarantees an extra consistent and solid power deliver, lowering the dependency on a unmarried supply and mitigating the intermittency issues commonplace in renewable power [4,5]. The gadget generally includes solar panels, a wind turbine, fee controllers, batteries for energy garage, and an inverter to transform the generated DC power into AC for household or grid use. These systems are mainly useful in remote or off-grid areas, in which reliable power is tough to get right of entry to, and are increasingly more used in residential, commercial, and rural electrification programs. Although the preliminary setup value can be better than the use of an unmarried strength source, the lengthy-term benefits in phrases of reliability, performance, and sustainability make sun-wind hybrid structures a promising answer for smooth electricity technology [6,7].

The solar wind hybrid system is shown in figure 1. With the increasing demand for sustainable energy, hybrid photovoltaic system has emerged as a promising solution for renewable power generation. These systems provide significant environmental and economic benefits by reducing the dependence on fossil fuels and reducing greenhouse gas emissions [8,9]. However, despite these benefits, hybrid solar wind systems have sufficient challenges, especially related to power quality. The intermittent nature of solar and wind energy leads to ups and downs in power generation, which can cause voltage variation, frequency instability and hormonic malformations when integrated into the main grid. Such problems not only affect online stability but also affect the efficiency and reliability of the distribution of power [10-12].

The basic challenge with hybrid Solar-Hurry Energy Systems derives from unpredictable and varying nature of renewable energy sources. Production of solar energy depends on factors such as the availability of sunlight, cloud cover and seasonal changes, while wind energy is affected by air velocity and disruption. These ups and downs result in deviations in the power supply, making it difficult to maintain a stable and reliable energy production. As a result, electrical quality disorders such as voltage saws and cheese, flicker and harmonic malformations create significant concerns for both online operators and final users [13,14].

In addition to variation in power generation, the integration of solar and wind energy in the network provides compatibility challenges. The traditional power grid was designed for stable and controlled energy sources such as coal, atoms and hydropower.

Reporting and decentralized nature of renewable energy sources create a discrepancy between power generation and demand, which can cause electrical imbalance and disruption in grid operations. To solve these problems, it is important to implement advanced technologies and intelligent control mechanisms that increase online stability and optimize the power quality. Various technological advances are designed to reduce power quality problems in hybrid solar wind systems [15,16]. Transmitters, active power filters (APFS) and flexible AC transfer systems (facts) play an important role in improving power electronics, voltage control, reactive power compensation and improvement of improvement. In addition, using smart network technologies and surveillance systems in real time increase the ability to predict and handle power fluctuations. Artificial intelligence (AI) work -free control strategies, machine learning algorithms and adaptive control methods have also been used to adapt energy management and ensure efficient use of renewable energy sources. Another important aspect of improving the power quality of the hybrid system is energy storage. Energy storage system (ESS), such as Battery Energy Storage system (BESS), Supercappers and Flywheel Energy Storage Integration, provides a buffer against electric ups and downs and enables even grid operations. These storage solutions help balance energy supply and demand and ensure more stable and reliable power generation [17-19].

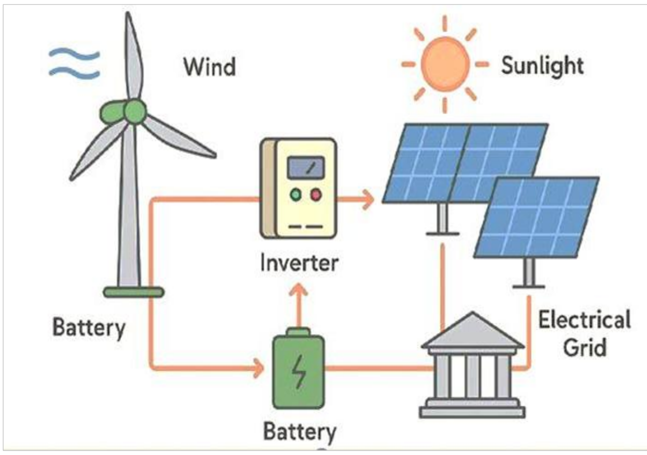


**Fig.1 Solar Wind Hybrid Power System**

By storing extra energy during the high-generation period and freeing it under low production, the energy storage system plays an important role in maintaining voltage stability and frequency control in the web-connected hybrid solar-sink system. The aim of this review letter is to find out recent trends and technological advances that address the power quality challenges associated with the network-looking solar system. This provides intensive analysis of different power condemination techniques, intelligent control strategies and energy storage solutions designed to increase the general performance of these systems. By examining condition species functioning and innovative approaches, this study contributes to the ongoing efforts to develop efficient, reliable and durable renewable energy solutions. The findings of this letter highlight the importance of advanced power electronics, real-time monitoring and the importance of AI-operated control mechanisms to improve the power quality and stability of hybrid renewable energy systems [20-22].

