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RESEARCH ARTICLE

Solution for Integration of Renewable Energy Power Plants into Smart Grids with Active Power Control

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HIGHLIGHTS

- *Effect and important of this article in literature*
- *Exchange between sources in related subjects of this article*
- *Contribution and strongest impact on the related sobject of this article*
- *Examined study and obtained results why is important*

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ABSTRACT

This article addresses the integration of renewable energy power plants into smart grids and active power control. Renewable energy sources contribute to environmentally friendly and sustainable energy production, but the fluctuations inherent in these sources pose a challenge for energy grids. The article examines various technologies that can be used to overcome this challenge and make energy grids more reliable. Smart grids aim to improve energy grids by optimizing energy production, transmission, and distribution using data analytics, automation, and communication technologies. The integration of renewable energy power plants into these smart grids offers significant advantages, including the ability to predict energy production, integrate with energy storage systems, and manage energy demand. The article also emphasizes the importance of active power control. Active power control is used to manage energy production steadily, thereby maintaining grid stability. Balancing energy fluctuations from renewable energy sources and storing excess energy when needed enhances grid stability. In conclusion, this article discusses the crucial role of integrating renewable energy power plants into smart grids and implementing active power control in the energy sector. These integration and control methods are important steps in making energy grids more sustainable, efficient, and reliable.

Keywords: *Renewable Energy, Smart Grids, Active Power Control*

I. INTRODUCTION

Energy strategies are underpinned by the expanding utilization of natural gas and renewable energy sources (RES), coupled with an increased focus on enhancing energy efficiency. Nonetheless, recent government initiatives have shifted towards the promotion of innovative and sustainable energy resources. The national "Renewable Energy 3020 Implementation Plan" is geared towards augmenting the share of renewable energy generation to approximately 20% by 2030. Presently, the proportion of renewable energy generation lags behind that of major nations; hence, the government aspires to achieve this objective by providing clean energy, such as solar and wind power, to over 95% of new installations [1]. Furthermore, there is a growing trend in the adoption of Distributed Energy Resources (DERs) connected to small-scale distribution systems due to their rapid deployment and cost advantages [2, 3]. Nevertheless, variations in active power output resulting from wind and photovoltaic (PV) generation can introduce instability due to fluctuations in solar radiation and temperature shifts. Additionally, voltage-related issues like under-voltage and overvoltage complications can manifest in the power distribution network.

Creating a sustainable energy system and meeting the increasing demand for electrical load requires the integration of Renewable Energy Sources (RES) models into the grid [4]. However, this poses several challenges in providing active power control, and this generational transformation of the power system requires a more extensive communication network to maintain grid integrity [5, 6]. Many existing RES technologies are highly dependent on geographical and environmental factors, making them unpredictable and uncontrollable, thus limiting their large-scale integration into power grids. This also necessitates innovative strategies in renewable integration along with demand-side management [7-9]. Most of the current solutions in the literature, such as renewable forecasting, peak shaving, load filling, power electronic converters, smart meters, and smart inverters, rely on state-of-the-art communication networks for their effectiveness. Therefore, establishing an effective smart grid enables load management, significantly reduces system losses and energy wastage, provides accurate data monitoring, and ensures flexibility in expansion and integration within the power system network. Similarly, the electricity grid, with limited sensing devices, manual control, and maintenance, offers customers limited participation options [10-13]. In this context, the smart grid focuses on maintaining intergenerational diversity with updated processes, enhanced efficiency, and active power control. Through intensive observation-based automation, utilizing smart and digitalized energy solutions, it ensures flexibility, self-healing, resilience, reliability, customer involvement, and security in the power system network [14]. Globally, there is a systematic transition towards smart grid development, observed concurrently with intense innovation in each smart grid framework domain, considering their respective challenges [15, 16]. However, this multidisciplinary theory and application of multi-faced research and industrial development need to consider the technical, economic, and social requirements of participants. From the perspective of the power grid, technical challenges include diversity and distributed transformation while maintaining power quality, stability, and flow appropriately [17]. Power system operators and planners ensure the technical and economic viability of the smart grid; thus, research efforts towards better interoperability will lead to the development and formulation of standards and protocols enabling the integration of existing and emerging smart grid technologies of energy, communication, and information into grid operation concurrently and expeditiously, potentially reducing overall costs through technological diversification. Socially, government incentives encourage customers to transition to prosumers and participate in the electricity market [18-20]. The progress of smart grid realization and expansion depends on social aspects related to transparency, including security, justice, and trust among smart grid participants. In this regard, numerous conceptual, terminological, and componential analyses of smart grids have been extensively presented to outline their foundational understanding and technological operation [21, 24]. Additionally, to accelerate smart grid visualization and creation, analytical, strategic, and business models such as Strengths, Weaknesses, Opportunities, and Threats (SWOT), Political, Economic, Sociological, Technological, Legal, and Environmental (PESTLE), etc., have been presented to promote smart grid feasibility [25-28]. These models have helped identify relevant factors hindering successful smart grid implementation [29-31]. Based on available literature models, this review article focuses on the perspective of power system planners and customers regarding the required technological innovations and considerations needed for accelerated smart grid development and implementation

