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Research article

Renewable energy integration and distributed generation in Kosovo: Challenges and solutions for enhanced energy quality

Arben Gjukaj[1], Rexhep Shaqiri[2,*], Qamil Kabashi[3] and Vezir Rexhepi[1]

[1] Department of Power Engineering, Faculty of Electrical and Computer Engineering, University of Prishtina, Republic of Kosovo
[2] Department of Power Systems, University for Business and Technology—UBT, Republic of Kosovo
[3] Department of Computerized Automation and Robotics, Faculty of Electrical and Computer Engineering, University of Prishtina, Republic of Kosovo

* **Correspondence:** Email: rexhep.shaqiri@ubt-uni.net; Tel: +38344456829.

Abstract: The growing demand for energy, driven by rapid economic development, necessitates higher electricity consumption. However, conventional energy systems relying on fossil fuels present environmental challenges, prompting a shift towards renewable energy sources. In Kosovo, coal-fired power plants dominate electricity production, highlighting the need for cleaner alternatives. Worldwide efforts are underway to increase the efficiency of photovoltaic systems using sustainable materials, essential for ecological and human health. Solar and wind energy are emerging as sustainable alternatives to traditional fossil fuels. However, global concerns about energy security and environmental sustainability are driving countries to prioritize renewable energy development.

In Kosovo, the integration of renewable energy sources, such as wind and solar energy, is progressing rapidly. However, challenges such as voltage stability and power losses need to be addressed. Distributed generation offers a solution by increasing energy reliability and reducing greenhouse gas emissions. Further research is needed to assess the technical, economic, and environmental implications of integrating renewable resources into Kosovo's energy system, focusing on power quality, system reliability, and voltage stability. The research focused on the eastern region of the country, operating at the 110 kV substation level. Challenges in energy quality arise due to the lack of 400 kV supply and the continuous increase in energy consumption, especially in the Gjilan area. This paper investigated integrating renewable energy, especially wind and solar sources, into the medium- and long-term plans at the Gjilan 5 substation to enhance energy quality in the area. Successful integration requires detailed analysis of energy flows, considering the impact of photovoltaics (PVs) on distribution system operation and stability. To simulate and analyze the effects of renewables on the transmission system, voltage profile, and power losses, a case study was conducted using ETAP software. The simulation results present a comparison between scenarios before and after integrating renewable systems to improve energy quality in the identified area.

Keywords: distributed generation (DG); power quality; power system; renewable energy sources (RES); voltage profile

1. Introduction

The core elements of an energy system are generation, transmission, and distribution. In the context of Kosovo, electricity generation predominantly relies on conventional power plants, which are fueled by fossil resources, primarily coal. Despite being the primary energy source for decades, fossil fuels' adverse environmental effects, limited storage capacity, and resource depletion emphasize the critical necessity for alternative energy sources.

In today's world, various scientists are conducting studies on strategies to reduce emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from sources like fossil fuel combustion, with a focus on the necessity for efficient and cost-effective solutions, particularly from coal-fired power plants, to combat air pollution [1].

People are working hard to turn sunlight into chemical energy and exploring hydrogen as a new and hopeful option [2]. Meanwhile, the growing global energy demand and environmental concerns are spurring nations to focus on renewable energy development. Research is currently investigating novel environmentally sustainable materials aimed at improving the efficiency of photovoltaic systems.

Currently, in Kosovo, a mere 9% of consumption is derived from renewable energy sources (RES) whereas certain regions grapple with low voltage issues owing to insufficient investments. Additionally, Kosovo's technical losses exceed those observed in the energy systems of Western countries. Research is currently investigating novel environmentally sustainable materials aimed at improving the efficiency of photovoltaic systems.

The integration of renewable energy sources (RES) is at a critical stage in Kosovo and is progressing rapidly towards a green transition, but with concerns about their impact on the efficiency and sustainability of the system overall. RES are increasing because of climate change, global warming, running out of fossil fuels, and the growing need for energy [3–8]. The progressive expansion of the RES share throughout the last decade has exerted a pronounced influence on the operational parameters of the energy system. In the past decade, the cost of RES and the focus of energy policies on expanding their presence have led to a doubling of installed generating capacity [5]. Numerous studies have explored the potential of wind-solar complementarity [8–12]. Existing literature suggests that, in general, wind and photovoltaic (PV) technologies tend to complement each other at a local level. They explore small-scale renewable energy systems, focusing on the dynamic behavior of hybrid PV and wind turbine models and their impact on the power system stability [13]. An analysis of integrating solar photovoltaic (PV) and wind centers into a hybrid plant found that PV yield loss due to wind turbine shading was negligible. The hybrid plant can reduce grid connection requirements, with a 50% PV and 50% wind system allowing the power line capacity to be up to 70% of the hybrid hub's nominal capacity, with minimal shorting losses. This is due to the complementary nature of solar and wind resources, reducing peak generation occurrences. The study also highlights economic and logistical benefits, particularly in areas with grid congestion or limited land. These findings suggest that hybrid integration optimizes resource use and should be considered for new and existing wind farms [14]. This means that there are few instances where both technologies produce high electricity simultaneously [12]. However, the quantitative impact varies significantly from one location to another, even with identical system configurations. This variability is attributed to specific local factors such as wind speed, solar radiation profiles, and other environmental conditions [9].

The growing use of variable renewable energy sources (RES) like wind and solar power raises concerns about disruptions. A major challenge is the need for backup solutions to manage outages and enhance network reliability. An article provides an overview of the significant technical challenges and potential solutions related to the high penetration of photovoltaic (PV) generation in the power system [15,16]. While technical measures like demand response, the use of energy storage technologies, and excess energy reduction are expected to alleviate these challenges, the focus of this article is on studying the impact of integrating RES on voltage levels and losses in the power system.

Contemporary energy systems are shifting away from fossil fuel-based power plants due to climate change concerns. Instead, distributed generators (DG), mainly utilizing renewable sources like wind turbines, solar panels, and biomass, are increasingly prevalent. These generators are strategically located near consumption centers within the distribution network, with capacities ranging from kilowatts to megawatts. Their integration transforms the distribution network from passive to active, significantly altering energy flow dynamics [17].

The installed capacity of RES for electricity generation, including wind generators, photovoltaic (PV) parks, hydropower plants, geothermal generators, and biomass, constitutes a significant portion of Kosovo's energy portfolio [18]. Presently, the predominant contributors are wind, PV, and small hydropower plants.

Advancements in technology have led to increased capacity and efficiency of RES. In this context, distributed generation (DG) emerges as a potential solution to curbing greenhouse gas emissions, reducing reliance on fossil fuels, and diversifying Kosovo's energy matrix [8,18,19]. DG also plays a crucial role in providing backup power during peak electricity demand, leading to enhanced voltage profiles and reduced power losses in the distribution system [20,21].

The integration of wind power plants into the distribution network encompasses multiple impacts, including technical, economic, techno-economic, techno-ecological, and economic-ecological dimensions [22,23].

Technically, the integration of wind and solar power plants into the distribution network manifests in the reduction of energy losses, improved voltage stability, enhanced quality of electricity, heightened system reliability and security, and impacts on protection coordination, among other aspects [24].

Adherence to specified requirements is essential for both new and existing generators connected to the network. Criteria encompass frequency stability, voltage deviation, voltage waveform, voltage symmetry, power factor, functionality, earthing level, and insulation level as outlined in the Kosovo network.

The ongoing utilization of RES, coupled with battery storage, and the strategic deployment of power distribution networks near load centers, responds to escalating energy demands. It is imperative to conduct reliability analyses and risk assessments to ensure the robust operation of the power transmission system [25]. When considering the power system of Kosovo, characterized by high demand during the day and low demand during the night hours, this knowledge is beneficial for optimization.