## 2. Power Quality Enhancement Strategies

Power excellent is a crucial difficulty in sun-wind hybrid structures because of the intermittent and nonlinear nature of renewable energy resources. To address strength nice issues such as harmonics, voltage sags/swells, flicker, and frequency deviations, various enhancement strategies are hired. One of the primary tactics entails the usage of energy digital devices like voltage supply inverters and multilevel converters that make certain smoother integration with minimal harmonic injection. Active and passive filtering strategies are also broadly used; lively filters dynamically adjust to actual-time disturbances, while passive filters target unique harmonic frequencies. Flexible AC Transmission Systems (FACTS) devices which include STATCOMs (Static Synchronous Compensators) and SVCs (Static Var Compensators) are deployed to offer voltage balance and reactive strength compensation. In addition, electricity garage systems inclusive of batteries or supercapacitors are included to soak up fluctuations and assist load balancing [23]. Advanced manipulate strategies using PI controllers, fuzzy true judgment, or artificial intelligence (AI) algorithms further decorate device adaptability and precision. Synchronization strategies, which includes section-locked loops (PLL), make certain proper coordination with the grid, even as pulse width modulation (PWM) and predictive manipulate strategies refine inverter output and reduce switching losses. Real-time tracking through IoT-enabled smart sensors and communication networks lets in proactive renovation and rapid fault detection. Together, these techniques form a sturdy framework to decorate the strength first-class and operational balance of solar-wind hybrid power structures [24-26]. The Power Quality Enhancement Strategies observed in practices are given in figure 2.

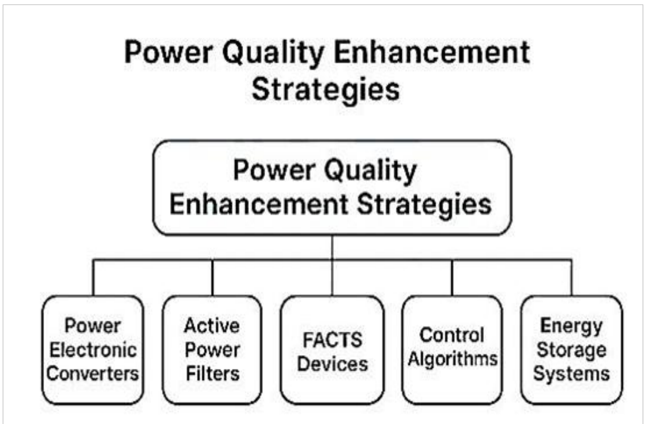


**Fig.2. Power Quality Enhancement Strategies**

## 3. Comparative Analysis of THD Mitigation Techniques

Total Harmonic Distortion (THD) is a essential energy satisfactory difficulty due to nonlinear masses and switching operations in electricity digital devices, in particular in renewable strength systems. To make certain grid compliance and operational efficiency, numerous mitigation strategies have been advanced. These consist of passive filters, lively electricity filters (APFs), hybrid filters, multilevel inverters, and superior control strategies together with PWM, fuzzy good judgment, and AI-based manage. Each approach gives specific blessings and barriers in terms of cost, overall performance, dynamic response, and complexity. For example, passive filters are value-powerful but much less adaptable, even as APFs offer dynamic harmonic repayment at a higher fee and manipulate complexity. Hybrid filters purpose to balance each. Inverters using PWM can drastically reduce THD via improving output waveform excellent. Advanced AI-based totally controllers adapt to system modifications in real time, imparting sensible harmonic suppression [27-31]. THD mitigation techniques are shown in table 1 as follows:

**Table 1: Comparative Table THD Mitigation Techniques** [31]

| Technique | Principle | THD Reduction | Cost | Complexity | Adaptability | Remarks |
|---|---|---|---|---|---|---|
| Passive Filters (PFs) | LC circuits tuned to specific harmonic frequencies | Moderate | Low | Low | Low | Simple and economical; not effective for dynamic loads |
| Active Power Filters (APFs) | Inject compensating current using power electronics | High | High | High | High | Effective for dynamic and nonlinear load compensation |
| Hybrid Filters | Combination of PFs and APFs | High | Medium-High | Medium | Medium-High | Balanced cost and performance; better stability |
| Multilevel Inverters | Use multiple voltage levels to approximate sine wave | High | High | High | Medium | Reduces THD directly at inverter output |
| PWM Techniques | Modulates switching to shape output waveforms | Moderate-High | Medium | Medium | Medium | Widely used; improved waveform but not fully adaptive |
| AI/ML-based Controllers | Adaptive learning algorithms to control harmonics | Very High | High | Very High | Very High | Smart response to varying loads and grid conditions |
| Fuzzy Logic Control | Rule-based reasoning for dynamic load management | High | Medium | Medium | High | Good for systems with uncertainty and nonlinearity |
| Custom Harmonic Controllers (HAPF, DVR, DSTATCOM) | Target specific harmonics and disturbances | High | High | High | High | Specialized devices for power quality enhanceme |

## 4. Recent Advances and Trends in PQ Improvement for Hybrid Systems

Hybrid power structures, which combine traditional energy resources with renewable strength sources (RES) like sun and wind, have received recognition because of their performance and environmental benefits. However, these structures introduce big demanding situations associated with Power Quality (PQ). The intermittent and unpredictable nature of RES, at the side of the increasing use of electricity electronic devices and nonlinear loads, regularly leads to issues which includes voltage fluctuations, harmonic distortion, frequency instability, flicker, and strength unbalance [32-33].

To address those challenges, latest advances have focused on more than one fronts. Power electronic gadgets, including multilevel inverters, Static Synchronous Compensators (STATCOM), and Dynamic Voltage Restorers (DVR), were developed to improve voltage balance and suppress harmonics. Active and passive filters also are broadly used to mitigate cutting-edge and voltage harmonics. On the control aspect, advanced strategies like Model Predictive Control (MPC), adaptive hunch manage, and the utility of Artificial Intelligence (AI) and Machine Learning (ML) are being utilized for real-time tracking, load forecasting, and optimization of PQ control techniques.

The integration of Energy Storage Systems (ESS), particularly Battery Energy Storage Systems (BESS) and hybrid garage structures (e.g. batteries mixed with supercapacitors), performs a crucial role in retaining voltage and frequency balance by means of compensating for the variability of RES. Moreover, the emergence of smart grid technology and Internet of Things (IoT) systems lets in actual-time PQ tracking, predictive preservation, and better coordination among grid elements. Regulatory frameworks and international standards like IEEE 519 and IEC 61000 are an increasing number of being enforced to make certain PQ compliance in hybrid strength systems. These trends collectively have goal to create more strong, reliable, and efficient hybrid energy systems with stepped forward power great [34,35]. The recent advances and tends in PQ improvement for hybrid systems is shown in table 2

**Table 2. Recent Advances and Trends in PQ Improvement for Hybrid Systems**

| Category | Advances/Trends | PQ Issues Addressed |
|---|---|---|
| Power Electronics | Multilevel inverters, STATCOM, DVR, active/passive filters | Harmonics, voltage sags/swells, flicker |
| Control Techniques | Model Predictive Control (MPC), adaptive droop, AI/ML-based control | Voltage/frequency regulation, load sharing |
| Energy Storage Systems | Battery Energy Storage Systems (BESS), hybrid ESS (battery + SC) | Frequency stability, voltage support |
| Smart Grid & IoT | Real-time monitoring, smart sensors, predictive maintenance | Early fault detection, dynamic PQ management |
| AI/ML Applications | Load and fault prediction, optimization of PQ compensation strategies | Proactive PQ improvement, system efficiency |
| Standards & Regulations | IEEE 519, IEC 61000 compliance, evolving grid codes | Harmonic limits, voltage fluctuation control |

## 5. Techniques for THD Reduction in Hybrid Systems

Electrical quality disorders in hybrid renewable energy systems can be classified in many types, with each different causes and effects. One of the most important disturbances is the voltage variation, which is due to the nature of the ups and downs of air and solar energy production. These variations lead to voltage and cheer, which can cause instability in the mains. Hormonic deformities represent another important case, which is mainly introduced by the electrical electronic inverters used in the integration of renewable energy. These deformities result in non-synzodel waves, which reduces the efficiency of electrical equipment and overheats the transformer and engines. Another common disturbance is the flicker effect, which refers to rapid voltage rapid tension due to changes in air velocity and cloud movements on solar panels. These ups and downs can cause visible flickering, which can be problematic for consumers [36].