[32]. Compared to some recent works, this study makes a substantial contribution by effectively amalgamating current knowledge in the fields of smart grids, renewable energy sources, energy storage, and communication systems comprehensively. Specifically, it precisely delineates areas of inquiry that have not been well-addressed, providing direction for future research and serving as a helpful reference for academic researchers [33, 34]. The paper's value is enhanced by its practical focus on difficulties and solutions, as well as its distinctive bottom-up methodology [35]. The review focuses on current developments and addresses contemporary concerns in the power sector, maintaining its relevance to ongoing conversations [36]. Furthermore, the aim is to bridge the gap between strategic reviews and quantifying their technological equivalents in terms of smart grid technologies by highlighting identified smart grid analytical models and translating them into technological research advancements and focus areas needed for smart grid realization.

Numerous methodologies have been proposed to address voltage problems triggered by DERs within a power distribution system. One technique employed to mitigate overvoltage issues is the on-load tap changer and step voltage regulator. These voltage control components are effectively deployed in conventional general distribution networks. However, the effectiveness of voltage control has become increasingly variable and unpredictable due to the recent elevation in voltage levels at the terminus of the distribution network, stemming from the upsurge in solar energy production. In conformity with the traditional distribution network's voltage profile, the measured voltage tends to be low owing to the distance of the voltage measurement point from the voltage source. Currently, voltage rise is observed at the end of the distribution line, and as a result, DER connections engender overvoltage predicaments, including reverse power flow (RPF) within the distribution network.

In summary, it is imperative to take voltage issues into account in bi-directional power flow scenarios and enhance the stability of the distribution network under multifaceted circumstances. The concept of a smart inverter pertains to a category of inverters capable of independently regulating DER output. These intelligent inverters operate to ensure the stability of the distribution network and encompass functionalities such as fixed power factor control, voltage-reactive power control, voltage-power control, frequency-power control, voltage ride-through, frequency ride-through, as well as manual active and reactive power control, among others. The autonomous functions needed for system stabilization are defined in the IEEE 1547-2018 standards. The application of test procedures and the definition of control criteria are structured to facilitate the utilization of an IEC 61850-7-520-based communication interface, which includes pivotal input parameters like voltage-reactive power control (VVC) and voltage-power control (VWC) [37, 37]. The VVC control method fine-tunes the voltage at the point of common coupling (PCC) for the PV inverter. In accordance with a predefined VVC curve, the inverter is adjusted to either absorb or inject reactive power. Current grid infrastructure requires updates to preserve grid flexibility, encompassing various operational facets associated with the integration of renewable energy sources [38]. These facets include generation, transmission, distribution, operational management, and power system planning [39, 40]. Efforts are underway to address short and long-term uncertainties, facilitating grid transformation and diversification [41-43].

Energy Storage Systems (ESSs) are predominantly intricate and nonlinear systems, hence their efficiencies cannot be succinctly quantified by a single numerical value (e.g., an average efficiency of 90%) [43-46]. This complexity arises due to a myriad of factors that necessitate consideration: the specific application (operational cycle), the efficiency of each module and subsystem within the ESS facility (comprising the aggregate of individual module efficiencies), operational conditions of the device, and the instantaneous power profile delivered by the ESS facility, among others. Consequently, it is imprudent to treat ESS efficiency as a static, singular value. Rather, a comprehensive evaluation of efficiency, contingent upon a multitude of parameters (including power requirements, consumption or generation, system configurations, and state of charge), is imperative. Furthermore, this efficiency evaluation should be customized to a specific application and operational cycle [44, 45]. Thus, a nuanced analysis is crucial to enhancing the sizing process of ESS facilities.

