

## Investigating Safe and Economic Adjustment of Power Balance in Smart Grids Based on Integration of Renewable Energy

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### Abstract

The present pace of integration of renewable sources into the electrical grid is insufficient, failing to fulfill the expectations of producers or coincide with sustainable national objectives. Furthermore, sustainable national policies are not being executed. Despite the growth of the solar and wind energy industry and the installation of decentralized energy production systems, this scenario has emerged. Several factors contribute to this scenario, including advancements in administration, forecasting, and oversight, along with enhancements in infrastructure. These issues may arise notwithstanding the decentralized nature of renewable energy sources. The integration rate of renewable energy sources into networks, along with the efficiency of these networks, is clearly hindered as a result of this. Furthermore, we will examine the problems associated with the implementation of this network. We will focus on the low injection rate and the balance between supply and demand. Subsequently, we will examine the impact they have on the operation of the interconnected system. We will provide management solutions tailored to each detected issue, along with the suggested cures for any recognized concerns. The aim is to discover the structures, procedures, and tools that will enhance the network's reliability and energy efficiency while simultaneously reducing installation costs and fortifying the network. The findings indicate that the interruptions in voltage, frequency, and power have been mitigated due to the dynamic simulations using the proposed method. The calculations were predicated on an integration of solar and wind energy, with twenty percent of the energy derived from wind.

**Keywords:** Solar energy, Wind energy, Voltage fluctuations, Power variations, Frequency variations, Renewable energy and Smart Grid.

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### 1. Introduction

Incorporating renewable energy sources into transmission networks, such as solar and wind power, is becoming an increasingly frequent practice. The output of renewable energy sources is prone to fluctuate depending on the weather and the time of day. Renewable energy sources have a propensity to be intermittent, and their production is subject to fluctuation. As a consequence of

this, the inclusion of renewable energy sources into power networks may result in substantial issues to the system's capacity to retain its stability [1-3]. As a direct consequence of these problems, which ultimately resulted in the development of intelligent power networks, they have only lately been placed into business. Smart grids (SG) are able to complete the functions of monitoring, managing, and optimizing the functioning of the electrical network [4,5]. This is made possible by the use of

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information and communication technologies among these smart grids. This event has resulted in the development of a method that allows for the incorporation of renewable energy sources into smart networks [6-10]. At the current moment, a number of countries all over the world have committed to achieving ambitious objectives for the adoption of smart grids and renewable energy sources.

The objective of this study is to develop strategies and frameworks for the development of smart grids that include renewable energy sources. By establishing a connection between the grid and a network of intelligent sensors, this objective will be successfully accomplished. This is something that you need to do if you want to get the results that you want. Additionally, by combining new algorithms and software, we may be able to enhance the prediction of storage as well as the computation of consumption patterns by making use of data obtained from a variety of sources. Due to the fact that we are able to make effective use of the data, this will be within our capabilities. This technology, which was ingeniously devised to compensate for the unpredictability of renewable power output, contributes to the expanding body of data that supports the supply and storage of sustainable energy. Because of this, the absorption of renewable energy sources is simpler, and as a consequence, it becomes more predictable [11-13]. Our investigation will primarily focus on the electrical and energy performance of smart grid networks so that we may better understand their capabilities. Additionally, we will investigate what can be done to increase the percentage of decentralized energy production stations that are connected to the network. The issues of linking solar power producing equipment and other renewable energy conversion systems will also be investigated, and we will look at how smart grid approaches and tools may be used to overcome these challenges. The total effectiveness of the network is going to be improved according to this plan.

## 1.1. Contribution

By solving the fundamental difficulty of preserving power balance while simultaneously integrating renewable energy sources, this study significantly contributes to the evolution of smart grid technology.

In this study, the techniques for correcting power balance in real time are presented. These strategies ensure that the system remains stable even when there are changes in the output of renewable energy. Optimization of energy storage and demand response programs are two examples of the cost-effective solutions that are being investigated in this research project for power balancing. This line of study makes it easier to incorporate higher quantities of renewable energy into the grid by creating efficient strategies for adjusting the power balance.

## 1.2. The Renewable Energy Sources: Integration to Smart Grids

Fossil fuels are becoming costlier due to the greenhouse impact and rising energy prices; renewable resources are better for the environment and more efficient. Nonetheless, fossil fuels outperform renewable alternatives in terms of efficiency and environmental friendliness. If we want to control energy use and reduce emissions of greenhouse gases, the best solution is to utilize solar power. This technology is not only the best solution to the problem at hand, but it is also a giant leap forward in the quest to generate renewable energy. Technologies that produce energy from renewable sources, such as wind, solar, hydropower, and biomass, are among the most impressive [14-16]. Concerning the energy supply in the future, there are many aspects to consider. Variables such as distributed generation, distributed energy storage, and demand-side load control are instances of this. If these three things are considered, the use of these kinds of technological advancements and inventions might increase. Distributed generation (DG) is a method of generating power that involves connecting many energy sources to the grid. Many different kinds of resources exist, and they can all provide the data that is required to meet this demand [17, 18]. One example of a source that fits this description is a combined or hybrid power plant, which produces electricity on both the national and regional levels.