Frequency deviation is another concern, which arises by not matching between power generation and loading requirements. A stable frequency is important for maintaining the reliability of the grid, and deviations can interfere with the synchronization of electrical equipment. Finally, the imbalance in reactive strength affects web stability and strength factor, making it necessary to use corrective measures such as reactive power compensation tools. Understanding these disorders is important for developing effective coating strategies that ensure spontaneous integration of the Solar-Hill Hybrid system in the power grid. The Power Quality Disturbances are shown in figure 3.

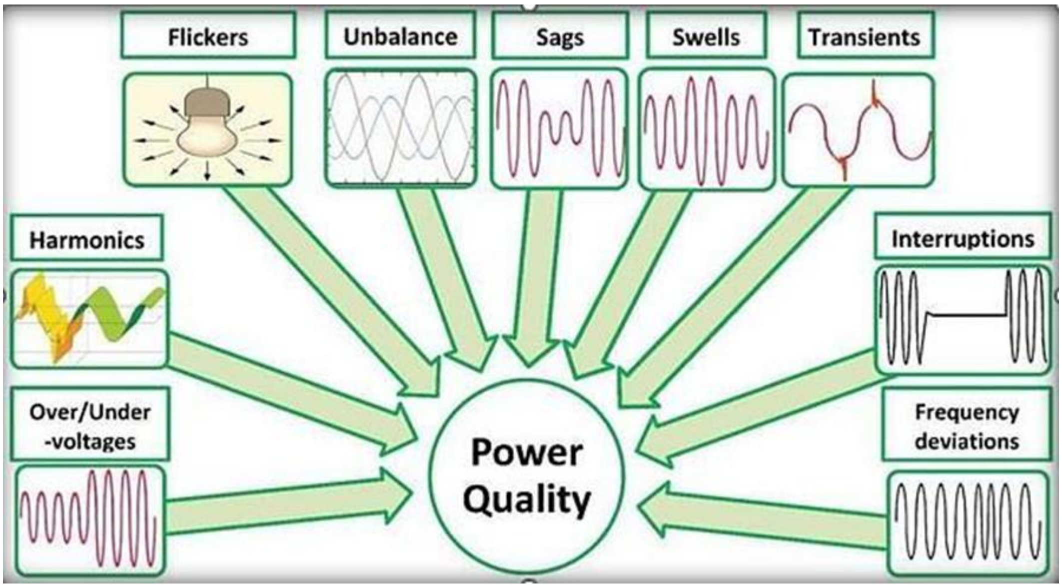


**Fig.3. Power Quality Disturbances**

**Factor affecting Power Quality as given below [30,33,36]:**

- **Flickers:** Flickers consult with the rapid and repeated modifications in voltage stages that motive visible fluctuations inside the brightness of lighting gadget. This is most noticeable in incandescent lamps and can be pretty worrying for human eyes. Flickers are usually caused by hundreds that draw massive and fluctuating currents, which includes arc furnaces, welding machines, or big vehicles beginning and stopping. Though they'll not usually harm system immediately, glints notably reduce the comfort of users and might purpose sensitive system to behave erratically. Mitigation strategies include the use of voltage stabilizers, Static VAR Compensators (SVCs), or strength storage systems that can deliver or absorb reactive strength.
- **Unbalance:** Unbalance occurs in a 3-section energy system whilst the voltage or modern magnitudes aren't same in all 3 levels, or while there may be an unequal segment angle separation among them. This circumstance is commonly a end result of unequal loading on stages, broken conductors, or uneven transformer winding. Electrical unbalance leads to the generation of bad series currents that produce greater heating in cars and transformers, lowering their lifespan and performance. To correct unbalance, it's essential to design the device well, balance the burden across levels, and use phase-moving transformers if vital.
- **Voltage Sags:** A voltage sag, also called a dip, is a short-length reduction in the RMS voltage level. It normally lasts from a few milliseconds to numerous seconds and is generally resulting from excessive inrush modern loads together with the startup of huge motors or due to faults at the electricity gadget. Voltage sags can reason laptop structures to reboot, machinery to experience, or relays to malfunction, disrupting operations. They are one of the most not unusual strength best issues. To mitigate sags, utilities and clients can deploy Uninterruptible Power Supplies (UPS), Dynamic Voltage Restorers (DVR), and ensure right fault coordination within the electric network.
- **Voltage Swells:** Voltage swell is a brief growth in RMS voltage stage, normally lasting for some milliseconds to a few seconds. Swells normally occur due to surprising load drop or because of switching operations, such as turning off a large inductive load. Prolonged or frequent voltage swells can harm touchy electronics, overheat device, and shorten the existence of insulation systems. To manage voltage swells, surge arresters, voltage regulators, and properly rated device may be used.
- **Transients:** Transients are short-lived surges in voltage or modern, lasting from some microseconds to a few milliseconds. They are typically due to lightning strikes, switching of inductive masses, or capacitor financial institution switching. Though quick, transients can have very high magnitudes and can damage digital devices, erase statistics, or degrade insulation substances.