The research aims to investigate DG's impact on the transmission system, particularly its operation and stability. Existing studies lack detailed technical analysis on integrating renewable energy sources (RES) into systems with poor electrical energy quality. The article discusses including wind and solar resources in long-term plans for areas with poor energy quality but calls for a comprehensive assessment of obstacles, limitations, and opportunities related to integrating renewables. This includes evaluating their impact on energy quality, voltage stability, energy losses, and system reliability.

For future studies, a detailed analysis of the specific technical, economic, and environmental challenges associated with the incorporation of RES into the existing energy system in Kosovo would be necessary.

2. Materials and methods

This research aims to analyze the impact of integrating DGs, such as solar panels and wind turbines, on power quality in the transmission network and technical losses. The analysis will be based on simulations and data for a specific area, such as Eastern Kosovo. The study aims to address challenges and opportunities related to integrating RES and DGs into Kosovo's energy system, focusing particularly on the Eastern region and the Gjilan area.

The case study involves simulations and analysis of connecting two RES, one with wind turbines and the other with a solar system, both situated on the NS Gjilani side at 110 kV. The study involved creating two simulation models and conducting an analysis based on four cases. Each case examined the voltage profile, with the first model also considering technical losses. The study utilized ETAP software to build a model for analyzing and simulating results, focusing on the performance of wind turbines and solar systems, as well as their impacts on the connected electrical substation [26].

The researchers performed load flow analysis using the Newton-Raphson numerical method, a widely used technique in power system analysis for determining the steady-state operating conditions of an electrical network. This analysis was crucial for evaluating changes in voltage, current, and power within the power system under various operating conditions. The study primarily aimed to analyze the impact of RES on voltage profiles when integrated at the 110 kV level [27].

The manuscript is composed of three sections. First, it outlines the challenges and opportunities regarding power quality, voltage stability, and power losses in integrating renewable energy sources into electrical grids. Second, it examines the impact of incorporating wind and solar systems into Kosovo's electrical grid using ETAP software. Finally, the research examines and interprets its findings.

3. Power and voltage quality

In conventional power systems, the primary focus of power quality lies in addressing voltage-related challenges due to unusual operation or non-linear load behavior. The integration of renewable energy into the electricity grid introduces nuanced power quality issues and associated challenges. The inherent uncertainties linked to RES contribute to both minor and major power quality (PQ) complications. To address these challenges, bespoke solutions tailored to specific causes are imperative, emphasizing the necessity for effective elimination or minimization strategies.

Research in this field indicates that the effect of a wind power plant on voltage control depends on the power flow within the network. In the absence of a connected wind power plant, the voltage at the busbar exceeds that on the primary side of the transformer. When the wind power plant is deactivated, it may trigger a reverse flow of power, resulting in an increase in voltage at consumer connection terminals. This voltage rise becomes a critical factor limiting the integration of additional wind power plants into the transmission network. As the capacity of these units increases, a thorough analysis of voltage regulation becomes essential.

Renewable energy utilization, notably from solar and wind sources, poses power quality challenges encompassing sag, swell, flicker, harmonics, interruptions, and voltage imbalance. As conventional resources deplete, the indispensability of satisfying consumer demands with renewables escalates. This review delves into the intricacies of issues precipitated by solar and wind energy within the grid, proposing enhancements via controllers, grids, power quality enhancement devices, and converters [28–30]. Approximately 90% of Kosovo's energy sector is centralized, primarily reliant on coal-fueled sources to meet consumption demands. Presently, centralized energy systems confront dual constraints: the diminishing availability of fossil fuels and the imperative to curtail pollution. Consequently, the importance of DG resources has surged, facilitated by the integration of RES into the grid [31].

The connection of a substantial wind generator to an inadequately robust transmission network can engender significant electricity quality issues. Moreover, power electronics tend to generate elevated harmonics, intensifying challenges in ensuring electricity quality.

Power quality stands as a pivotal parameter influencing the operational efficacy of power systems. Therefore, a profound understanding of the impacts associated with wind or photovoltaic systems becomes essential for an insightful analysis of factors influencing power quality performance.

The significance of power quality within contemporary power distribution systems is paramount, particularly with the increasing sensitivity of loads and the proliferation of non-linear loads in electrical distribution networks. Given the distributed nature of harmonic loads, the imperative for advanced distributed power quality improvement (PQI) solutions is incontrovertible. While researchers have devoted years to developing diverse filters and devices aimed at augmenting the overall power quality of the system, the evolving nature of distribution systems now sees a pivotal role for power electronics based DGs in distribution networks [32,33].

The stability of the electric power system is intricately tied to load variability, with economic development and escalating electricity consumption driving energy systems to operate near voltage instability thresholds. Wind generators contribute significantly by offering backup power during periods of heightened electricity demand, thereby mitigating energy losses in the power system. Consequently, it is imperative to meticulously assess the impact of DGs on power system stability, emphasizing voltage stability considerations when optimizing DG distribution.

The PV power system provides direct power supply to users, leading to a reduction in distribution network losses. However, the degree of loss reduction from PV power depends on factors such as installation location and generating capacity, both of which directly affect distribution network losses [34].

When calculating distribution network losses with PV power connected, the impact of distributed PV generation on network voltage is often overlooked, and it is commonly assumed that the voltage at each node in the distribution network is equal. If the injected power of PV is $P_{PV} + jQ_{PV}$, the unit line resistance is $R + jX$, the distance from the PV to the supply power is *N*, and the distance from the PV to the load is *M* [34].

The loss of the distributed network without PV is:

$$P = \frac{(P_{load}^2 + Q_{load}^2)}{U}(R + jX) \cdot M \tag{1}$$

The loss of the distributed network with PV connected is:

$$P = \frac{(P_{load} - P_{pv})^2 + (\mathrm{Q}_{load} - Q_{pv})^2}{U}(R + jX) \cdot N + \frac{(P_{load}^2 - Q_{load}^2)}{U}(R + jX)(M - N) \tag{2}$$

The impact of connecting PV systems on network losses is influenced by the installation location and generating capacity of the PV systems. If the PV capacity is less than twice the load power, it can help decrease network losses. Distributed PV power primarily supports network voltage, particularly at voltage outlets and adjacent nodes. It is crucial to thoroughly evaluate the effect of distributed PV power on node voltage and analyze how PV power affects distribution network losses [35].

There are a couple of requirements that need to be met by the case company to be connected to the national grid. This is in accordance with the national network code grid. The company must follow the requirements related to frequency stability and voltage stability [36].

In a power system featuring renewable energy sources, such as solar photovoltaic (PV) systems, the generated power must be integrated into the distribution network via power inverters. These inverters introduce harmonics into the system. Therefore, reducing harmonic order and harmonic distortion can effectively improve the voltage quality and line losses.

Consequently, as the frequency of these harmonics increases, the effective impedance of the transmission line rises, and the skin effect becomes more noticeable, leading to a concentration of current near the surface [37].

Under harmonic content, considering the skin effect, the impedance of the conductor is:

$$Z(n) = \sqrt{n}(R + jX) \tag{3}$$

where n is the harmonic order.

The harmonic loss of the line can be expressed as:

$$P_{loss} = 3\sum_{n}^{m} R_n I_n^2 = 3I_1^2 R_1 \sum_{n=2}^{m} \sqrt{n}(HRI_n)^2 \tag{4}$$

where m is the degree of modulation, R_1 is the line fundamental frequency resistance, whereas HRI_n is the ratio of the harmonic current to fundamental current. In the Eqs (3) and (4), the effects of permeability, conductor radius, and conductivity are not considered [37].