The needs of the smart grid deployment can only be met by producing power at the regional level via the use of renewable energy sources [19]. Complex arrangements and operations based on the notion of to-be-implemented technologies are required for the management of renewable energy sources [20]. Improvements in the grid's flexibility, dependability, and intelligence are necessary if it is to fulfill the demands of a large-scale distributed renewable producing system [21]. In addition, the concept of energy storage serves as the fundamental basis upon which the smart grid constructs its foundation. The use of this strategy provides aid in the generation of energy that is in accordance with environmental standards [22]. On display in Figure 12 is a comprehensive illustration of the system that is responsible for the integration and storage of renewable energy. The share of renewable energy sources that contribute to the chain of supply of electricity is expected to continue to increase, which will ultimately result in an increased need for energy storage [23]. When a substantial amount of electrical power storage is used, not only is it challenging, but it also has the potential to result in losses for the system. Since the deployment of distributed energy system (DES) has the ability to partly alleviate the problems connected with the energy backup demands of the smart grid, there is a chance that it may be a solution. This is because DES has the capacity to offset these downsides. Two further benefits that may be obtained from the installation of DES in a smart grid are

the improvement of load management (LM) via the adoption of a small-scale backup plan [24] and the enhancement of generating performance through the use of support for peak demand [25, 26]. Both of these benefits are possible outcomes of the deployment of DES. In order to efficiently manage the process of fulfilling the demand for energy at peak times, the use of the local backup of energy is implemented. This is done for the aim of achieving greater efficiency. For the purpose of regulating peak demand, techniques that are both efficient and bright will be used. This will result in the grid becoming more trustworthy and intelligent, in addition to performing better [27]. Therefore, the use of a hybrid system for the generation of electricity will be the result in order to accomplish the goal of achieving a more balanced and controlled administration of the grid. Because the hybrid power producing technology is able to give the service, there are no transmission losses [28]. This is because the power production is becoming closer and closer to the end user. When contrasted with the conventional way of doing things, hybrid generation that is combined with the smart grid approach offers a number of advantages. To begin, there is a relatively low cost concerned with the transmission and dissemination of the information. The cost of electric transmission to other areas accounts for around thirty percent of the entire cost when it comes to typical electricity distribution networks. At the same time as the domestic supply line does not need a substantial amount of cash for the initial setup, long-distance

transmission lines are responsible for a bigger amount of energy loss than the domestic supply line. Local connection connections do not incur significant construction expenditures, while long-distance distribution lines do not result in substantial energy losses. Neither of these factors contribute to the overall energy consumption of the system. In addition, the newly designed inventive devices have resulted in a reduction in the amount of energy that is used [29]. Second, distributed generation makes it feasible to incorporate locally produced renewable energy sources into power plants, which helps to reduce emissions of greenhouse gases [30]. This is a significant contribution to the reduction of greenhouse gas emissions. In order to reduce emissions and ensure that the level of energy supply is sufficient to fulfill the demand from end-users, the development of hybrid power generation that is connected to the smart grid is a significant step [31, 32].

On an open real-world load dataset, both with and without the calendar or weather information, a TCN-based load forecasting model that incorporates both outperforms three deep learning and four machine learning baselines [33]. A new forecasting model known as Prophet-LSTM has been developed, which blends the Prophet model's strong trend fitting capabilities with the LSTM model's strong prediction accuracy, leading to more precise and efficient peak load forecasting [34]. Table 1 presents a literature review for relevance of this research with existing research

Table 1. A literature review for relevance of this research with existing research

Author	Year	Title	Key Findings	Relevance to proposed work
S. Kakran et al. (2018) [37]	2018	Smart operations of smart grids integrated with distributed generation: A review	Discusses various technologies like smart meters, renewable energy integration, and demand response.	Provides a broad overview of smart grid technologies and their potential impact on power balance.
I.O. Ozioko, et al. (2022) [38]	2022	Wind energy penetration impact on active power flow in developing grids	Analyzes the challenges of integrating large-scale wind power into power systems, particularly grid stability issues.	Highlights the importance of effective power balance control in the context of renewable energy integration.
Wenhao Zhuo, (2019) [39]	2019	Control Strategies for Microgrids with Renewable Energy Generation and Battery Energy Storage Systems	Proposes control strategies for microgrids to ensure power balance and stability.	Provides insights into control techniques that can be applied to smart grid scenarios.
Moreno Escobar, et al. (2021) [40]	2021	A Comprehensive Review on Smart Grids: Challenges and Opportunities	Discusses the role of demand response in balancing power supply and demand in smart grids.	Highlights the potential of demand response to mitigate the variability of renewable energy sources.

## 2. The Architectural Design of a Smart Grid

The implementation of smart grids (SG) facilitates the effective integration of renewable energy sources into the existing power network. This enables more effective management of the intermittent characteristics of renewable energy sources. Moreover, SGs consist of a larger array of components.