II. POWER BALANCE WITH STORAGE METHOD

Smart grids, along with distributed energy systems like energy communities and energy hubs, are emerging as a viable alternative to traditional grids. They offer solutions to grid expansion challenges, reducing transmission losses, and addressing environmental concerns by facilitating the integration of a higher share of renewable energy technologies. Recent years have witnessed growing public acceptance of distributed renewable energy systems, with some countries achieving as much as 10% of their electricity production from these sources [46, 47]. While distributed energy systems offer numerous advantages such as proximity to energy demand centers, emissions reduction, and decreased renewable energy technology costs, they also present considerable hurdles in ensuring a stable and dependable energy supply due to the variable nature of renewable energy sources (RES). ESS have emerged as a promising means to mitigate the fluctuations in RES and enhance the reliability of distributed energy systems. They play a pivotal role in the global transition towards sustainable energy systems, offering a wide array of services to facilitate this shift, including active and reactive power regulation, frequency management, reserve capacity, and various grid services [48-50]. Additionally, ESS can enhance the energy self-sufficiency and self-consumption metrics of energy communities [51-53], leading to improved grid flexibility and lower energy expenses. These systems can absorb surplus energy when electricity demand is low and feed it back into the grid during peak demand, contributing to grid stability. The cost of energy storage has seen a remarkable reduction over the last decade, particularly in the case of lithium-ion (Li-ion) batteries, which have experienced an 85% cost decrease thanks to widespread deployment.

Determining the appropriate size of ESS is a critical area of research for professionals involved in the design and implementation of DERs, typically in the context of independent PV systems. Sizing methodologies aim to strike a balance between PV and ESS capacities, ensuring that they can deliver energy at a desired level of reliability and meet user demands. The reliability of an independent system is commonly assessed using the Loss of Load Probability (LOLP) metric [54, 55], which represents the ratio of the expected energy deficit to the total energy demanded during the entire operational period. An optimization-based sizing methodology has been developed for independent PV systems, incorporating reliability considerations and leveraging long-term data. The methodology explores different combinations of battery capacity and PV array size to meet specific LOLP targets, ultimately identifying the PV-battery configuration that minimizes the total system cost.

The importance of determining suitable sizes for ESS is highlighted for experts in the DERs sector. Sizing methodologies aim to achieve the provision of energy at the desired reliability level and meet user demands by establishing a balance between PV and ESS capacities. Additionally, it indicates the increasing prevalence of energy storage systems in grid systems alongside the growing utilization of renewable energy. However, it underscores the variation of ESS technologies based on various applications, emphasizing the significance of identifying appropriate applications. The text underscores the flexibility of sizing methodologies, enabling the reassessment of ESS sizes in existing systems. Finally, it emphasizes the importance of incorporating energy storage efficiency into the sizing process, thereby facilitating more accurate determination of ESS capacity and reduction of energy losses.

The current trend suggests that storage devices will become increasingly prevalent in grid systems as renewable energy becomes a more prominent component of the energy supply mix [56, 57]. The infrastructure of power systems utilizes ESSs at various stages. However, ESS technologies vary depending on their applications [57-59]. Despite the multidimensional application of ESS, it is essential to identify their applications and scopes in accordance with their technical specifications (such as power density, rating, energy density, lifetime, self-discharge rate, etc.) [60]. This sizing methodology relies on evaluating the energy balance between generation and demand over a defined sizing period to determine the optimal ESS capacity. The choice of the sizing period is flexible and can be tailored to meet user-specific requirements, ranging from a few days to several years. This sizing approach is versatile, catering to both independent and grid-connected energy systems. Moreover, it can be applied to resize ESS in existing systems when measured data is available, and it is adaptable for scenarios like peak shaving and grid-connected services. In the contemporary landscape of distributed energy resources, encompassing smart grids, microgrids, energy communities, and leveraging advancements in information and communication technologies (ICT), this proposed methodology proves to be highly effective and user-friendly. Additionally, it incorporates the efficiency of energy storage in the sizing process, accounting for losses during the storage and release of energy, making the estimated ESS size more accurate, as illustrated in Figure 1.

In conclusion, this approach offers adaptability when choosing charge and discharge efficiency parameters, given that these parameters are contingent on the technology of the Energy Storage System (ESS). In practice, the charge and discharge efficiency values (represented as ηin and ηout) are typically less than one and are subject to variation based on the specific ESS technology and the environmental conditions under which it operates. Reduced charge efficiency values are associated with an increase in the required ESS capacity.