4. Problem formulation—Case study

The energy sector in Kosovo faces significant technical and non-technical losses, particularly in the distribution network. Current efforts are focused on enhancing efficiency and reducing these losses. Transmission system losses are at an acceptable level of 1.26%, comparable to those in the region and in Europe. However, technical losses in the distribution system remain high, accounting for 12.21% in 2022. Unauthorized consumption, or commercial losses, constitute 10.42%. Notably, unbilled energy in the four northern municipalities of Kosovo represents 5.85% (362 GWh) of the distribution demand [18]. The power system of Kosovo has gone through a difficult period of development due to a lack of investments, both in new generating capacities and in the development of the transmission and distribution network. Therefore, some areas still face poor quality of electrical energy. One of the most affected areas is the Eastern part of the country, where the medium-term development plan until 2030 envisages the integration of several renewable sources, which are precisely part of this study.

The simulations in our case were conducted through the analysis of connecting two renewable energy source (RES) centers: one with wind turbines, comprising 11 turbines (each with a capacity of 6.3 MW) totaling an installed power of 69.6 MW, and a solar system with a capacity of 30 MW. These DGs are situated on the NS Gjilani side at 110 kV, as illustrated in Figure 1. This segment of the overall energy system in Kosovo is equivalent to two swing bus energy networks: Prishtina 4 (220/110 kV) and Ferizaj 2 (400/110 kV), acting as robust balancing bars for active and reactive power.

Figure 1. Site location of PV solar and wind farm.

The wind farm, named Kamenica Wind Farm, will be located 25 km away from the Gjilani 5 substation at coordinates 42°27'16" latitude, 21°30'15" longitude, with an altitude of 503 meters. The solar farm, named PS Kamenica-3 Solar PV Park, will be situated at coordinates 42°35'13" latitude, 20°54'7" longitude, with an altitude of 586 meters.

The models in this case study were constructed using the ETAP software, where analyses and simulation results were obtained to address the performance aspects of wind turbines and solar systems, along with their impacts on the electrical substation to which they were connected [38]. Load flow analysis was conducted employing the Newton-Raphson numerical method, a technique widely used in power system analysis to determine the steady-state operating conditions of an electrical network. This analysis, also known as power flow analysis, is crucial for assessing changes in voltage, current, and power within the power system under various operating conditions [39].

Given the identified issues in this segment of the power system of Kosovo, particularly related to voltage drop, the primary focus of the study was to analyze the impact of RES on voltage profiles when integrated at the 110 kV level.

This study focuses on assessing the performance of renewable energy source (RES) integration, specifically wind and photovoltaic (PV) systems, across five primary 110 kV substations: Gjilani 1, Gjilani 5, Vitia, Sharr, and Berivojca. The energy injection originates from a RES at substation Gjilani 5. The analysis encompasses various scenarios: Pre-RES integration, individual integration of wind turbines, separate integration of PV systems, and full RES integration. The assessment involves a detailed comparison of the impact on voltage profiles and losses within these substations for each scenario.

5. Results and analysis

Model 1: In this model, simulations have been conducted by observing this area and modeling the actual power system of Kosovo. The single-line diagram, as shown in Figure 2, is essential for understanding the initial state of the electrical system and identifying potential areas for improvement. It allows for a comprehensive assessment of the system's capacity and performance, serving as a reference point for evaluating the impact of integrating RES. Through the following hypotheses, the voltages at selected substations of the area and the level of technical losses before and after the integration of renewable sources have been analyzed.

Comprehensive models for analysis and simulations were developed and implemented for both the high-voltage side of the substation under investigation and the 10 kV medium-voltage line. These models were designed to thoroughly assess the operational characteristics and potential impacts of various scenarios on the electrical system's performance.

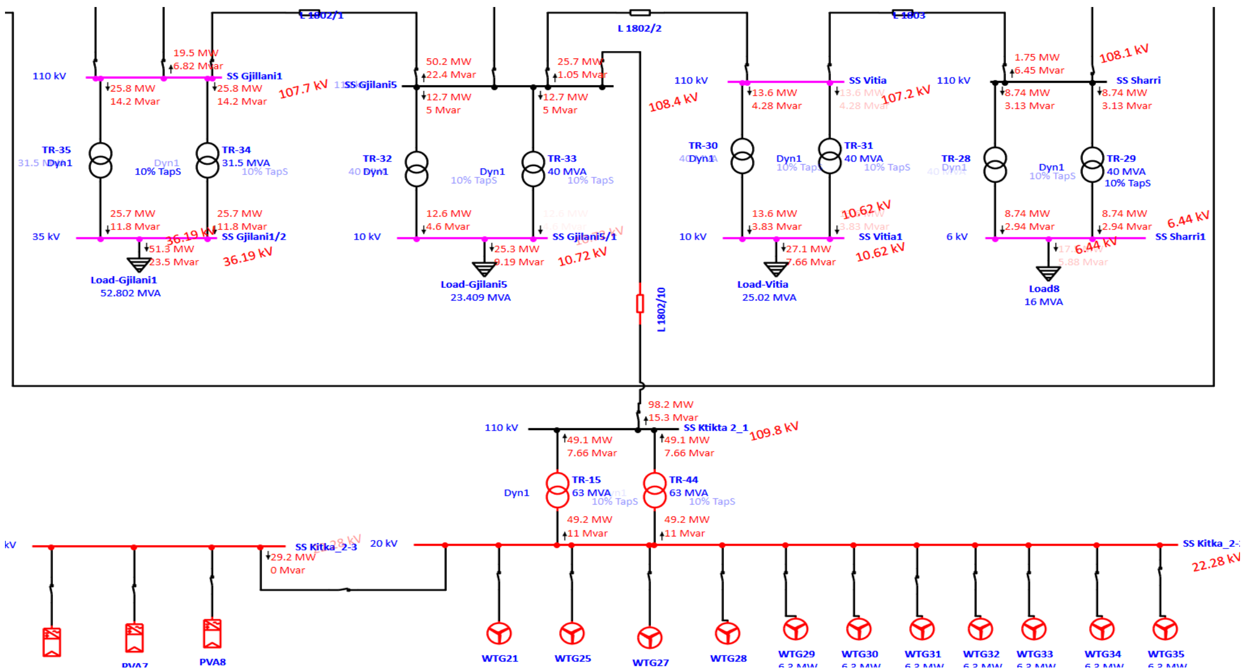

Figure 2. Single-line diagram of the power system model of Kosovo pre-connecting the wind turbines and PV systems.

Case 1: In this case, Figure 3 displays the voltage profiles in selected nodes. The observation shows that the voltage quality does not meet the desired levels. Simultaneously, this condition may lead to increased losses, escalating economic costs, and adversely affecting the power quality distributed to consumers.

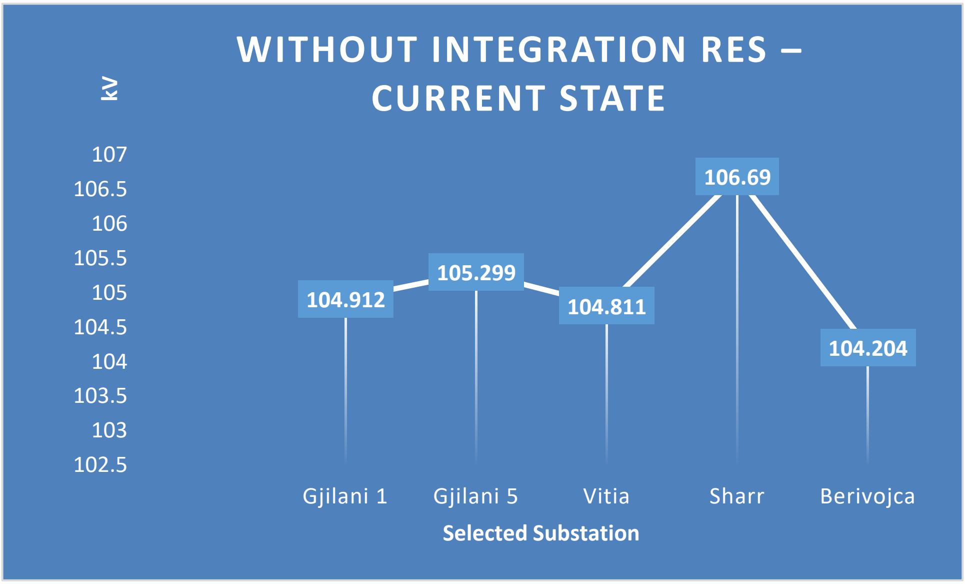

Figure 3. Voltage profiles in selected bus bars before connecting the wind turbines and PV systems.