Smart meters are electronic instruments capable of measuring real-time power consumption. Smart meters can interact with the energy network and continually monitor power use. Communication infrastructures are essential to enable bidirectional communication among the various components of the network. This applies to communication networks. Technologies that may be used including fiber optic networks, powerline communication systems, and wireless communication networks. These represent only a selection of the technologies that might be used [35, 36]. To significantly decrease power use during peak hours, a technique known as "demand management" is employed. Methods such as dynamic tariffs, systems for managing home energy use, and other similar strategies are among the several potential options that may be employed to attain this goal. The primary purpose of intelligent distribution networks is to improve the accuracy and efficiency of power delivery. This is attributable to regulatory and control processes. Figure 1 depicts a block design demonstrating the integration of renewable energy sources, such as solar and wind, with smart network infrastructures. A smart grid consists of a sophisticated and interconnected network. It incorporates many technologies to provide a more efficient and responsive management of electrical energy. The integration facilitates the amalgamation of diverse systems. The amalgamation of several disparate systems makes this capacity viable.

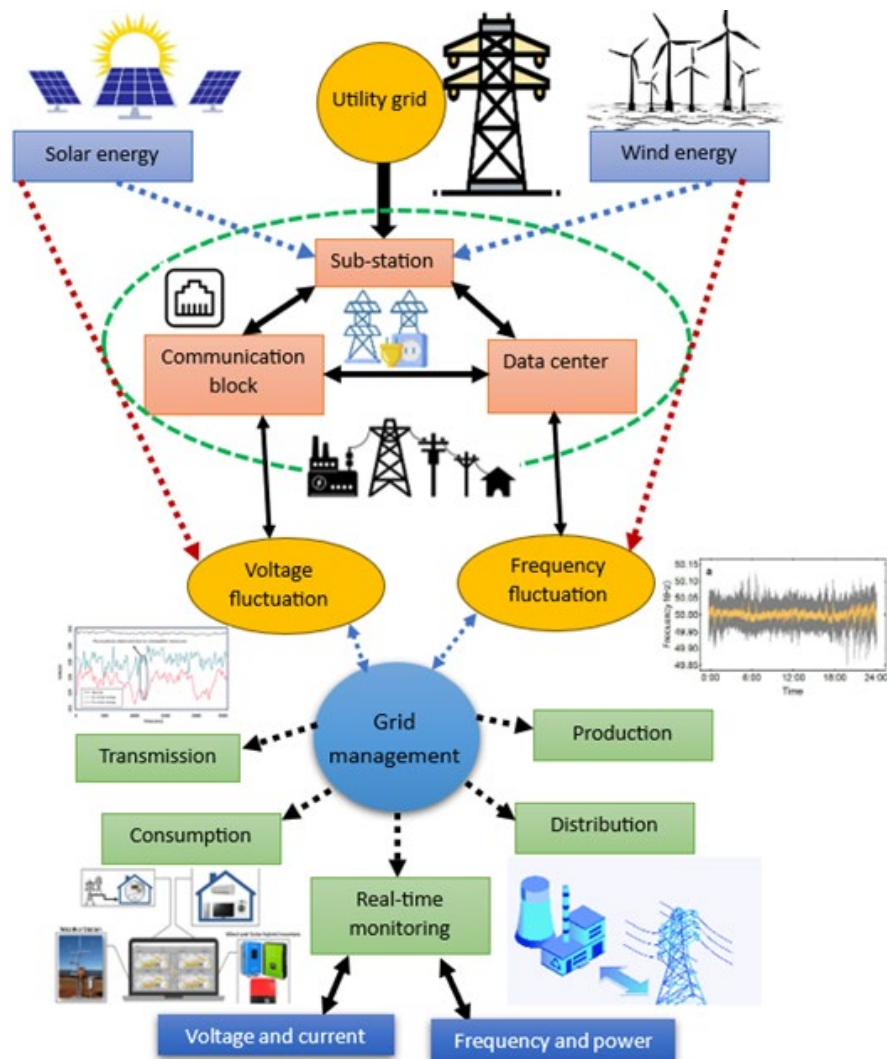
### 2.1. Obstacles Encountered: The Incorporation of Renewable Energy Sources Into SG

Also, there are a lot of challenges that come with using renewable energy sources in smart networks, and they aren't always easy to overcome. Some of the most serious problems that have arisen are listed below [8–10].

Another major challenge to effectively integrating renewable energy sources into smart networks is the capacity to store energy. More and more, smart networks are crucial. It is theoretically feasible to generate power from renewable sources during times of low demand; but this generated energy must be stored for use during times of higher demand. Be that as it may, there is a limit on the available storage capacity, and the price of energy storage devices remains exorbitant.

Costs related to improving the electrical network's technical capabilities: investing heavily in renewable energy sources for smart grid integration typically requires substantial financial outlays. Countries whose power grids are still under construction or whose power networks are still under establishment may not be able to afford these costs.

Making renewable energy self-sufficiency a reality, streamlining the market for renewable energy, and encouraging private investment in renewable energy all require overcoming several legislative obstacles. By conquering these challenges, it is possible to achieve these objectives. In order for smart networks to include renewable energy sources, it is often necessary to rearrange energy regulations. Reason being, energy's bright future lies in smart networks. Current restrictions may not be enough to make smart networks more attractive to those who want to use renewable energy.