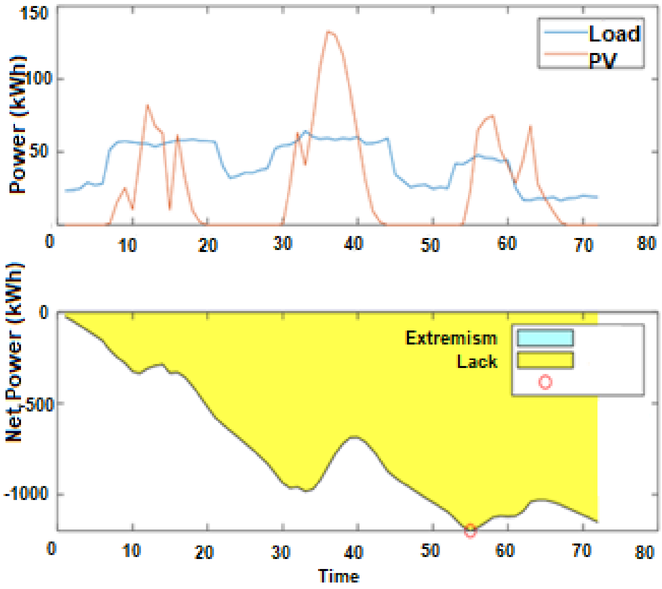

Figure 1. Sizing of an Independent PV System's EES

A. *Smart Grids Power Balance with Voltage Control*

In smart grid systems, inverters play a crucial role in maintaining voltage stability through various control functions. The volt-var control function allows inverters to respond to variations in Point of Common Coupling (PCC) voltage, either by supplying or absorbing reactive power. When an overvoltage condition occurs, the power control mechanism continuously monitors the voltage. It incrementally increases power generation to raise the voltage to an appropriate level. Conversely, if the PCC voltage exceeds the desired range, the inverter releases capacitive reactive power to lower the voltage.

Another essential control function, known as volt-watt control (VWC), focuses on managing active power output concerning voltage fluctuations. VWC utilizes measurements of the PCC voltage to make real-time adjustments. When the voltage surpasses the stable range, VWC intervenes to reduce the active power output, effectively lowering the voltage. VWC typically works in conjunction with volt-var control (VVC) to address overvoltage situations.
It's important to note that the primary method for stabilizing the distribution network's voltage is by controlling reactive power, particularly when employing VVC. The inverter autonomously adjusts the reactive power output based on the PCC voltage, following a predefined Q-V droop control curve. This method includes continuous measurement of the inverter's PCC voltage and reactive power control. Consequently, the DER's voltage stability relies on the generation of reactive power by the inverter. This iterative process leads to a stable operating point, ensuring a stable and reliable system operation.

B. Flow Chart of the Recommended Algorithm in Scanned Optimization

Reactive power control, guided by the VVC curve, is characterized by tracking the stable reactive power output. The final convergent voltage value is determined based on various system-specific parameters at the smart inverter's connection point. These parameters include Thevenin equivalent impedance, active power values, reactive power values, and other relevant factors. The proposed real-time active power control method within a smart grid is illustrated in Figure 2.

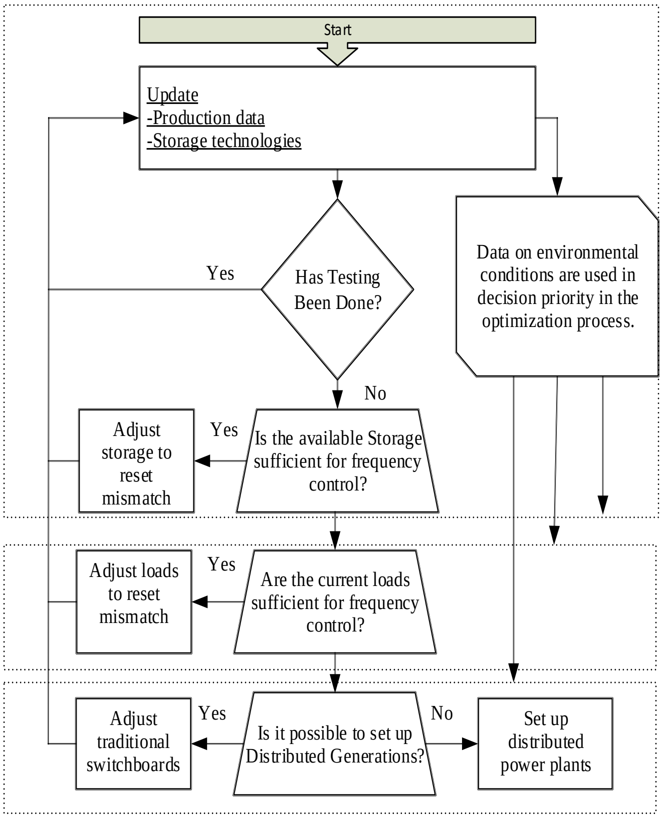

Figure 2. Flowchart of the Proposed Algorithm

A fundamental aspect of a smart grid is its robust communication and information infrastructure, enabling seamless data and information exchange among the grid components. Additionally, integrated sensors and data collection devices enhance the grid's situational awareness. Leveraging the smart grid's advantages, as outlined above, allows for effective real-time management of the active power generation-consumption mismatch, a capability not present in traditional power systems. [59].