Case 2: This case involves conducting simulations with wind turbines integrated into the system. This simulation aims to assess the impact of integrating wind turbines on the electrical grid at the selected point substation Gjilani 5. Figure 4 presents the voltage profiles in selected nodes, allowing for a detailed analysis of the system's performance. The observation from the simulation reveals that the voltage quality is notably improved compared to the previous scenario depicted in Case 1. This improvement indicates the potential positive effects of integrating wind turbines on the overall voltage quality within the electrical system. Furthermore, the enhanced voltage quality suggests an improvement in the economic efficiency of the system, ultimately benefiting the quality of power distributed to consumers.

Case 3: Simulations are carried out with the integration of photovoltaic (PV) systems into the existing electrical system. This simulation is intended to examine the impact of incorporating PV systems on the voltage profiles within the system. Figure 5 provides a visual representation of the voltage profiles in selected nodes, offering insights into the performance of the system following the integration of PV systems. The observation from the simulation indicates a notable improvement in voltage quality compared to the initial scenario outlined in Case 1. This improvement suggests that the integration of PV systems has the potential to enhance the overall voltage stability and quality within the electrical network. Additionally, the enhanced voltage quality may lead to improved economic efficiency, ultimately contributing to the delivery of higher-quality power to consumers.

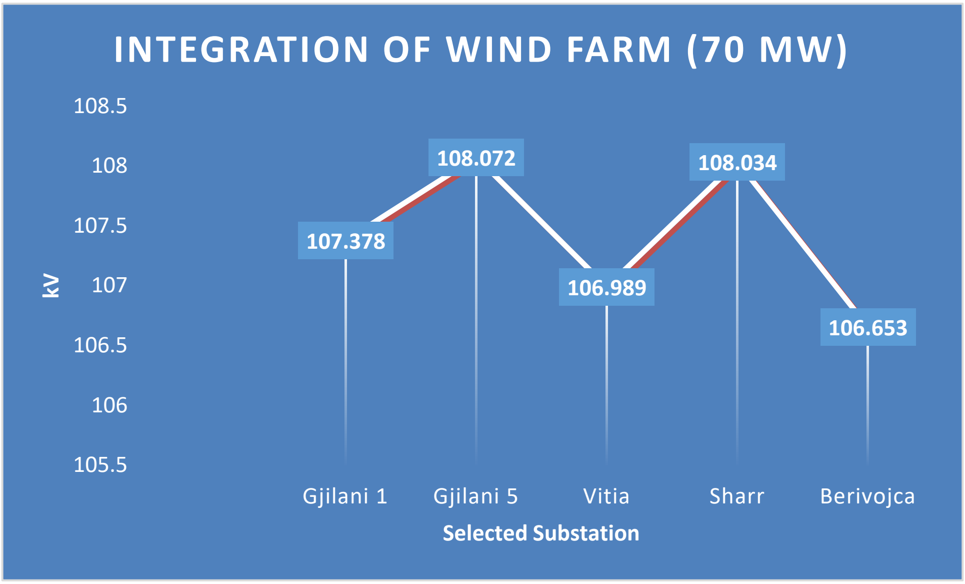

Figure 4. Voltage profiles in selected bus bars with the connection of wind turbines in the grid.

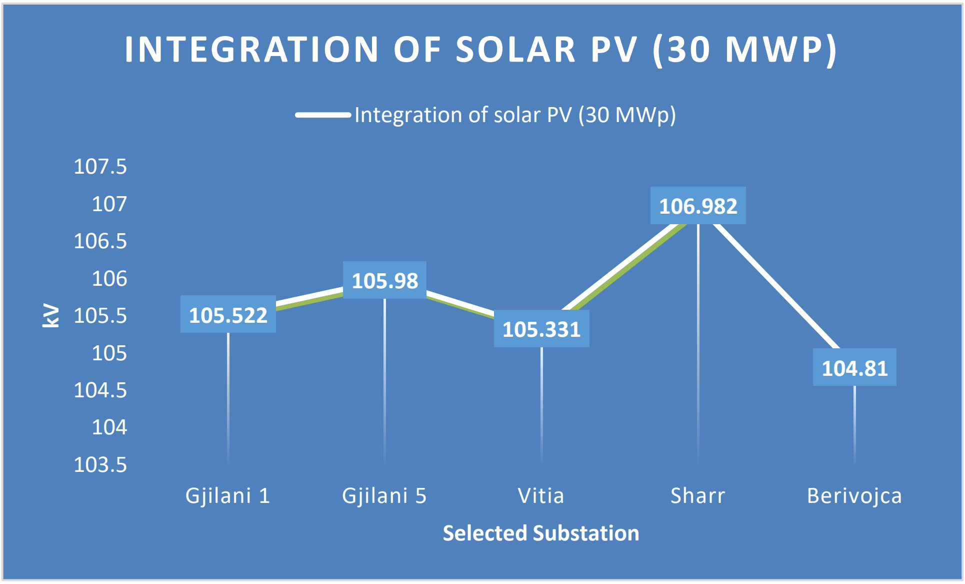

Figure 5. Voltage profiles in selected bus bars with the connection of photovoltaics (PVs) in the systems.

Case 4: The simulations involve the integration of both wind turbines and photovoltaic (PV) systems into the existing electrical infrastructure. This comprehensive simulation aims to assess the combined impact of integrating both RES on the voltage profiles within the system. Figure 6 provides a visual representation of the voltage profiles in selected nodes, offering a detailed view of the system's performance following the integration of wind turbines and PV systems.

The observation from the simulation reveals a significant improvement in voltage quality compared to the previous scenarios outlined in hypotheses 2 and 3. This improvement indicates that the simultaneous integration of wind turbines and PV systems has a synergistic effect, leading to enhanced voltage stability and quality within the electrical network. The improved voltage quality is expected to contribute and improve economic efficiency, and deliver higher-quality power to consumers, highlighting the potential benefits of leveraging multiple RES within the electrical grid.

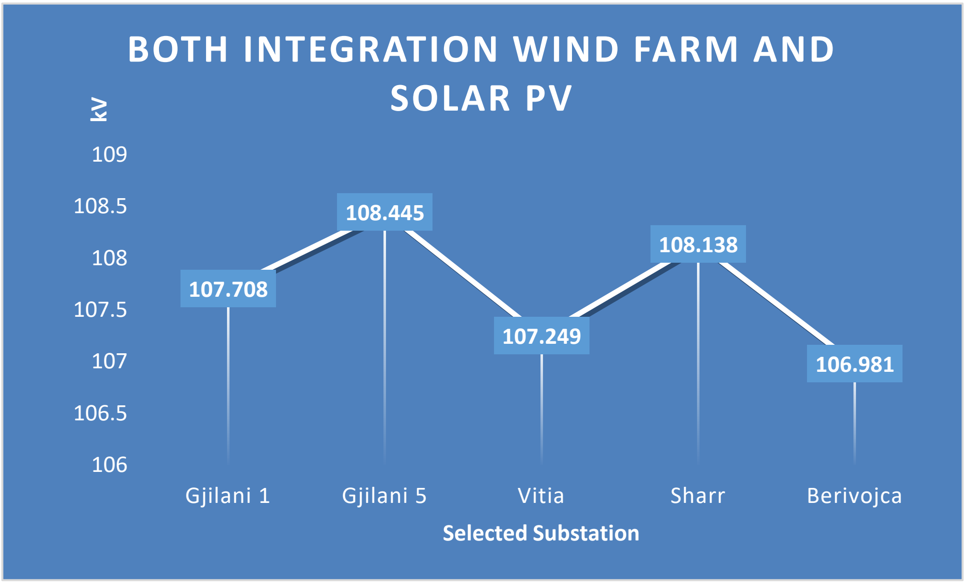

Figure 6. Voltage profiles in selected bus bars with the connection of wind turbines and photovoltaics (PVs) in the systems.