**Figure 1.** Block diagram of integration of renewable resources (solar and wind) in smart grids

## 2.2. The Functioning of SG

Through the use of digital technologies that are capable of processing and disseminating the data that is received, it is possible to establish a smart grid by linking the different components of the electrical infrastructure [22, 23].

Interoperability between the many networks that comprise the electrical network; these networks include the transmission and distribution networks; this interoperability is what defines the electrical network as a whole. Both the regions that generate and consume energy are connected by one of these primary axes, while the other one travels over the whole of the nation. It is the beneficiaries who are responsible for making effective use of the authority. Through the facilitation of the instantaneous flow of data between the two sets of

administrators, smart grids make it possible to operate in an interoperable manner.

The foundation of smart grids is an information system that is capable of predicting future consumption and output levels. This is the basis upon which intelligent grids are constructed. Before the building of a smart grid can begin, this database must already be in existence. As an example, wind power is a renewable energy source that can be regulated more effectively than other forms of energy due to the fact that its operation is unpredictable and intermittent. This is due to the fact that the behavior of wind power is quite unpredictable.

### 2.3. Technical Challenges and Solutions

Renewable energy sources must be incorporated into smart networks by overcoming certain technological challenges. Wind and solar energy are by nature sporadic and erratic. This might lead to unexpected changes in energy output, which will complicate the maintenance of a steady power balance. Encouraging consumers to adjust their energy use based on grid conditions may thus aid in sustaining power balance.

The integration of substantial amounts of renewable energy may jeopardize grid stability, leading to frequency fluctuations and voltage variations. Real-time monitoring of grid conditions is advised to detect and address any potential stability issues. Power balancing in a grid with significant renewable energy integration may be an economically challenging task, especially when factoring in the costs of energy storage and equipment upgrades. Consequently, optimization techniques are provided to identify the most efficient and cost-effective power use approaches. Integrating smart grid technologies and renewable energy sources with existing power infrastructures may pose significant challenges. Consequently, investing in the enhancement of current infrastructure to accommodate technologies such as smart grids and renewable energy might provide cost benefits.

The proposed method is typically adaptable and may be used for power systems of different sizes, however the exact difficulties and costs can change depending on the size and complexity of the grid. With proper planning and attention to the aspects that influence scalability, power balance correction in smart grids of any scale may be accomplished in a safe and cost-effective manner.

### 3. The Methods Used

It is of the utmost importance to ascertain which structure provides the most advantages from both a technical and an economic point of view. As a digital tool, the MATLAB application will be used for the goal of simulating the quantities of energy and electrical current. Algorithm 1 is presented to model grid disturbances such as voltage fluctuations or frequency variations. This simulation is going to be carried out in line with the specific operational circumstances that are present. We introduce disturbances into the network, such as the injection of harmonics, frequency fluctuation, or short circuits, and then study the effect that these disturbances have on the system. Disturbances may be introduced into the network like this. We have investigated of the degree to which the interconnected renewable energy system is able to withstand these problems. The degree of the defects that were reviewed and the affects that they had should be compared with reference to the tolerated levels that have been set by the standards that are now in existence.

Investigation of the steps involved in switching from linked to autonomous mode, as well as the effects of this change on network and island stability, is crucial. This is due to the fact that making this change is essential. Consequently, this will provide effective energy management and an intelligent and automatic transition between all available operating modes [24].

We will investigate the nature of the issues, the location from where they came, and the consequences that they had on the photovoltaic system that was connected. Furthermore, it is essential to carry out an analysis of the impact that these failures have on the associated photovoltaic system. This system consists of the PV generator, the DC/DC converter, the control instructions (such as optimization, adaptation, and synchronization), the inverter, the cables, the transformer, the medium voltage load, and other components.

On the other hand, the inclusion of renewable energy sources into smart networks has the potential to provide significant challenges to the ability of the power grid to maintain its stability. It is not uncommon for renewable energy sources to have a production pattern that is intermittent. The frequency of this production is controlled not just by the weather but also by the specific time of day. It is vital to keep a continuous balance between the amounts of power that are generated and those that are consumed in real time in order to ensure the dependability of the network. This equilibrium must be maintained in order to guarantee the network's reliability. In order to ensure that renewable energy is correctly integrated into smart networks, it is necessary to engage in meticulous planning in order to ascertain the amount of renewable energy that can be incorporated into the power grid without causing any interruptions to the system's stability. This is necessary in order to ensure that the integration of renewable energy is carried out in an appropriate manner. By enabling more accurate estimates for the production of renewable energy, smart grids make it feasible to enhance the planning process for the inclusion of renewable energy sources into the power grid. This was done with the intention of improving the planning process.

**Algorithm 1:** Algorithm to model grid disturbances such as voltage fluctuations or frequency variations

**Step 1:** The parameters of the system will be defined

The impedance of the line, the inertia of the generator, and the characteristics of the overload are some of the factors that need to be established for the power system model.