In the proposed method, load data will be collected from the system through Advanced Metering Infrastructure (AMI). AMI enables two-way communication between consumers and suppliers. Real-time load data will be retrieved from the load data server. These real-time data may include the sizing of controllable loads such as electric vehicles, water heaters, dryers, etc., which can be used to adjust the system in case of discrepancies between supply and demand. It is assumed that consumers will release a portion of their loads for system regulation in response to incentives through demand response.

A secure and reliable communication system will be employed for data and command exchange between the operating system and AMI. One of the fundamental features of a smart grid is the presence of suitable communication and information infrastructure that facilitates data and information flow among the components of the smart grid. Additionally, sensors and data collection devices integrated into the system will make it more aware of various conditions. As a result, leveraging the advantages of a smart grid mentioned above, it will be possible to manage the real-time mismatch between active power generation and consumption, which is not feasible in a traditional power system (Equations 1, 2, and 3)

$$P_{RTTP}(t) = \sum_{i=1}^{n} P_{RTTP}(t) + \sum_{j=1}^{m} P_{RTStorage}(t) + \sum_{k=1}^{g} P_{RTTP}(t) \tag{1}$$

$$P_{RTLoad}(t) = \sum_{l=1}^{f} P_{RTCLoad}(t) + \sum_{r=1}^{s} P_{nonRTCLoad}(t) \tag{2}$$

$$\Delta P(t) = P_{RTTP}(t) - P_{RTLoad}(t) - P_{lost} \tag{3}$$

$$DGP\ (t) = \Delta P(t) - DP(t) \tag{4}$$

$$DYP\ L(t) = \Delta P(t) - DP(t) - P_{DKY}(t) \tag{5}$$

$$DBSP\ (t) = \Delta P(t) - DSP(t) - P_{CLB}(t) - P_{SGB}(t) \tag{6}$$

In the proposed method, real-time total production (MW) is represented by $P_{RTTP}(t)$, real-time distributed production (MW) by P_{RTDP} (t), real-time supplied power from storage to the grid (MW) by $P_{RTStorage}$, real-time total load (MW) by $P_{RTLoad}(t)$, real-time controllable total load (MW) by $P_{RTCLoad}(t)$, real-time uncontrollable total load (MW) by $P_{nonRTCLoad}(t)$), total system loss in power (MW) by $P_{lost}(t)$, balancing share distributed by storage (MW) by $DBSP\ (t)$, stored power for balancing (MW) by $DP\ (t)$, controllable load set for balancing (MW) by $P_{CLB}(t)$, and smart grid production set for balancing (MW) by $P_{SGB}(t)$. In addition, the expressions *n, m, k, f* and *s* in the formulas are variables that indicate the unit types.

The utilization of distributed production resources, in addition to traditional production sources, can correct the imbalance of generated energy. The appropriateness of using distributed production sources alongside smart production sources can be examined (see the flowchart in Figure 2). The use of distributed production for regulation can be considered when the penetration level of distributed production resources is very high, and smart production resources are insufficient for system regulation. However, in such cases, distributed production sources are limited in their power capacity so that they can be used like traditional production sources. This, however, comes with the disadvantage of reducing the power generated from distributed production sources. After the real-time total production and load matching condition, the power value is calculated as shown in Equation (1). If the mismatch between supply and demand is within the allowed range, meaning that it doesn't affect the system's frequency and stability, the controller updates the data after the specified delay time (e.g., regular intervals for data updates are performed to prevent system ramping). If the mismatch between supply and demand is outside the allowed range, the controller must take action to correct the mismatch. Depending on the system, all available resources may be used to correct the mismatch, or only some resources may be used based on the magnitude of the mismatch. For example, following the sequence shown in the flowchart, existing storage systems are first used to absorb the mismatch power, followed by controllable loads, and finally, smart productions. If the load increases or production decreases, the balancing process is carried out as shown in Equations (4 to 6). If the existing storage resource is large enough to absorb the mismatch, the controller continues to update the data for the next step within the specified interval. Otherwise, storage transfers the remaining mismatch to controllable load or an appropriate resource, which has the ability to correct the mismatch.

This study demonstrates the critical importance of active power control strategies in integrating renewable energy sources into smart grids. These strategies play a pivotal role in managing the variability and intermittency inherent in renewable energy sources. By dynamically adjusting power generation and distribution, grid operators can ensure system stability and reliability, facilitating a smooth transition to a cleaner and more sustainable energy future. One advantage of this approach is its ability to enhance the efficiency and stability of the grid. Additionally, it enables the mitigation of imbalances in the integration of renewable energy sources, contributing to the resilience and reliability of energy systems.