Protection against transients can be completed the use of surge protectors, brief voltage surge suppressors (TVSS), and isolation transformers.

- **Interruptions:** Interruptions constitute a complete loss of electrical strength for a period starting from fractions of a 2nd to hours. These are labeled as temporary (much less than 1 second), brief (up to a few minutes), or sustained (greater than five mins). Interruptions are due to faults in the energy device, system screw ups, or deliberate outages. The impact of interruptions is extensive in industries, leading to manufacturing losses and capability damage to structures that are not well shut down. To mitigate interruptions, backup power elements inclusive of generators, UPS structures, and automated switching to trade resources are generally used.
- **Frequency Deviations:** Power structures are designed to function at a stable frequency, including 50 Hz or 60 Hz. Frequency deviations occur while there is a mismatch between generated energy and the call for, frequently due to era disasters, unexpected load adjustments, or inadequate manage. Small deviations are typically corrected mechanically with the aid of gadget controls, however large or prolonged deviations can cause equipment malfunction, synchronization loss, or system-extensive instability. Frequency manage is done using load losing, computerized technology manipulate (AGC), and higher call for forecasting.
- **Over/Under Voltages:** These are lengthy-period voltage abnormalities where the voltage degree remains always above or underneath the applicable limits. Over voltages can end result from immoderate era, faulty voltage regulators, or long transmission lines with mild loading. Under voltages regularly arise due to overloading, lengthy distance energy transport, or distribution faults. Prolonged exposure to over voltages can also damage insulation and connected gadgets, whilst under voltages can purpose motors to stall and overheat. Solutions consist of voltage regulation gadget, transformer faucet changers, and proper device planning.
- **Harmonics:** Harmonics are undesirable frequencies which are multiples of the essential electricity system frequency and distort the authentic waveform. They are commonly generated by way of non-linear masses together with variable frequency drives (VFDs), computer systems, UPS structures, and LED lighting fixtures. Harmonics motive extra heating in electrical machines, neutral conductor overloading, interference with verbal exchange structures, and malfunctioning of sensitive gadgets. To lessen harmonics, harmonic filters (energetic or passive), isolation transformers, and proper load distribution are used.

## 6. Technologies to Improve Power Quality

### 6.1 Power Electronics-based Solution

Power Electronics plays an important role in reducing power quality problems in grid-promoting hybrid systems. Advanced power electronic inverters, such as tension sources converter (TSC) and current sources enable converter (CSEC), effective energy converting and synchronization of the grid. The active power filter (APF) is widely used to eliminate hormonics and improve the power factor by injecting compensation streams into the system. In addition, facts, including STATCOM and SVC, help in voltage control and reactive power compensation, and ensure uniform power current in the grid. Another important technique is the dynamic voltage restaurant (DVR), which protects the network from the tension saws and the inflammation of the dynamically injected voltage into the series with the supply of the grid. Continuous progress in semiconductor technology has also led to the development of electronic switches with high demonstration that improves the efficiency and reliability of these support techniques [27-28,37].

### 6.2 Advanced control strategies

Modern control strategies have played an important role in increasing the quality of power in the Solar-Hawa Hybrid system. The Model Predictive Control (MPC) has gained popularity due to the ability to provide real -time adjustment of control signals, which has improved system stability. Artificial intelligence and machine learning -based controls have revolutionized power quality control by enabling intelligent decisions and adapted control of energy resources. These AI-based totally techniques can analyze ancient records, expect strength pleasant problems and enforce corrective corrective tasks. In addition, unclear common sense and adaptive control methods are designed to address voltage and frequency versions greater efficaciously. These intelligent control techniques provide better performance in dynamic running situations and offer sturdy answers for renewable energy systems associated with the net [38,39].

### 6.3 Energy storage systems

Energy garage technology play a vital role in stabilizing strength generation and reducing troubles with electricity first-class in hybrid renewable electricity systems. Battery Energy Storage System (BES) has emerge as a famous opportunity for pinnacle load manipulate and voltage stability. These batteries keep more electricity for the duration of the high era length and permit it to boom it and make sure a balanced electricity supply. Supercapacitors provide quick response to electric ups and downs, suitable for improving transient stability. In addition, flywheel storage systems are used for frequency control and transient stability increase, which provides high efficiency and rapid response time [40,41].