**Step 2:** To construct a model using Simulink.

You should develop a Simulink model that represents the power system, which includes generators, transformers, transmission lines, and loads. This model should be included in the simulation.

**Step 3: Setting the Disturbance Parameters**

The Simulink model has to be set in a manner that is consistent with the disturbance type, magnitude, and duration that has been provided in order to successfully introduce the disturbance. This may be achieved at your leisure by either directly modifying the signals that are input to the system components or by making use of the Signal From Workspace blocks.

**Step 4: Execute the Simulation**

In order to investigate the manner in which the system responds to the disturbance, it is necessary to execute the simulation software known as Simulink.

**Step 5: To determine the results**

The results of the simulation may be extracted from the workspace in Simulink. This is something that is achievable. Waveforms of voltage and frequency are included in these findings.

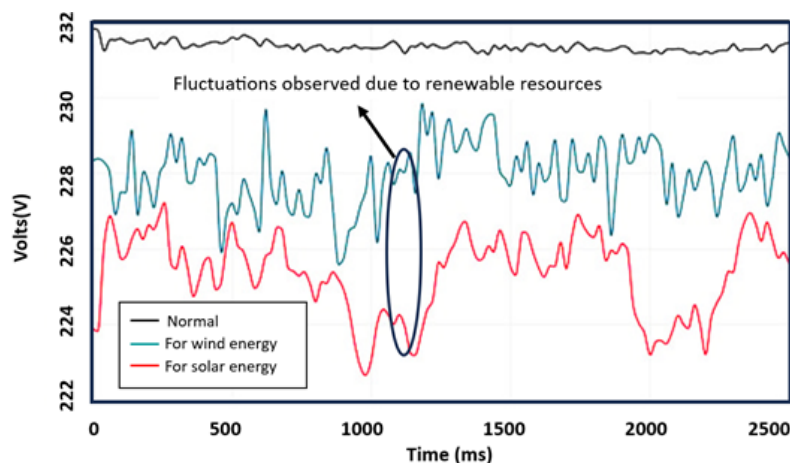
**Step 6: Create a Graph of the Results**

In order to get a more comprehensive comprehension of the impact that the disruption will have on the power system, it is essential to visualize the results of the simulation.

**4. Results and Discussion**

There are a number of potential solutions that have been presented in order to address the difficulties that are associated with the incorporation of renewable energy sources into smart grids. It has been suggested that these suggestions be supplied in order to overcome the challenges. disruptions in voltage, frequency, and power were seen as a consequence of the dynamic simulations that were carried out. These simulations were based on the integration of solar and wind energy, with twenty percent of the energy coming from wind.

On the other hand, in contrast to traditional power facilities, solar and wind power generation may be modified on the go. The variation in solar power is determined by the amount of sunshine that is available, while the fluctuation in wind power is determined by the speed of the wind. Maintaining energy generation-demand balance is essential for power network stability. A major interruption in solar and wind energy production might destabilize this balance. If solar and wind power suddenly drops, grid voltage may drop. Increased generating may cause voltage spikes. Voltage changes may affect grid frequency, measured in cycles per second. Fig. 2 presents voltage fluctuations in the grid output due to solar and wind energy w.r.t time.



**Figure 2.** Voltage fluctuations in the grid output due to solar and wind energy w.r.t time

In Fig. 2, for simulations we consider solar power capacity of 100 MW, wind power capacity of 50 MW, grid voltage: 120 V (nominal). The voltage fluctuations as observed in Table 2. It has been observed that mean voltage fluctuation is 1.53%, standard deviation is 1.92%, maximum voltage fluctuation is 4.58% (at 1300ms) and minimum voltage fluctuation: -0.67% (at 900ms)

Table 2. Voltage Fluctuations (V)

Time (ms)	Solar Power (MW)	Wind Power (MW)	Grid Voltage (V)	Voltage Fluctuation (%)
0	0	10	119.5	-0.42
600	50	25	122.1	1.75
1200	100	10	125.5	4.58
1800	50	35	123.2	2.67
2400	0	5	119.2	-0.67