Figure 7 presents a comparison of bus bar voltages before and after connecting the wind power plant and the solar panel power plant to the 110 kV transmission line. This line supplies power to the 110/10 kV substation, Gjilani 5, from the 400/110 kV substation, Ferizaji 2. The simulation results, depicted in the diagrams, reveal a 2.1% improvement in voltage profiles at the key point of the wind turbines and PV systems, and an approximate 1.5% improvement at other selected points.

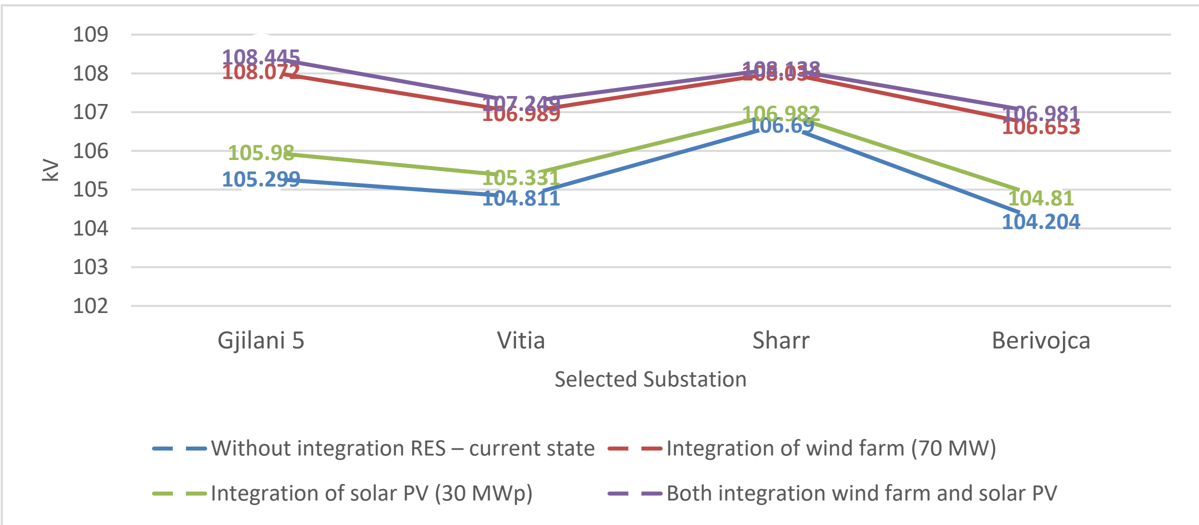

Figure 7. Voltage profiles at the bus bars of selected substations before and after switching on the wind turbine and PV system.

odel 2: In this model, simulations are conducted through the observation that this area and the overall power system of Kosovo are equivalent to two swing bus energy networks: Prishtina 4 (220/110 kV) and Ferizaj 2 (400/110 kV), acting as robust balancing bars for active and reactive power as shown in Figure 8.

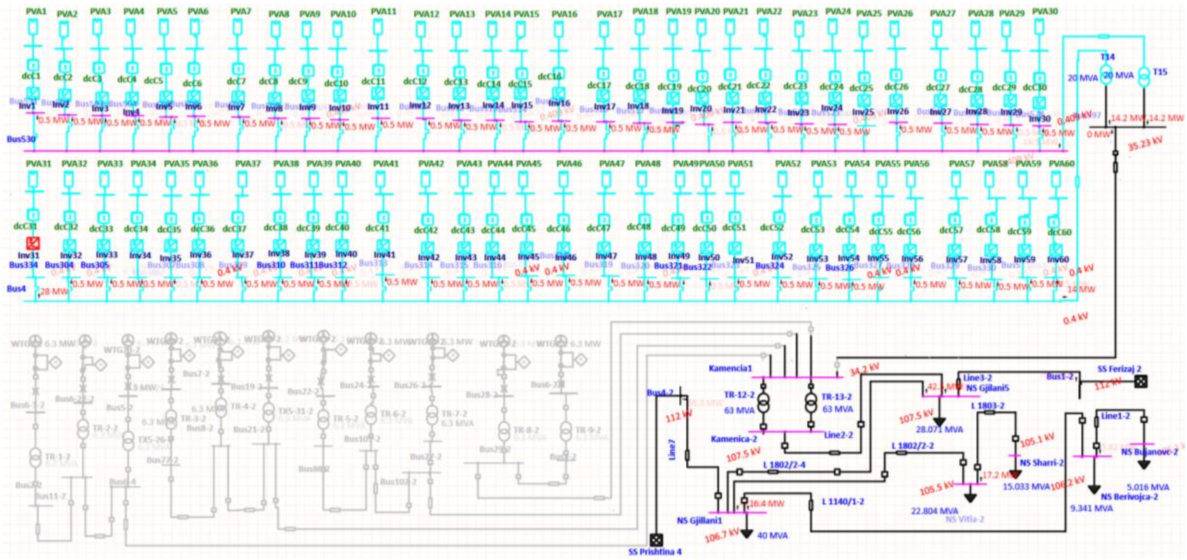

Figure 8. Single line diagram of Model 2 for the power system of Kosovo.

Figure 9 illustrates the simulations that have been summarized for the four cases, as outlined in Model 1. Additionally, it presents a detailed comparison of the voltage levels at the bus bars of the selected substations within the specific area where the impact of connecting these energy sources, such as wind turbines and PV photovoltaic systems, is notably significant.

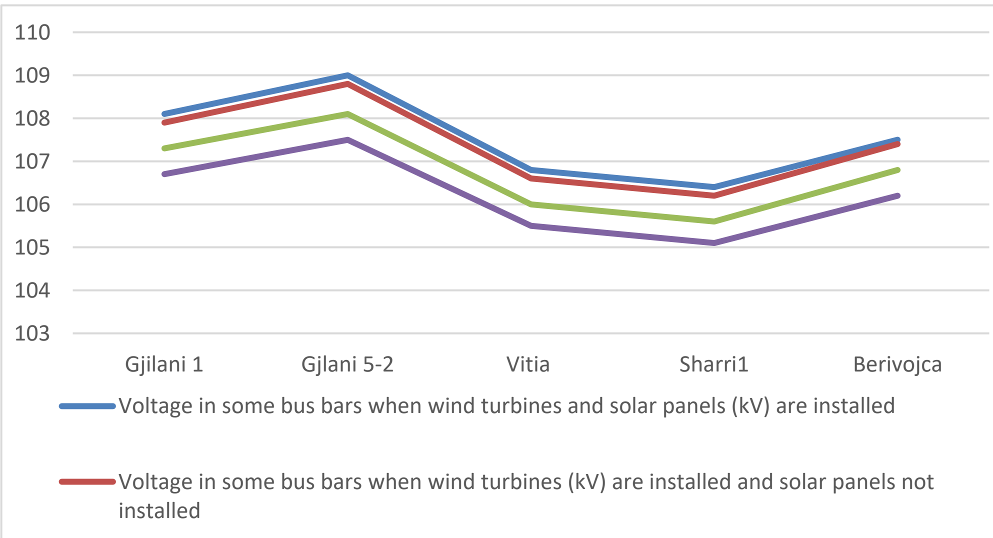

Figure 9. Comparison of wind turbines and PV systems (cases when RES are connected and not connected).