This paper study importance of smart grids and distributed energy systems, particularly in integrating renewable energy technologies. It highlights the benefits and challenges associated with distributed energy systems, emphasizing the role of ESS in mitigating the variability of renewable sources. The text also discusses methodologies for sizing ESS in independent PV systems, focusing on reliability metrics like Loss of Load Probability (LOLP). It underscores the increasing prevalence of energy storage in grid systems and the importance of efficient sizing methodologies. Furthermore, it delves into the role of inverters in maintaining voltage stability in smart grid systems through functions like volt-var control and volt-watt control. The proposed real-time active power control method within a smart grid is detailed, showcasing its ability to manage mismatches between supply and demand, thereby enhancing system stability and reliability. Overall, the text emphasizes the crucial role of active power control strategies in integrating renewable energy into smart grids for a sustainable energy future.

III. ANALYSIS FINDINGS AND DISCUSSION

This thesis demonstrates that when smart grids, especially inherently intermittent renewable energy systems, are integrated into the power system, it makes the power system more efficient and stable. In a smart grid, it is possible to integrate renewable energy systems and control the system in real-time to overcome the imbalance between supply and demand. This requires access to data such as generators, loads, storage systems, energy markets, etc. In smart grids, this is possible due to the communication, information, and sensor infrastructure deployed throughout the electrical grid. This study will show that even when the ratio of renewable energy systems in the system is very high, the system's imbalance can be corrected. This method is crucial, especially when there are fewer synchronous machines in the network and the system's inertia is low. The order of choice for the controller in deciding whether to use storage, controllable loads, smart productions, or load shedding depends on factors such as available capacity, environmental data, market data, resource locations, etc.

B. Storage System Model Designed for Power Balance

The network seen in Figure 3 represents a part of the Electric Power Grid. In this model, an islanded (standalone) operation mode was adopted, and the testing of the proposed algorithm was conducted. Furthermore, energy storage systems and controllable loads were added to the system.

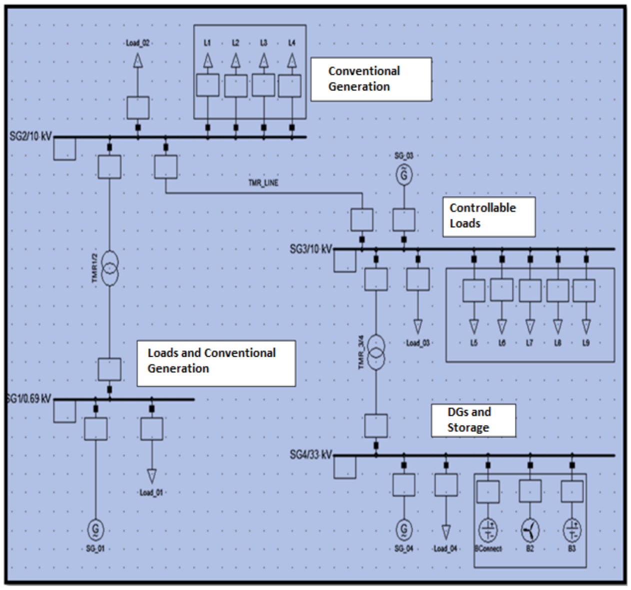

Figure 3. Model for Testing the Proposed Algorithm

The integration of these components was done to better understand the dynamics and imbalances of the network, as the original system did not have storage systems. This simulation addresses fluctuations caused by renewable energy sources (RE), but it is possible to consider load variability or a combination of both. The fluctuations from distributed energy resources (DER) are addressed, as shown in Figure 4.

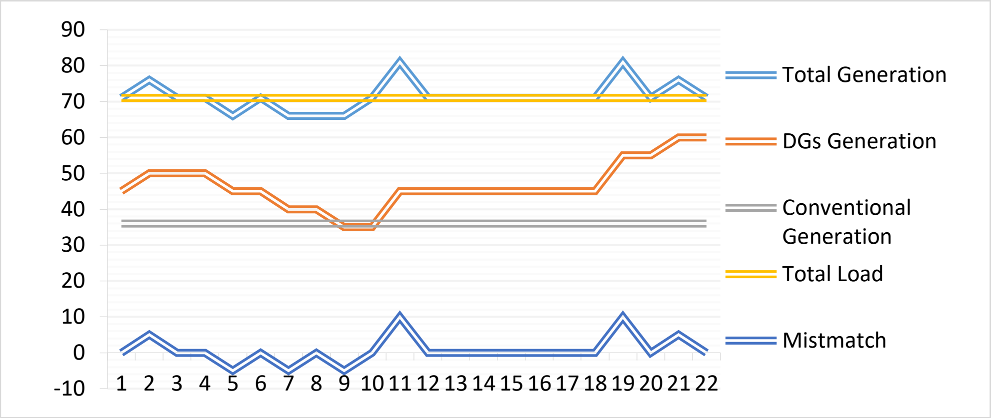

Figure 4. Production from RES, Production from Conventional Power Plants, Total Production

Production from DERs (wind energy) ranges from 25 MW to 50 MW, while the load remains constant at 60 MW, and the power system's energy storage system capacity is set at 35 MW. Energy imbalances result from fluctuations in DERs and are illustrated in Figure 5.