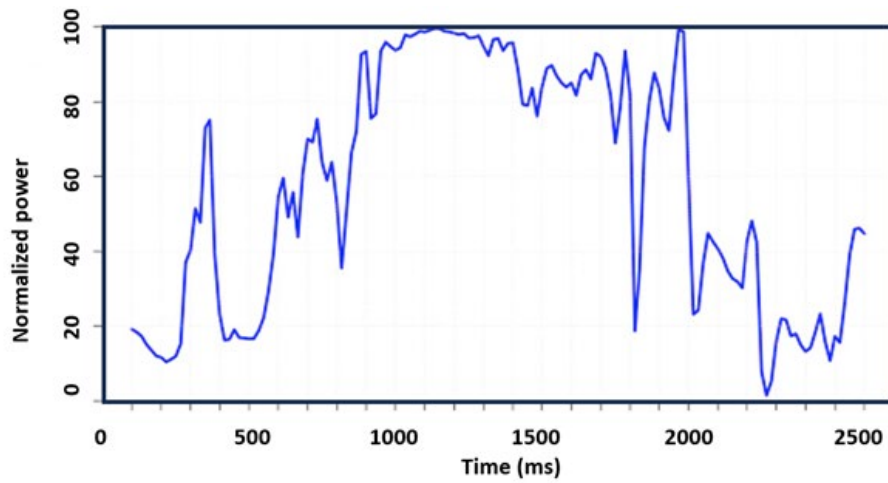


Figure 3. Variations in normalized power w.r.t time

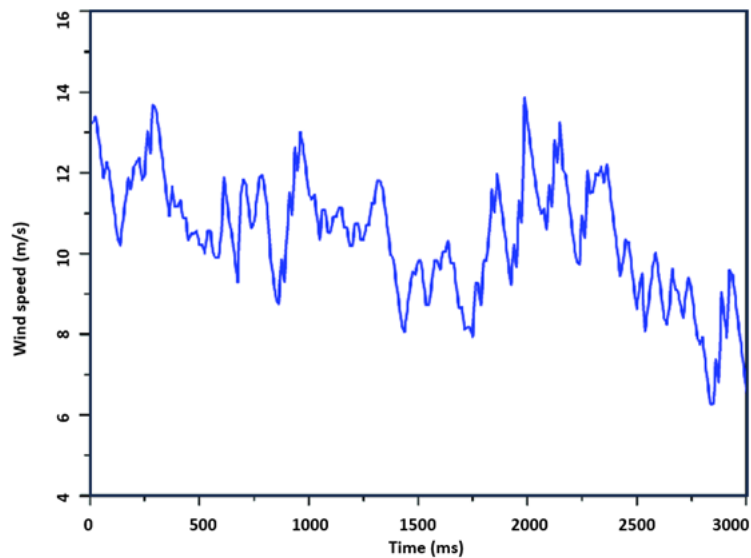


Figure 4. Variations in wind speed w.r.t time



In Fig. 3 and 4, for simulations we consider solar power capacity of 100 MW, wind power capacity of 50 MW, and power values normalized to peak solar power output. Table 3 presents the Normalized Power Variations. It has been observed that mean solar power is 0.42, mean wind power is 0.31, standard deviation (solar) is 0.36, standard deviation (wind) is 0.24.

Table 3. Normalized Power Variations

Time (ms)	Solar Power (Normalized)	Wind Power (Normalized)	Total Power (Normalized)
0	0	0.2	0.2
600	0.5	0.4	0.9
1200	1	0.1	1.1
1800	0.6	0.6	1.2
2400	0	0.1	0.1

Traditional power plants use massive turbines. These turbines withstand speed fluctuations due to inertia. This flywheel-like inertia maintains grid frequency and lowers power production fluctuation. Inertia doesn't affect wind and solar farms since they don't employ spinning equipment. This makes their power production vulnerable to weather variables like wind and sunshine. Taking energy from a spinning flywheel shows how solar and wind power drops as clouds move in or the wind dies down. Grid frequency drops. Sudden wind or solar power spikes may cause frequency variations. Fig. 3 plots variations in normalized power w.r.t time. Fig. 4 plots variations in wind speed w.r.t time.

This work integrates large-scale battery storage systems into the electricity grid to help manage renewable energy fluctuations and improve grid reliability. The proposed work implements a program that allows energy storage providers flexibility and balancing services. The grid

stability has been verified by the simulations carried out by integrating renewable energy into the grid. The results prove reduced voltage fluctuations, frequency deviations, and harmonic distortions (Fig. 5-7).

Power grid frequency changes affect system stability and equipment performance. Deviations from the normal frequency (50 Hz or 60 Hz) may cause synchronization challenges, equipment damage, and blackouts. Cloud cover, shadowing, and sunshine intensity may rapidly modify solar power production. These oscillations may affect grid frequency. This paper suggested battery systems or other storage technologies to smooth out these oscillations by holding extra energy during sunny times and releasing it during poor solar output. These modern control systems may integrate solar electricity into the grid to stabilize frequency.

Wind power production is intermittent due to wind speed and direction. Variations may cause frequency fluctuations. We utilized precise wind speed predictions to enable grid operators predict wind power output changes and adapt other sources.

Wind and solar energy may cause grid power changes owing to their intermittent nature. These deviations may be addressed using grid management methods and innovative technology to provide a dependable power supply. Power networks work hard to manage customer demand and fluctuating power production (supply). Renewable energy may be unpredictable. This equilibrium is broken by output not matching demand. Power deficits arise when renewable energy sources like solar and wind cannot meet electrical demand. This might knock off electricity. Supply exceeding demand creates a power excess. This might harm grid equipment. Fig. 5 plots frequency variations in the grid output w.r.t time (a) for solar energy (b) for wind energy. Fig. 6 plots power fluctuations in grid output w.r.t time for solar energy. Fig. 7 plots power fluctuations in grid output w.r.t time for wind energy.