Integration of hybrid energy storage solutions makes it possible to improve frequency stability and synchronization of the grid, to ensure reliable and high-quality power supply.

## 7. Conclusions and Future Scope

The integration of sun and wind energy structures into the grid offers a promising solution to fulfill growing electricity needs sustainably. However, the inherent variability and intermittency of these renewable assets often cause strength excellent troubles, specifically Total Harmonic Distortion (THD). This evaluate highlights diverse techniques and manipulate techniques consisting of superior inverter topologies, adaptive filtering, and actual-time tracking that have validated powerful in mitigating THD and enhancing typical strength fine in hybrid systems. The evaluation confirms that a nicely-coordinated layout of electricity digital interfaces and sturdy manage mechanisms can appreciably lessen harmonics, enhance voltage balance, and make sure seamless grid integration, thereby promoting the reliability and efficiency of sun-wind hybrid structures.

As the adoption of sun-wind hybrid structures keeps developing, future studies have to awareness on integrating greater intelligent and adaptive answers for THD discount and electricity fine improvement. The use of artificial intelligence (AI), machine mastering (ML), and predictive analytics can enable actual-time monitoring and dynamic manage of electricity excellent parameters, making the device greater aware of changing environmental and cargo situations. Additionally, the development of multifunctional inverters and advanced clear out designs able to dealing with each harmonic mitigation and voltage regulation is vital. Exploring the synergy among hybrid structures and energy storage technologies can also assist in balancing strength fluctuations and similarly stabilizing output. Moreover, implementing Internet of Things (IoT)-based smart grid conversation protocols will decorate device coordination and fault detection. Finally, complete trying out under real-global situations and adherence to evolving grid codes and requirements will be important to ensure the reliability, scalability, and giant deployment of those hybrid power systems.

## Nomenclature

| | | | |
|---|---|---|---|
| AC | Alternative Current | ML | Machine Leraning |
| AGC | Automatic gain control | MPC | Model Predictive Control |
| AI | Artificial intelligence | MPC | Model Predictive Control |
| APFS | active power filters | PLL | Pulse locked loops |
| BESS | Battery Energy Storage system | PQ | power quality |
| CSEC | current sources enable converter | PV | Photovoltaic |
| DC | Direct Current | PWM | pulse width modulation |
| DVR | Dynamic Voltage Restorers | RES | renewable strength sources |
| ESS | Energy storage system | STATCOMs | Static Synchronous Compensators |
| FACTS | Flexible AC Transmission Systems | SVCs | Static Var Compensators |
| HRES | hybrid renewable energy systems | THD | Total Harmonic Distortion |
| IEC | International Electrotechnical Commission | TSC | tension sources converter |
| IEEE | Institute of Electrical and Electronics Engineers | UPQC | Unified Power Quality Conditioner |
| IoT | Internet of Things | UPS | Uninterruptible Power Supplies |
| LED | light emitting diode | VFDs | variable frequency drives |

## Declarations

## Conflicts of Interest

The authors declare that they have no conflict of interest.

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## Authors' contributions or CRediT Roles

**Mahendra Kumar:** Conceptualization, Writing-original draft.
**Alok Kumar Singh:** Writing and Editing
**Shiv Lal:** Review and Editing

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## References

[1] Fuskele, V., Baredar, P., Sarviya, R.M., Lal, S., Awasthi, S., Wind Turbine Nacelle Cooling Systems: A review. WIRE-Energy and Environment Journal (Wiley), 11(6) ,1-13, DOI: 10.1002/wene.456

[2] Shiv Lal, Verma P., Rajora R. 2013. Performance analysis of photovoltaic based submersible water pump. Pp. 552-560. International journal of engineering and technology, vol. 5, issue 2, pp. 552-560. ISSN: 0975-4024, http://www.enggjournals.com/ijet/.