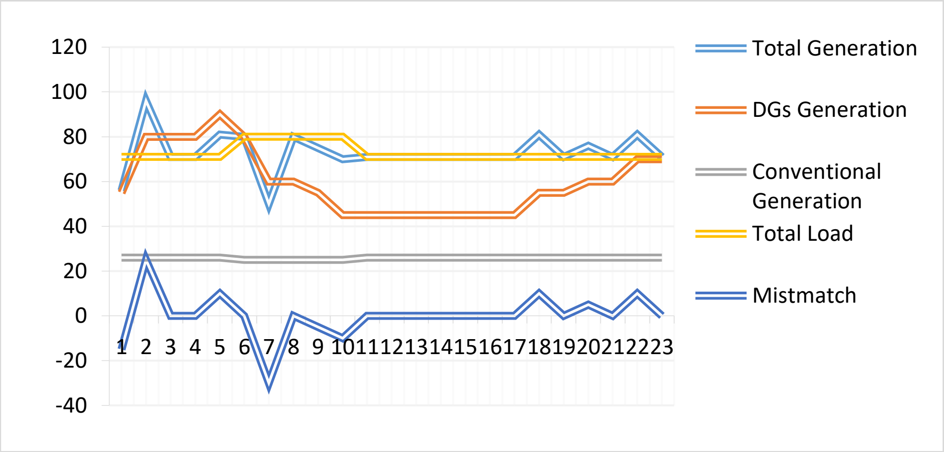

Figure 5. The storage system monitors fluctuations from RES and balances the mismatch.

Certainly, the system's controller functions automatically by constantly retrieving data from a network of strategically placed sensors distributed throughout the infrastructure. These sensors serve as the vital data sources that enable the controller to make informed real-time decisions. To make these decisions, the controller relies on a meticulously designed algorithm, which is visually represented in Figure 6. This algorithm plays a pivotal role in determining the most suitable and effective resource for addressing any prevailing imbalances within the system.

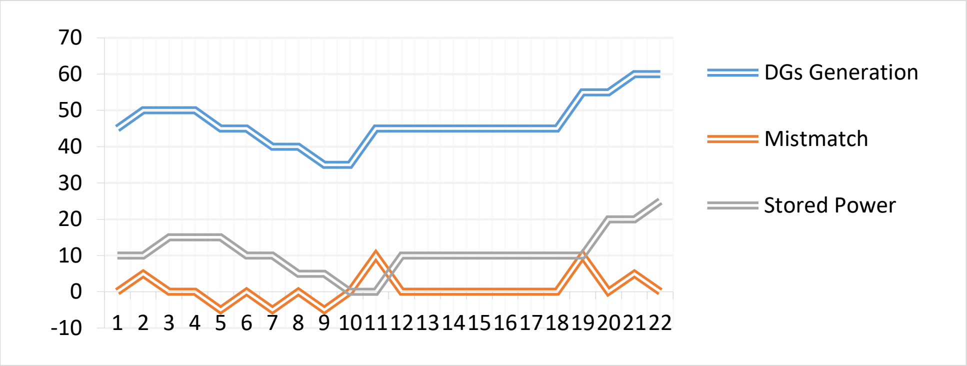

Figure 6. Production from DGs Generator, Mismatch and Stored Power

For instance, when the system boasts an ample capacity for energy storage, the algorithm swiftly triggers the activation of the storage system to counteract and rectify the detected imbalances. This mechanism ensures that the system remains stable and optimized to meet its energy demands. The controller automatically collects data through sensors placed at different points in the system and makes real-time decisions based on this data. An algorithm is used by the controller to select the most appropriate resource to address the imbalance. For instance, if suitable storage capacity is available, the algorithm defined in Figure 7. activates the storage system to address the imbalance.