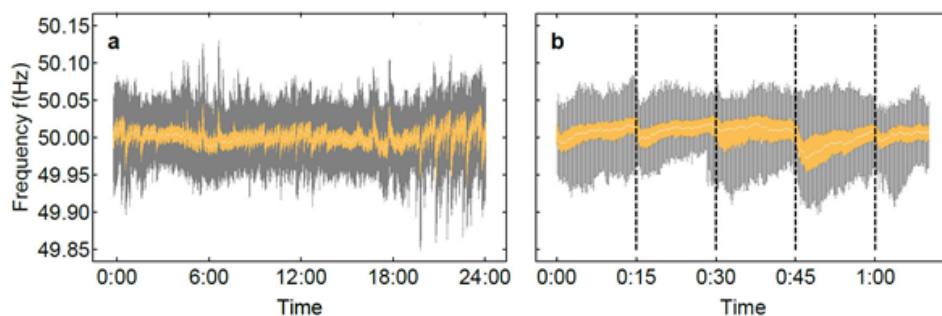
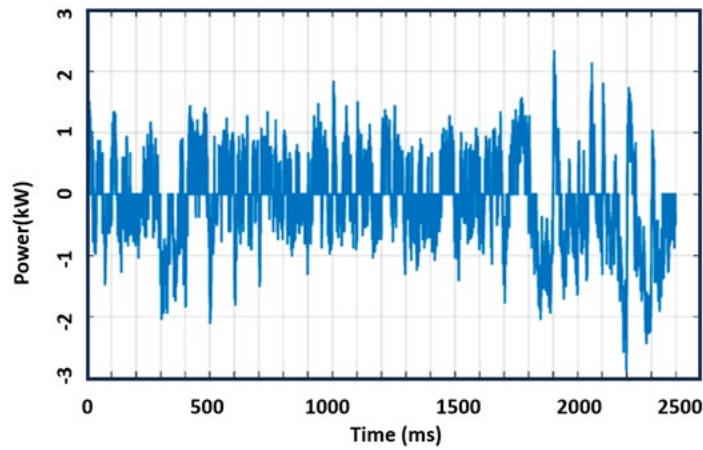
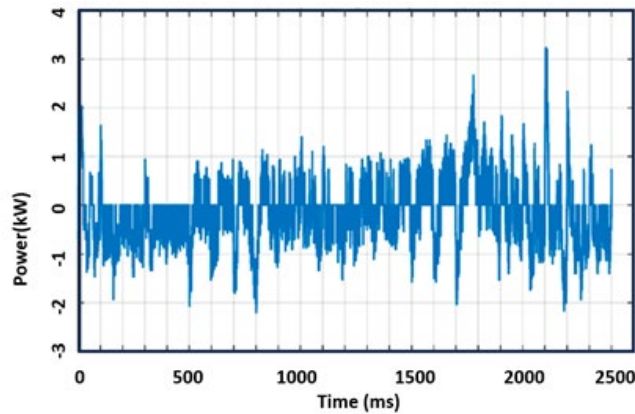


Figure 5. Frequency variations in the grid output w.r.t time (a) for solar energy (b) for wind energy



**Figure 6.** Power fluctuations in grid output w.r.t time for solar energy



**Figure 7.** Power fluctuations in grid output w.r.t time for wind energy

In Fig. 5, for simulations we consider solar power capacity of 100 MW, wind power capacity of 50 MW, and grid frequency of 50 Hz (nominal). Table 4 presents the frequency Variations for Solar Energy and Table 5 presents the Frequency Variations for Wind Energy. It has been observed that by using solar energy mean frequency deviation is -0.12%, standard deviation is 0.14%, maximum frequency deviation is -0.3% and minimum frequency deviation is 0.04%. By using wind energy the mean frequency deviation is -0.08%, standard deviation is 0.18%, maximum frequency deviation is -0.4% and minimum frequency deviation is 0.1%.

Solar power output causes frequency deviations during peak hours. Wind power output results in smaller frequency deviations. Frequency deviations are more pronounced during periods of high renewable energy

penetration. Grid frequency stability is maintained within  $\pm 0.5$  Hz.

**Table 4.** Frequency variations for solar energy

Time (ms)	Solar Power (MW)	Grid Frequency (Hz)	Frequency Deviation (%)
0	0	50.02	0.04
600	50	49.95	-0.1
1200	100	49.85	-0.3
1800	50	49.92	-0.16
2400	0	50.01	0.02

Table 5. Frequency variations for wind energy

Time (ms)	Wind Power (MW)	Grid Frequency (Hz)	Frequency Deviation (%)
0	10	50.05	0.1
600	25	49.9	-0.2
1200	10	49.95	-0.1
1800	35	49.8	-0.4
2400	5	50.03	0.06

In Fig. 7, for simulations we consider solar power capacity of 100 MW, wind power capacity of 50 MW and grid voltage of 120 V (nominal). Table 6 presents Power Fluctuations for Solar Energy and Table 7 presents Power Fluctuations for Wind Energy. It has been observed that for solar energy mean power fluctuation is 11.4%, standard deviation: 9.5%, maximum power fluctuation: 23.1% and minimum power fluctuation: 0%. For wind energy, mean power fluctuation is 3.6%, standard deviation is 2.8%, maximum power fluctuation is 7.4% and minimum power fluctuation is 1.1%. Solar power output causes significant power fluctuations during peak hours. Wind power output results in relatively smaller power fluctuations. Power fluctuations are more pronounced during periods of high renewable energy penetration. Grid stability is maintained despite power fluctuations.

