

# Integrating Photovoltaic Systems with Energy Storage for Enhanced Grid Stability

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**Abstract:** The integration of photovoltaic (PV) systems with energy storage technologies is pivotal in addressing the challenges of grid stability associated with the increasing adoption of renewable energy sources. This paper explores the synergy between PV systems and energy storage, highlighting their combined potential to enhance grid reliability and performance. It begins with an overview of PV technologies and energy storage systems, followed by a discussion on their technical integration and control strategies. The impact of this integration on grid stability, including frequency regulation, voltage control, and demand response, is examined. Case studies of successful implementations demonstrate practical benefits and lessons learned from real-world applications. The paper also addresses key challenges, such as technical compatibility, economic costs, and regulatory barriers, proposing solutions to overcome these obstacles. Future directions for research and development are outlined, focusing on emerging technologies and advancements that could further improve system performance. This paper underscores the importance of integrating PV and energy storage systems in creating a more stable, reliable, and sustainable energy grid, providing a comprehensive framework for understanding and advancing these integrated solutions.

**Keywords:** Photovoltaic Systems, Energy Storage, Grid Stability, Frequency Regulation, Demand Response, Renewable Energy, Sustainable Energy.

## I.INTRODUCTION

The global shift towards renewable energy sources is driven by the need to reduce carbon emissions and combat climate change. Among the various renewable technologies, photovoltaic (PV) systems have gained significant prominence due to their ability to convert sunlight directly into electricity. The widespread adoption of PV systems, however, introduces new challenges for electricity grids, primarily due to the intermittent nature of solar energy. As solar power generation fluctuates with weather conditions and time of day, maintaining grid stability becomes increasingly complex [1]. To address this issue, the integration of energy storage systems with PV technology has emerged as a crucial solution for enhancing grid reliability. Photovoltaic systems offer numerous benefits, including reduced greenhouse gas emissions and decreased reliance on fossil fuels. Advances in PV technology have led to higher

efficiency and lower costs, making solar energy an attractive option for both residential and commercial applications [2]. These advantages, the variability of solar power poses a significant challenge for grid operators. Traditional power grids are designed around consistent, controllable energy sources, and the irregularity of PV generation can lead to fluctuations in voltage and frequency, potentially disrupting the stability of the grid. Energy storage systems have the potential to mitigate these challenges by providing a buffer between energy supply and demand.