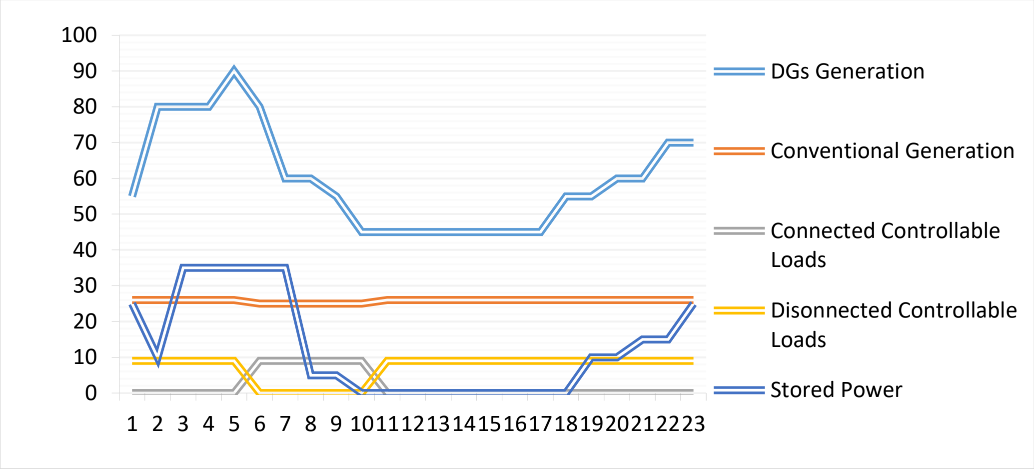

Figure 7. Storage, Controllable Load, and Smart Generation involved in adjusting the imbalance.

As seen in Figure 5, the energy storage system balances fluctuations by storing energy when there is excess production from RES and supplying energy to the grid when RES production decreases. Similarly, as shown in Figure 6, RES production varies between 25 MW and 60 MW, while the energy storage capacity remains at 15 MW, and the total capacity allocated to controllable loads to address the mismatch is 6 MW. In this scenario, the imbalance is addressed solely by the energy storage system. If the energy storage source is either full or empty, the controller searches for loads in the load data server that are allocated for use by the controller (these loads could be related to demand response or loads that customers allocate based on their intensity, such as electric vehicle charging or discharging). In this situation, neither energy storage nor controllable loads can address the imbalance, and as a result, the controller activates smart generation systems to further stabilize the system. Figure 7 illustrates the use of controllable loads and smart generation resources in addition to the energy storage source to address the imbalance.

IV. RESULTS AND RECOMMENDATIONS

In conclusion, the successful integration of renewable energy power plants into smart grids hinges on the implementation of active power control strategies. These strategies play a pivotal role in enabling grid operators to effectively manage the inherent variability and intermittency of renewable energy sources. By actively adjusting power generation and distribution in real-time, grid operators can maintain grid stability and reliability, ensuring a seamless transition to a cleaner and more sustainable energy future.

In conclusion, this research demonstrates that a smart grid, especially when integrated with intermittent renewable energy systems, can make the power system more efficient and stable. In a smart grid, it is possible to integrate renewable energy systems and control the imbalance between supply and demand in real-time. This requires access to data obtained from generation, loads, storage systems, energy markets, and more. This data access is made possible through the communication, information, and sensor infrastructure embedded within the smart grid. This study shows that the imbalance in the system can be addressed, even when the proportion of Renewable Energy Sources in the system is very high. This method is particularly important when there are fewer synchronous machines in the network, and the system has low inertia. The selection order of the controller methods, such as energy storage systems, controllable loads, smart generators, or load shedding, depends on factors like available capacity, environmental data, market data, the location of resources, and more. Achieving an efficient and effective solution requires optimization. Ongoing research in this direction aims to further refine these methods and explore the optimal strategies for managing imbalances within the grid.

In conclusion, this research demonstrates that in smart grids, especially when integrating intermittent renewable energy systems, the power system can become more efficient and stable. In smart grids, it is possible to integrate renewable energy systems and control the imbalance between supply and demand in real-time. This requires access to data obtained from productions, loads, storage systems, energy markets, and more. This data access can be achieved through the communication, information, and sensor infrastructure embedded in the smart grid. This study shows that the system's imbalance can be addressed even when the ratio of RES within the system is very high. The proposed method is particularly important in cases where there are fewer synchronous machines in the network and low system inertia. The method can also be applied to balance supply and demand in cases of load variation or other contingencies. The selection order of controller methods, such as storage systems, controllable loads, smart generation systems, or load shedding, depends on factors like available capacity, environmental data, market data, resource locations, and more. Optimization is required to achieve a suitable and efficient solution. Ongoing research is focusing on further exploring this area. Future research in the field of "Integration of Renewable Energy Power Plants into Smart Grids, Active Power Control" should explore advanced control algorithms and technologies that enhance the accuracy and responsiveness of active power control systems.

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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