After comparing the results for both models, it is evident that the results are completely identical, but the conclusion drawn is that with the integration of renewable sources in the respective area, there will be significant improvements in voltage levels and, consequently, an increase in the quality of energy for consumers in the area.

The analysis of losses has been conducted by comparing the total losses in the system, as illustrated in Table 1 and Figure 10.

Table 1. Technical losses.

Cases / Losses	Without integration RES—current state	Integration of wind farm (70 MW)	Integration of solar PV (30 MWp)	Integration of both wind farm and solar PV
Losses (MW)	32.079	29.94	30.862	30.113
Losses (MVar)	76.795	66.325	70.962	66.433

Figure 10 illustrates the positive impact on the level of technical losses resulting from the integration of RES, showing a 1.6% decrease in technical losses in the connected area. One contributing factor to this reduction is the influence of distributed resources and the enhancement of voltage levels in the integrated RES area.

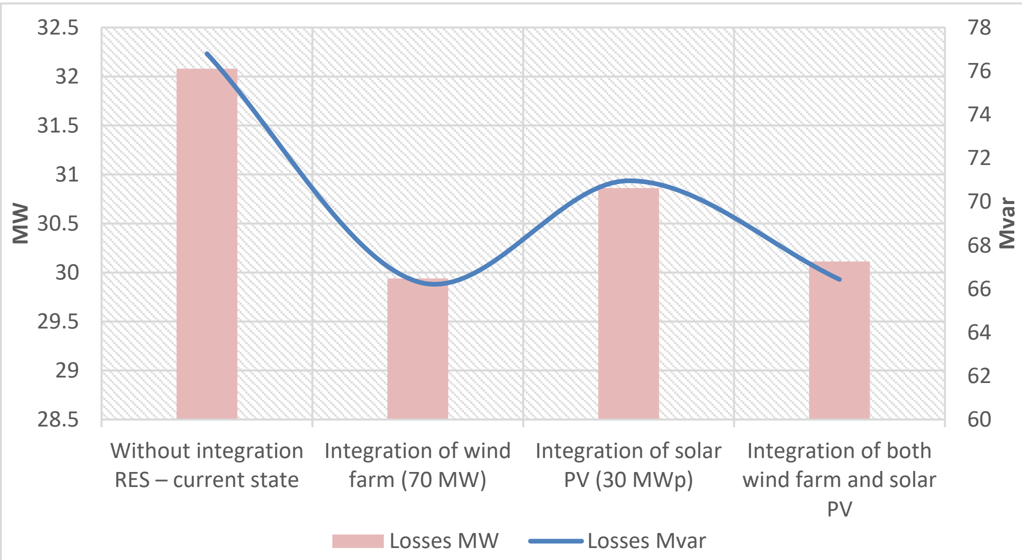

Figure 10. Visual analysis of technical loss differences.

Both the estimation of voltage levels and the analysis of technical losses in the model are essential steps that must be taken before any positive conclusion can be reached. By performing this comparison, valuable insights are gained regarding the impact of RES integration into the electricity grid within that region. This comprehensive analysis sheds light on the potential benefits and challenges associated with the implementation of renewable energy technologies, providing a deeper understanding of the overall effects on electrical infrastructure in the area. Kosovo's energy system, known for its concentrated generation resources in one place, experiences improved voltage profiles and reduction of technical losses by integrating resources in peripheral areas of the country.

The study also examined the impact of integrating renewable energy sources, such as wind and solar, into the medium- and long-term plans at the Gjilan 5 substation on the low-voltage side. As shown in Figure 11, the integration of renewable energy sources has a positive impact, increasing voltage by 1%

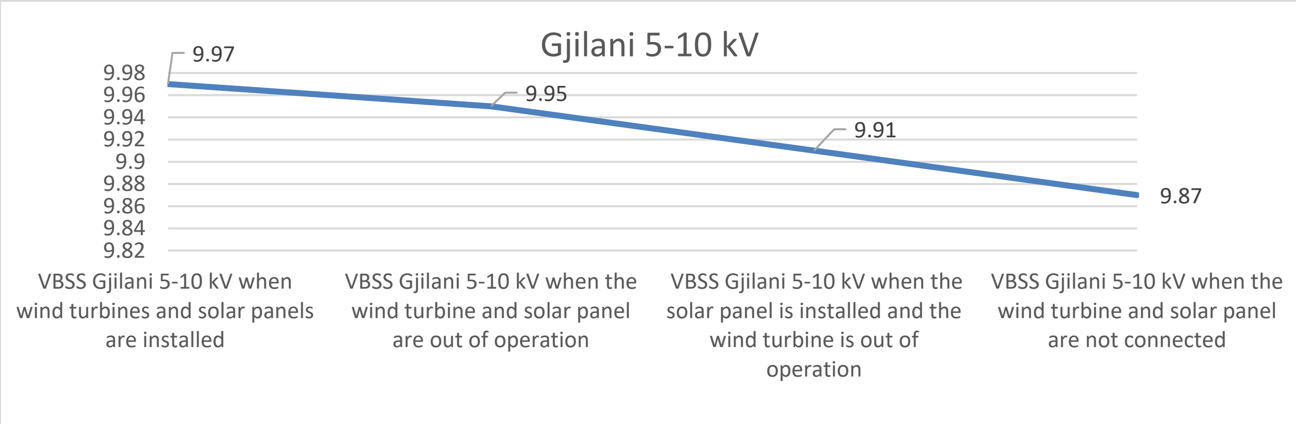

Figure 11. Impact of connecting the DG on the low side.

6. Discussion

Researchers have conducted a comprehensive review of PV solar systems, detailing their principles, components, and classifications. The review examines three generations of PV technology: the first generation, characterized by high efficiency and cost; the second generation, noted for lower efficiency and cost, and increased flexibility; and the third generation, which boasts high efficiency and low cost but is not yet commercially viable. The review demonstrates the critical role of PV systems in reducing fossil fuel consumption and CO_2 emissions while enhancing solar energy utilization. Monocrystalline and polycrystalline silicon cells are prevalent in residential and industrial applications, thin-film PV cells are suitable for large-scale industrial use, and CPV cells are suitable for high-power applications. Additionally, dye-sensitized and organic solar cells are considered appropriate for household applications [40–42].

However, solar panels are subjected to external environmental conditions such as sunlight, humidity, and temperature fluctuations, which induce chemical interactions between construction materials and these factors. These interactions lead to degradation and a reduced lifespan of the panels. Therefore, selecting appropriate materials and chemicals is essential to enhance their longevity. Similarly, wind turbines are exposed to atmospheric conditions that cause corrosion and material degradation. Therefore, it is essential to use environmentally friendly materials that protect the structural components. Composite materials are notable for their high surface area, reusability, and adsorption capacity.

The exponential growth in the use of solar photovoltaic panels over the last decade lacks relevant end-of-life management legislation. Organizations such as the International Renewable Energy Agency emphasize the need for strong policies like product stewardship or extended producer responsibility to prevent significant waste. Consequently, designs have been proposed for legislation addressing these concerns, covering new and existing panels, second-hand markets, and levies to support recycling industries. Effective end-of-life laws for solar PV panels can facilitate material circulation and mitigate waste-related environmental damage [43].

Recent research on the integration of renewable energy and DGs emphasizes the challenges and solutions for improving energy quality. Key challenges include voltage fluctuations, reverse power flow, and the need for significant grid reinforcement [4]. Solutions involve advanced grid planning, optimal capacity selection, and the integration of technologies such as solar PV, biomass, and wind energy. This trend is driven by global climate concerns, technological advances, and regulatory issues [44].

This comprehensive review covers the technical, economic, and regulatory challenges of integrating renewable energy sources into existing power grids, focusing on DGs and their impact on energy quality [5].