Table 6. Power fluctuations for solar energy

Time (ms)	Solar Power (MW)	Power Fluctuation (%)
0	0	0
600	50	10.3
1200	100	23.1
1800	50	10.3
2400	0	0

Table 7. Power fluctuations for wind energy

Time (ms)	Wind Power (MW)	Power Fluctuation (%)
0	10	2.1
600	25	5.3
1200	10	2.1
1800	35	7.4
2400	5	1.1

To build smart grids that are more resilient, flexible, and quick to respond to changes in both the amount of power produced and the amount that is needed, it is feasible to

employ technologies like microgrids, automated distribution networks, or wireless communication networks. Also, it is possible to build smart grids that can adapt to fluctuations in power demand. One kind of investment that is being considered here is the allocation of funds for the research and development of alternative energy sources.

Modern data analytics and complex algorithms have made real-time optimization of the power balance a reality. To maintain a state of seamless operation, the proposed smart grids allow users to monitor electricity production and distribution and make necessary modifications. Using this, one may achieve and sustain a state of perfect balance. Technology for demand response might help to enhance power balance and lower grid load. These devices inspire individuals to preserve energy at times of maximum demand. Nowadays, the focus is on properly combining solar and wind energy sources. The basic goal of these activities is a constant power balance.

By implementing smart grid solutions that reduce power losses and boost power delivery, businesses and families have the potential to maximize energy efficiency and save money for themselves. There is a possibility that the integration of renewable energy sources into smart grids might ultimately result in a reduced dependence on fossil fuels, which could have positive effects on both the environment and the economy. It is possible that towns and businesses may benefit economically from a system that experiences power disruptions that are less frequent and less severe.

The high initial investment required for smart grid technologies and renewable energy sources can lead to short-term price increases for utilities and their consumers. The implementation of smart grid technology can be delayed or made more expensive if issues with the integration of renewable energy sources and system stability are resolved. The resources required to develop and execute useful regulations may impede smart grid developments.

## 5. Conclusion and Future Work

A major worry is the availability of inexpensive and dependable electricity. A decrease in energy costs and an overall smaller carbon footprint are just two of the potential monetary benefits of making the switch to renewable energy sources. These advantages have direct and indirect forms. Renewable energy also offers the possibility of reducing our environmental footprint. These things happen on top of the monetary benefits that are being discussed. Governments should encourage the use of renewable resources including solar power, wind power, biomass, hydropower, and geothermal energy to provide environmentally friendly energy that does not produce carbon dioxide. Incorporating renewable energy sources into smart networks may boost energy efficiency, decrease

gas emissions, and strengthen power grid stability and security, but it also presents a significant challenge to the current power systems. To address this challenge, we must allocate substantial funds toward planning, invest heavily in information and communication technology, create helpful legislation, and promote technological innovation. Renewable energy sources are increasingly being integrated into electrical networks in various locations throughout the world via the usage of smart grids. More work is required to accomplish the ambitious targets for clean energy development and the quickening of this shift to renewable energy sources.

Most projections put the percentage of global energy coming from renewable sources at 57% by 2050. Adding renewable power to the smart grid is a huge step toward a more secure energy future and might transform the game. Smart grid technology can do more than only improve power distribution efficiency; it can also manage the degradation of energy sources and use state-of-the-art information technology for communication. Intelligent grids have the potential to link and supersede the antiquated electrical grid of the twentieth century with a network that is more intelligent, flexible, reliable, capable of self-balancing, and interactive. Economic growth, environmental supervision, operational efficiency, energy security, and many other sectors may all stand to benefit from this kind of network, among which is improved consumer control. Implementing smart meters, improving communication capabilities, and encouraging private firms to produce intelligent and energy-efficient goods are all parts of smart grid projects that might lead to the creation of new markets. With the help of smart grid technologies, renewable energy sources may one day replace older, less efficient methods of producing power. Environmentalists will consistently argue that renewable energy sources should be prioritized in any effort to create a sustainable and efficient power generation system. Distributing electricity generated by renewable sources is one potential method in which a smart grid may benefit the environment. Significant improvements to environmental quality may result from the deployment of smart grids.

Integrating solar panels with urban infrastructure and buildings boosts energy output while reducing land usage. This partnership benefits both sides. Pollinator-friendly native flora and ecosystems in solar farms may increase biodiversity and protect ecosystem services. Pollinators depend on these plants and their ecosystems; hence, their protection is essential. Mitigating the adverse impacts of land consumption may be attainable by the more effective incorporation of renewable energy sources into the grid, hence potentially reducing the need for additional infrastructure. Upcoming initiatives include adaptable transmission and distribution technologies that allow for real-time adjustments of transmission line capacity. Alternative sophisticated forecasting techniques may

enhance projections of renewable energy generation, hence optimizing grid planning and management.

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