[3] Shibna Hussain, Santosh Kumar Sharma, Shiv Lal, Feasible Synergy between Hybrid Solar PV and Wind System for Energy Supply of a Green Building in Kota (India): A Case Study using iHOGA, Energy Conversion and Management 315 (2024) 118783, https://doi.org/10.1016/j.enconman.2024.118783

[4] Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. Renewable and Sustainable Energy Reviews, 39, 748–764. https://doi.org/10.1016/j.rser.2014.07.113

[5] Sharma, R., & Kumar, A. (2022). Performance analysis of hybrid solar-wind energy systems: A review. Renewable Energy Reviews, 58(4), 112–128. https://doi.org/10.1016/j.rer.2022.03.015

[6] Rehman, S., Bader, M. A., & Al-Moallem, S. A. (2007). Cost of solar energy generated using PV panels. Renewable and Sustainable Energy Reviews, 11(8), 1843–1857. https://doi.org/10.1016/j.rser.2006.03.004

[7] Rajasekar, N., & Venmathi, A. (2020). Design and analysis of solar-wind hybrid power system for rural electrification: A case study. Energy Reports, 6, 581–589. https://doi.org/10.1016/j.egyr.2020.03.011

[8] Shibna Hussain, S.K. Sharma, Shiv Lal, 2023. Demand Side Management in Grid Part-I, Electrical India, 63(08):24-27, ISSN 0972-3277

[9] Shibna Hussain, S.K.Sharma, Shiv Lal, 2023. Demand Side Management in Grid Part-II, Electrical India, 63(08):31-35, ISSN 0972-3277

[10] Mekhilef, S., Saidur, R., & Safari, A. (2012). Comparative study of different fuel cell technologies. Renewable and Sustainable Energy Reviews, 16(1), 981–989. https://doi.org/10.1016/j.rser.2011.09.020

[11] Balamurugan, S., Ashok, S., & Jose, R. (2009). Optimal operation of a hybrid renewable energy system by forecasting demand and renewable energy sources. International Journal of Electrical Power & Energy Systems, 31(7-8), 323–328. https://doi.org/10.1016/j.ijepes.2009.02.001

[12] Bhattacharjee, S., & Acharya, N. (2021). Power quality issues and solutions in renewable energy systems: A review. Renewable and Sustainable Energy Reviews, 141, 110861. https://doi.org/10.1016/j.rser.2021.110861