Several recent studies have examined methods to address the variability of wind and solar resources in renewable energy systems. Key approaches include the use of storage and curtailment to enhance resource utilization, and hybrid generation systems that combine dispatchable renewable resources like hydropower and bioenergy [45,46]. Research highlights the potential benefits of wind-solar complementarity, which varies significantly based on local conditions. For instance, hybrid PV-wind systems have shown advantages in reducing grid connection capacity requirements by up to 30%, while maintaining low curtailment losses and minimal shading impacts from wind turbines on PV modules [47]. The current review article reports on smart grids and the various key factors that need to be addressed during their integration with renewable energy sources [12]. The research highlights the challenges of integrating renewable energy sources into the grid, particularly focusing on the intermittent nature of wind energy and its effects on power quality. The study aims to enhance electricity quality amidst grid voltage fluctuations [48].

Worldwide challenges for the integration of renewable energy with DG examines global issues and solutions related to integrating renewable energy and DGs, with a focus on enhancing power quality. The study presents comprehensive, current solutions involving new technologies, policies, and network management strategies. Utilizing an interdisciplinary approach, these solutions aim to improve energy reliability, stability, and efficiency across various regions and energy systems.

The present study introduces a novel approach to internal integrations within the electricity system, contingent upon fossil resources. In an era marked by escalating complexity in energy supply challenges, this approach presents an avenue for enhancing power quality for local consumers and mitigating losses across all voltage levels. Additionally, it strives to address environmental concerns in an effective and efficient manner.

7. Conclusions

The study has conducted an analysis of the impact of integrating renewable energy sources (RES) into the electricity network in Kosovo, focusing on a specific area with low voltage levels. The results have demonstrated significant improvements in voltage quality, stability, and reduction in losses following the integration of these renewable energy sources. In particular, the simulations showed that the integration of wind turbines led to a significant improvement in voltage quality compared to the baseline scenario, indicating possible positive effects on the overall performance of the power system. Similarly, integrating PV systems has resulted in a significant improvement in voltage quality, indicating increased voltage stability and efficiency within the electrical grid. Moreover, simulations involving both wind turbines and solar PV systems have demonstrated a synergistic effect, further enhancing voltage quality and stability within the system.

The study findings showed that integrated wind turbines and PV systems contributed to a 2.1% improvement in voltage profiles at key points and approximately a 1.5% improvement at other selected points along the 110 kV transmission line and a reduction in losses by 1.6%. These improvements imply potential benefits from the utilization of multiple renewable energy sources within the electrical system, emphasizing the positive impact on economic efficiency and the provision of higher quality energy to consumers. Overall, the results of the study highlight the potential of integrating wind and solar systems to enhance voltage quality, stability, and economic efficiency within the electrical grid, ultimately leading to improved power quality at the distribution level for consumers in the area.

Furthermore, the study emphasizes the pivotal role of distributed renewable energy sources in enhancing the resilience and sustainability of Kosovo's electricity network, particularly in areas with low voltage levels. The observed improvements in voltage stability and efficiency suggest promising prospects for scaling up renewable energy integration initiatives across the region. These findings offer valuable insights for policymakers and energy stakeholders seeking to optimize the performance and reliability of the electrical grid while advancing toward a greener and more resilient energy future.

In our forthcoming research, we intend to explore the presence of hazardous components and the safety protocols to be implemented throughout the investigative process. We recognize the critical importance of ensuring the absence of hazardous elements and are dedicated to investigating this aspect in future studies to contribute to a comprehensive understanding.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Author contributions

Conceptualization, Arben Gjukaj; methodology, Arben Gjukaj and Rexhep Shaqiri; validation, Qamil Kabashi and Vezir Rexhepi; formal analysis, Arben Gjukaj, Qamil Kabashi and Vezir Rexhepi; writing-original draft preparation, Arben Gjukaj; writing-review and editing, Arben Gjukaj and Rexhep Shaqiri; supervision, Qamil Kabashi. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflicts of interest.

References

1. Islam A, Teo SH, Ng CH, et al. (2023) Progress in recent sustainable materials for greenhouse gas (NOx and SOx) emission mitigation. *Prog Mater Sci* 132: 101033. https://doi.org/10.1016/j.pmatsci.2022.101033
2. Teo SH, Islam A, Taufiq-Yap YH, et al. (2021) Introducing the novel composite photocatalysts to boost the performance of hydrogen (H_2) production. *J Cleaner Prod*, 313. https://doi.org/10.1016/j.jclepro.2021.127909
3. IEA (International Energy Agency 2021), Renewables 2021, IEA, Paris. Available from: https://www.iea.org/reports/renewables-2021, License: CC BY 4.0.
4. Iweh CD, Gyamfi S, Tanyi E, et al. (2021) Distributed generation and renewable energy integration into the grid: Prerequisites, push factors, practical options, issues and merits. *Energies* 14: 5375. https://doi.org/10.3390/en14175375
5. Nadeem TB, Siddiqui M, Khalid M, et al. (2023) Distributed energy systems: A review of classification, technologies, applications, and policies. *Energy Strategy Rev* 48: 101096. https://doi.org/10.1016/j.esr.2023.101096
6. Patnaik S, Nayak MR, Viswavandya M (2022) Smart deployment of energy storage and renewable energy sources for improving distribution system efficacy. *AIMS Electron Electr Eng* 6: 397–417. https://doi.org/10.3934/electreng.2022024
7. Chen YT, Knüpfer K, Esteban M, et al. (2023) Analysis of the impact of offshore wind power on the Japanese energy grid. *AIMS Energy* 11: 110–134. https://doi.org/10.3934/energy.2023006
8. Ramos A, Magalhães F, Neves D, et al. (2023) Wind energy sustainability in Europe—A review of knowledge gaps, opportunities and circular strategies. *Green Finance* 5: 562–602. https://doi.org/10.3934/GF.2023022
9. Solomon AA, Child M, Caldera U, et al. (2020) Exploiting wind-solar resource complementarity to reduce energy storage need. *AIMS Energy* 8: 749–770. https://doi.org/10.3934/energy.2020.5.749
10. Slusarewicz JH, Cohan DS (2018) Assessing solar and wind complementarity in Texas. *Renewables*, 5. https://doi.org/10.1186/s40807-018-0054-3
11. Solomon AA, Kammen DM, Callaway D (2016) Investigating the impact of wind-solar complementarities on energy storage requirement and the corresponding supply reliability criteria. *Appl Energy* 168: 130–145. https://doi.org/10.1016/j.apenergy.2016.01.070
12. Kataray T, Nitesh B, Yarram B, et al. (2023) Integration of smart grid with renewable energy sources: Opportunities and challenges—A comprehensive review. *Sustainable Energy Technol Assess* 58: 103363. https://doi.org/10.1016/j.seta.2023.103363
13. Qaisi ZA, Alsafasfeh Q, Harb A (2018) Stability impact of integrated small scale hybrid (PV/Wind) system with electric distribution network. *AIMS Energy* 6: 832–845. https://doi.org/10.3934/energy.2018.5.832
14. Ludwig D, Breyer C, Solomon AA, et al. (2020) Evaluation of an onsite integrated hybrid PV-Wind power plant. *AIMS Energy* 8: 988–1006. https://doi.org/10.3934/energy.2020.5.988
15. Solomon AA (2019) Large scale photovoltaics and the future energy system requirement. *AIMS Energy* 7: 600–618. https://doi.org/10.3934/energy.2019.5.600
16. Herez A, Jaber H, Hage HE, et al. (2023) A review on the classifications and applications of solar photovoltaic technology. *AIMS Energy* 11: 1102–1130. https://doi.org/10.3934/energy.2023051