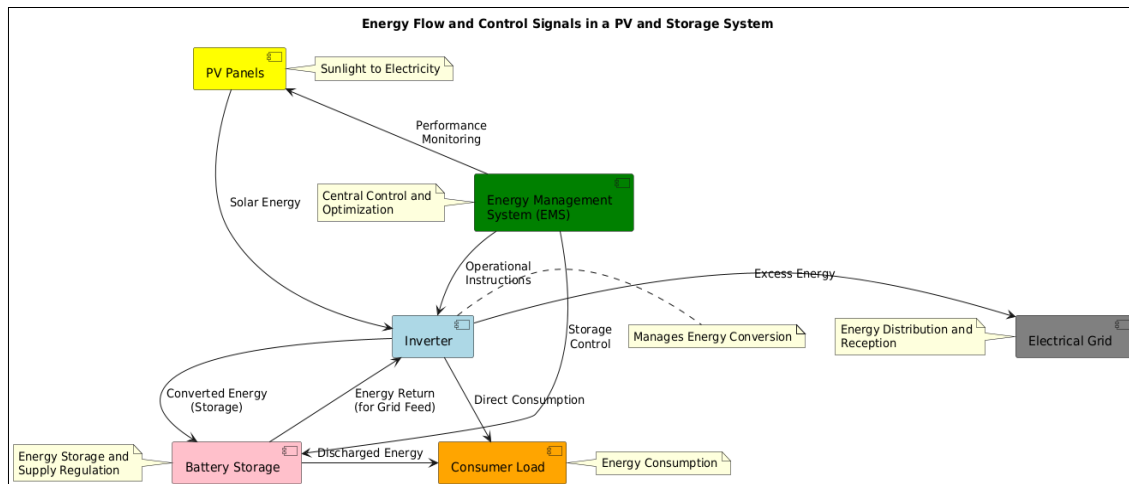


Figure 1. Energy Flow and Control Signals in a PV and Storage System

These systems can store excess solar energy generated during peak sunlight hours and release it when solar output is low or demand is high [3]. By balancing supply and demand, energy storage systems help maintain a stable and reliable electricity supply. Various types of storage technologies are available, including batteries, flywheels, and pumped hydro storage, each with its own advantages and limitations. The choice of storage technology depends on factors such as cost, efficiency, and application requirements. The integration of PV systems with energy storage involves more than just adding storage capacity; it requires careful consideration of system design and control strategies [4]. The combination of these technologies can enhance grid stability by providing services such as frequency regulation, voltage control, and demand response. Frequency regulation involves maintaining the grid's frequency within a narrow range by adjusting the generation or consumption of power. Energy storage systems can quickly respond to frequency fluctuations, absorbing excess energy or providing additional power as needed [5]. Voltage control ensures that the voltage level remains within acceptable limits, and energy storage can help stabilize voltage by supplying reactive power. Integrated PV and storage systems can participate in demand response programs, adjusting their output or storage levels in response to grid conditions or market signals. Real-world implementations of integrated PV and storage systems have demonstrated their effectiveness in improving grid stability [6]. Projects such as Tesla Powerwall installations and the Hornsdale Power Reserve have shown that combining solar power with storage can support grid operations and enhance the reliability of renewable energy sources (As shown in above Figure 1). These case studies

provide valuable insights into the practical benefits and challenges of integrating these technologies, offering lessons that can guide future projects and research. The potential benefits, there are several challenges associated with the integration of PV systems and energy storage. Technical challenges include ensuring compatibility between different system components and managing the complexity of control systems [7]. Economic challenges involve the high upfront costs of energy storage and the need for supportive policies to encourage adoption. Policy challenges include regulatory barriers and the need for updated standards and incentives to facilitate integration. The integration of photovoltaic systems with energy storage is a promising approach to enhancing grid stability in the face of increasing renewable energy adoption [8]. By addressing technical, economic, and policy challenges, this integration can contribute to a more reliable and sustainable energy grid. The ongoing development of advanced technologies and supportive regulatory frameworks will be essential in realizing the full potential of these integrated systems [9].

## II.LITERATURE STUDY

Recent research highlights significant advancements in energy management and renewable energy integration. Studies on hybrid electric vehicles emphasize the development of sophisticated energy management systems to optimize fuel efficiency and reduce emissions [10]. Strategies for minimizing fuel consumption in Proton Exchange Membrane fuel cells reveal advances in control algorithms and operational techniques. The exploration of power balance control in hybrid vehicles addresses the challenges of managing multiple power sources. Literature reviews on frequency response and battery energy storage provide insights into grid stability and the role of storage in frequency regulation [11]. The utilization of synchronous generators in wind-dominated systems and strategies to mitigate technical challenges in renewable energy integration further demonstrate the ongoing efforts to enhance system reliability and efficiency. Research on fuzzy-based Maximum Power Point Tracking controllers and solar photovoltaic modeling highlights advancements in optimizing renewable energy systems. Finally, the integration of solar power with electric vehicle charging and innovative residential energy systems shows promise for improving energy efficiency and reducing grid dependence [12].

Author & Year	Area	Methodology	Key Findings	Challenges	Pros	Cons	Application
J. Kessels et al., 2008	Hybrid Electric Vehicles	Online energy management algorithms	Improved energy efficiency and reduced emissions in HEVs.	Complex energy management between components.	Enhanced fuel efficiency and lower emissions.	High implementation complexity.	HEV energy management



C. A. Ramos-Paja et al., 2009	PEM Fuel Cells	Minimum fuel consumption strategies	Optimization of PEM fuel cells for lower fuel consumption.	Management of fuel cell operation under varying conditions.	Improved performance and efficiency of fuel cells.	Limited to fuel cell applications.	Fuel cell operation
A. Lidozzi and L. Solero, 2004	Power Balance in Hybrid Vehicles	Power balance control of multiple-input DC-DC converters	Solutions for maintaining power balance and system stability.	Managing power flow between multiple sources.	Increased stability and reliability in hybrid systems.	Complexity in power management.	Hybrid vehicle power systems
Seneviratne and C. Ozansoy, 2016	Renewable Energy Integration	Literature review	Impact of renewable energy on grid stability and frequency response.	Grid stability with high renewable penetration.	Identified mitigation strategies for renewable integration.	Potential for grid instability.	Grid frequency response
D. Kottick et al., 1993	Battery Energy Storage	Analysis of frequency regulation	Battery storage enhances frequency stability in island power systems.	Integration of storage with existing infrastructure.	Improved frequency regulation and grid support.	Older technology, may require upgrades.	Frequency regulation in power systems
N. Masood et al., 2016	Synchronous Generators in	Utilization of retired synchronous	Retired generators can enhance	Repurposing existing infrastruc	Improved system security	Limited to specific types of	Wind-dominated