[13] Mendonça, M., Lacey, S., & Hvelplund, F. (2009). Powering the green economy: The feed-in tariff handbook. Earthscan.
[14] Elnozahy, A., Abdel Aziz, R., & El-Saadany, E. F. (2015). A comprehensive study of the power quality issues in wind and solar photovoltaic hybrid power system. Renewable Energy, 84, 1–11. https://doi.org/10.1016/j.renene.2015.06.048
[15] Guerrero, J. M., Vasquez, J. C., Matas, J., de Vicuña, L. G., & Castilla, M. (2011). Hierarchical control of droop-controlled AC and DC microgrids-A general approach toward standardization. IEEE Transactions on Industrial Electronics, 58(1), 158–172. https://doi.org/10.1109/TIE.2010.2066534
[16] Abas, N., Kalair, A., Khan, N., Haider, A., Saleem, Z., & Saleem, M. S. (2018). Natural and hybrid ventilation systems in buildings: A review. Renewable and Sustainable Energy Reviews, 94, 486–499. https://doi.org/10.1016/j.rser.2018.06.057
[17] Blaabjerg, F., Teodorescu, R., Liserre, M., & Timbus, A. V. (2006). Overview of control and grid synchronization for distributed power generation systems. IEEE Transactions on Industrial Electronics, 53(5), 1398–1409. https://doi.org/10.1109/TIE.2006.881997
[18] Khalid, W., & Javaid, N. (2022). A review of energy management techniques for hybrid renewable energy systems. Renewable and Sustainable Energy Reviews, 156, 111887. https://doi.org/10.1016/j.rser.2021.111887
[19] Ghasemi, A., Sadeghi, M., & Fotuhi-Firuzabad, M. (2020). Artificial intelligence-based approaches for energy management in microgrids: State of the art, challenges, and future trends. Energy Reports, 6, 1228–1240. https://doi.org/10.1016/j.egyr.2020.04.012
[20] Divya, K. C., & Østergaard, J. (2009). Battery energy storage technology for power systems-An overview. Electric Power Systems Research, 79(4), 511–520. https://doi.org/10.1016/j.epsr.2008.09.017
[21] Elkazaz, M. K., Sumper, A., & Ramirez-Elizondo, L. (2020). A review of the energy management system for stand-alone microgrids: Control methods and algorithms. Renewable and Sustainable Energy Reviews, 124, 109742. https://doi.org/10.1016/j.rser.2020.109742
[22] Shafiullah, G. M., Amanullah, M. T. O., Shawkat Ali, A. B. M., Wolfs, P., & Jarvis, D. (2013). Smart grid for a sustainable future. Renewable and Sustainable Energy Reviews, 29, 643–654. https://doi.org/10.1016/j.rser.2013.08.072
[23] Mahendra Kumar, Alok Kumar Singh, Shiv Lal, Power Quality Enhancement in Grid Connected Solar Wind Hybrid System using FACTS Devices, J. Electrical Systems 2024, 20(11s): 4348-4359, DOI:10.52783/jes.8510
[24] Patel, H., & Agarwal, V. (2008). MATLAB-based modeling to study the performance of different MPPT techniques used for solar PV systems under various operating conditions. IEEE Transactions on Energy Conversion, 23(1), 402–410. https://doi.org/10.1109/TEC.2007.914308
[25] Siano, P. (2014). Demand response and smart grids-A survey. Renewable and Sustainable Energy Reviews, 30, 461–478. https://doi.org/10.1016/j.rser.2013.10.022
[26] Rezk, H., & Mohamed, A. Z. (2017). A novel fuzzy logic controller based MPPT of a PV system for both real and reactive power control of grid-connected inverter. Energy Reports, 3, 1-11. https://doi.org/10.1016/j.egyr.2017.02.001
[27] Bollen, M. H. J. (2000). Understanding power quality problems: Voltage sags and interruptions. IEEE Press. https://doi.org/10.1109/9780470531886
[28] Akagi, H. (2005). Active harmonic filters. Proceedings of the IEEE, 93(12), 2128–2141. https://doi.org/10.1109/JPROC.2005.858718
[29] Esmaeili, M., Bina, M. T., & Ajami, A. (2014). Artificial intelligence-based control strategies for power quality improvement in renewable energy systems: A review. Renewable and Sustainable Energy Reviews, 36, 281–293. https://doi.org/10.1016/j.rser.2014.04.051
[30] Singh, B., Singh, K., Chandra, A., Al-Haddad, K., Pandey, A., & Kothari, D. P. (2004). A review of single-phase improved power quality AC-DC converters. IEEE Transactions on Industrial Electronics, 50(5), 962–981. https://doi.org/10.1109/TIE.2003.817609
[31] Kumar, P., & Saini, R. P. (2021). A review on power quality improvement techniques for grid integrated renewable energy sources. Renewable and Sustainable Energy Reviews, 148, 111279. https://doi.org/10.1016/j.rser.2021.111279
[32] Kumar, N. M., & Fernandes, B. G. (2016). Power quality improvement in grid connected wind energy system using facts device. Renewable and Sustainable Energy Reviews, 63, 242–255. https://doi.org/10.1016/j.rser.2016.05.058
[33] Ghosh, A., & Ledwich, G. (2002). Power quality enhancement using custom power devices. Springer. https://doi.org/10.1007/978-1-4471-0103-7
[34] Yan, Y., Qian, Y., Sharif, H., & Tipper, D. (2013). A survey on smart grid communication infrastructures: Motivations, requirements and challenges. IEEE Communications Surveys & Tutorials, 15(1), 5–20. https://doi.org/10.1109/SURV.2012.021312.00034
[35] Kabalci, E. (2020). Internet of Things applications for smart grid: A comprehensive review. Journal of Ambient Intelligence and Humanized Computing, 11(1), 23–40. https://doi.org/10.1007/s12652-019-01314-7
[36] Emanuel, A. E. (2010). Power definitions and the physical mechanism of power flow. Wiley-IEEE Press.
[37] Hingorani, N. G., & Gyugyi, L. (2000). Understanding FACTS: Concepts and technology of flexible AC transmission systems. Wiley-IEEE Press. https://doi.org/10.1109/9780470546680
[38] Tushar, W., Saha, T. K., Yuen, C., Smith, D., & Poor, H. V. (2018). Peer-to-peer trading in electricity networks: An overview. IEEE Transactions on Smart Grid, 11(4), 3185–3200. https://doi.org/10.1109/TSG.2020.2968740
[39] Mohammadi, M., Hosseinian, S. H., & Gharehpetian, G. B. (2014). Robust design of a fuzzy logic controller for a hybrid energy system using adaptive particle swarm optimization. Applied Energy, 119, 114–123. https://doi.org/10.1016/j.apenergy.2013.12.066
[40] Luo, X., Wang, J., Dooner, M., & Clarke, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied Energy, 137, 511–536. https://doi.org/10.1016/j.apenergy.2014.09.081
[41] Chen, H., Cong, T. N., Yang, W., Tan, C., Li, Y., & Ding, Y. (2009). Progress in electrical energy storage system: A

critical review. Progress in Natural Science, 19(3), 291-312. https://doi.org/10.1016/j.pnsc.2008.07.014