17. Georgilakis PS, Hatziargyriou ND (2013) Optimal distributed generation placement in power distribution networks: Models, methods, and future research. *IEEE Trans Power Syst* 28: 3420–3428. https://doi.org/10.1109/tpwrs.2012.2237043
18. Annual Report 2022—ERO (Energy Regulatory Office), (2023). Available from: https://www.ero-ks.org/zrre/en/publikimet/raportet-vjetore.
19. Reddy GH, Chakrapani P, Goswami AK, et al. (2017) Optimal distributed generation placement in distribution system to improve reliability and critical loads pick up after natural disasters. *Eng Sci Technol*, *Int J* 20: 825–832. https://doi.org/10.1016/j.jestch.2017.05.001
20. Razavi SE, Rahimi E, Javadi MS, et al. (2019) Impact of distributed generation on protection and voltage regulation of distribution systems: A review. *Renewable Sustainable Energy Rev* 105: 157–167. https://doi.org/10.1016/j.rser.2019.01.050
21. Vita V, Alimardan T, Ekonomou L (2015) The impact of distributed generation in the distribution networks' voltage profile and energy losses. *2015 IEEE European Modelling Symposium (EMS)* Madrid, Spain, 260–265, https://doi.org/10.1109/EMS.2015.46
22. Leccisi E, Raugei M, Fthenakis V (2018) The energy performance of potential scenarios with large-scale PV deployment in Chile—A dynamic analysis. *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*, Waikoloa, HI, USA, 2441–2446. https://doi.org/10.1109/PVSC.2018.8547293
23. Rasool MH, Taylan O, Perwez U, et al. (2023) Comparative assessment of multi-objective optimization of hybrid energy storage system considering grid balancing. *Renewable Energy* 216: 119107. https://doi.org/10.1016/j.renene.2023.119107
24. Malik F, Khan M, Rahman T, et al. (2024) A comprehensive review on voltage stability in wind-integrated power systems. *Energies* 17: 644. https://doi.org/10.3390/en17030644
25. Javadi M, Liang X, Gong Y, et al. (2022) Battery energy storage technology in renewable energy integration: A review. 2*022 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, Halifax, NS, Canada, 435–440. https://doi.org/10.1109/CCECE49351.2022.9918504
26. ETAP—Electrical Power System Analysis & Operation Software(Demo version). Available from: https://etap.com.
27. Sereeter B, Vuik C, Witteveen C (2019) On a comparison of Newton—Raphson solvers for power flow problems. *J Comput Appl Math* 360: 157–169. https://doi.org/10.1016/j.cam.2019.04.007
28. Ezhiljenekkha GB, MarsalineBeno M (2020) Review of power quality issues in solar and wind energy *Mater Today: Proc* 24: 2137–2143. https://doi.org/10.1016/j.matpr.2020.03.670
29. Mahela OP, Khan B, Alhelou H, et al. (2020) Assessment of power quality in the utility grid integrated with wind energy generation. *IET Power Electron* 13: 2917–2925. https://doi.org/10.1049/iet-pel.2019.1351
30. Liang X (2016) Emerging power quality challenges due to integration of renewable energy sources. *IEEE Trans Ind Appl* 53: 855–866. https://doi.org/10.1109/TIA.2016.2626253
31. Razmi D, Lu T, Papari B, et al. (2023) An overview on power quality issues and control strategies for distribution networks with the presence of distributed generation resources. *IEEE Access* 11: 10308–10325. https://doi.org/10.1109/ACCESS.2023.3238685
32. Naderi Y, Hosseini SH, Zadeh SG, et al. (2018) An overview of power quality enhancement techniques applied to distributed generation in electrical distribution networks. *Renewable Sustainable Energy Rev* 93: 201–214. https://doi.org/10.1016/j.rser.2018.05.013

33. Toumi T, Allali A, Abdelkhalek O, et al. (2021) Voltage quality improvement in electrical distribution networks using dynamic voltage restorers: design, simulation and experimental tests of a robust controller. *Electr Eng* 103: 1661–1678. https://doi.org/10.1007/s00202-020-01158-5
34. Wang B, Sun Y, Lu F, et al. (2015) The calculation and analysis of distribution network loss with photovoltaic power generation connected. *Proceedings of the 3rd International Conference on Advances in Energy and Environmental Science 2015*. https://doi.org/10.2991/icaees-15.2015.100
35. Hemdan NGA, Kurrat M (2008) Distributed generation location and capacity effect on voltage stability of distribution networks. *2008 Annual IEEE Student Paper Conference, AISPC*, 1–5. https://doi.org/10.1109/AISPC.2008.4460571
36. Bründlinger R (2019) Grid Codes in Europe—Overview on the current requirements in European codes and national interconnection standards. Available from: https://www.researchgate.net/publication/338800967_Grid_Codes_in_Europe__Overview_on_the_current_requirements_in_European_codes_and_national_interconnection_standards.
37. Yuan W, Yuan X, Xu L, et al. (2023) Harmonic loss analysis of low-voltage distribution network integrated with distributed photovoltaic. *Sustainability* 15: 4334. https://doi.org/10.3390/su15054334
38. Ranjbar A, Vig S, Sharma K (2022) Performance analysis of grid connected distributed generation sources (DGS) using ETAP. *Cognit Inf Soft Comput*, 105–114. https://doi.org/10.1007/978-981-16-8763-1_10
39. Prasad A, Singh O (2022) Analysis of software tools used for load-flow studies. *4th International Conference on Advances in Computing, Communication Control and Networking (ICAC3N)*, Greater Noida, India, 2400–2405. https://doi.org/10.1109/ICAC3N56670.2022.10074587
40. Herez A, Jaber H, Hage HE, et al. (2023) A review on the classifications and applications of solar photovoltaic technology. *AIMS Energy* 11: 1102–1130. https://doi.org/10.3934/energy.2023051
41. Hossain MS, Shenashen MA, Awual ME, et al. (2024) Benign separation, adsorption, and recovery of rare-earth Yb(III) ions with specific ligand-based composite adsorbent. *Process Saf Environ Prot* 185: 367–374. https://doi.org/10.1016/j.psep.2024.03.026
42. Xiao H, Lai W, Chen A, et al. (2024) Application of photovoltaic and solar thermal technologies in buildings: A mini-review. *Coatings* 14: 257. https://doi.org/10.3390/coatings14030257
43. Majewski P, Deng R, Dias PR, et al. (2023) Product stewardship considerations for solar photovoltaic panels. *AIMS Energy* 11: 140–155. https://doi.org/10.3934/energy.2023008
44. Hassan Q, Hsu CY, MOUNICH K, et al. (2024) Enhancing smart grid integrated renewable distributed generation capacities: Implications for sustainable energy transformation. *Sustainable Energy Technol Assess* 66: 103793. https://doi.org/10.1016/j.seta.2024.103793
45. Rasool MH, Taylan O, Perwez U, et al. (2023) Comparative assessment of multi-objective optimization of hybrid energy storage system considering grid balancing. *Renewable Energy* 216: 119107. https://doi.org/10.1016/j.renene.2023.119107
46. Li J, Shi L, Fu H (2024) Multi-objective short-term optimal dispatching of cascade hydro-wind-solar-thermal hybrid generation system with pumped storage hydropower. *Energies* 17: 98. https://doi.org/10.3390/en17010098

47. Leccisi E, Raugei M, Fthenakis V (2018) The energy performance of potential scenarios with large-scale PV deployment in Chile—a dynamic analysis. *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*, Waikoloa, HI, USA, 2441–2446, https://doi.org/10.1109/PVSC.2018.8547293
48. Singh P, Arora K, Rathore UC, et al. (2024) Comparative study of controllers in battery energy storage system integrated with doubly fed induction generator-based wind energy conversion system for power quality improvement. *Energy Rep* 11: 4587–4600. https://doi.org/10.1016/j.egyr.2024.04.020