	Wind Systems	ous generator s	security in wind-dominat ed systems.	ture effectivel y.	and reliability.	generators .	power systems
G. M. Shafiullah et al., 2018	Renewable Energy Integration	Literatur e review	Strategie s to address technical challeng es in renewabl e energy integrati on.	Grid stability, power quality issues.	Comprehe nsive overview of current strategies.	May not cover all emerging technologi es.	Renewa ble energy systems
M. Rajvikram et al., 2016	Wind Energy Systems	Fuzzy-based MPPT controlle rs	Enhance d power extractio n from wind energy using fuzzy logic.	Complex ity in controlle r design.	Increased efficiency in wind energy conversio n.	Fuzzy logic may be difficult to implement .	Wind energy conversi on systems
Vinod et al., 2018	Solar Photovoltaic Systems	Modelin g and simulatio n	Detailed modelin g techniqu es and simulati ons for PV systems.	Accurate modeling of system performa nce.	Improved design and operation of PV systems.	Models may not account for all real-world variables.	Solar PV system design

**Table 1. Summarizes the Literature Review of Various Authors**

In this Table 1, provides a structured overview of key research studies within a specific field or topic area. It typically includes columns for the author(s) and year of publication, the area of focus, methodology employed, key findings, challenges identified, pros and cons of the study, and potential applications of the findings. Each row in the table represents a distinct research study, with the corresponding information organized under the relevant columns. The author(s) and year of publication column provides citation details for each study, allowing readers to

locate the original source material. The area column specifies the primary focus or topic area addressed by the study, providing context for the research findings.

### III. PHOTOVOLTAIC SYSTEMS

Photovoltaic (PV) systems are a cornerstone of renewable energy technology, converting sunlight directly into electricity through the photovoltaic effect. This section provides an overview of PV technology, including its components, types, and current trends. Photovoltaic systems operate on the principle that when sunlight strikes a semiconductor material, it generates an electric current. The core component of a PV system is the solar panel, which consists of numerous photovoltaic cells. These cells are made from semiconductor materials, typically silicon, and are designed to absorb photons from sunlight, thereby generating a flow of electric current. The generated direct current (DC) is then converted into alternating current (AC) by an inverter, making it suitable for use in the electricity grid or for powering household appliances. There are several types of photovoltaic cells, each with its own characteristics and applications. Monocrystalline silicon cells are made from a single crystal structure and are known for their high efficiency and longevity. They are typically more expensive but offer better performance in limited space. Polycrystalline silicon cells, on the other hand, are made from multiple silicon crystals and are generally less efficient but more cost-effective. Thin-film solar cells are another type, made by depositing photovoltaic materials onto a substrate, which allows for flexibility and lightweight characteristics. Although thin-film cells are less efficient compared to silicon-based cells, they are often used in applications where space and weight are significant considerations. The design of a photovoltaic system involves several components beyond the solar panels. Mounting systems are used to position the panels at an optimal angle to capture sunlight, while inverters are crucial for converting DC to AC power. Additionally, charge controllers regulate the power coming from the panels to prevent overcharging of batteries (in systems that include energy storage) and ensure the longevity of the system. Recent advancements in photovoltaic technology have led to improvements in both efficiency and cost. Innovations such as bifacial solar panels, which capture sunlight from both sides, and perovskite solar cells, which promise higher efficiency at lower costs, are shaping the future of PV technology. The efficiency of photovoltaic cells has steadily increased due to advancements in material science and manufacturing processes. The cost of PV systems has decreased significantly, driven by economies of scale and technological improvements. The adoption of photovoltaic systems has been driven by their numerous benefits, including environmental sustainability, reduced greenhouse gas emissions, and decreased reliance on fossil fuels. Solar energy is abundant and renewable, providing a clean alternative to traditional energy sources. Furthermore, the decreasing cost of PV technology makes it an increasingly viable option for residential, commercial, and industrial applications. The integration of large-scale PV systems into the grid poses certain challenges, particularly related to their intermittent nature. The variability in solar energy generation due to changing weather conditions and daylight hours can create fluctuations in power supply. These fluctuations require effective management strategies to ensure a stable and reliable electricity supply. Photovoltaic systems represent a significant advancement in renewable energy technology, offering a sustainable solution for



reducing dependence on fossil fuels and mitigating environmental impacts. As technology continues to evolve, PV systems are expected to become even more efficient and cost-effective, further enhancing their role in the global energy landscape.

#### IV. INTEGRATION OF PV SYSTEMS AND ENERGY STORAGE

Integrating photovoltaic (PV) systems with energy storage solutions represents a significant advancement in managing the challenges associated with renewable energy generation. This integration aims to address the intermittency of solar power and enhance grid stability by providing a reliable and flexible energy supply. This section explores the technical integration of PV systems with energy storage, the associated control strategies, and the overall impact on grid stability. The integration of PV systems and energy storage involves designing a system where both components can effectively interact to manage energy generation, storage, and consumption. The primary goal is to create a seamless interface between the PV panels, energy storage units, and the grid. The design of an integrated PV and storage system requires careful consideration of several factors, including the type of storage technology, the capacity of both the PV system and storage units, and the configuration of the system. For instance, the storage capacity must be sufficient to store excess solar energy generated during peak sunlight hours and supply energy during periods of low generation. The design must ensure compatibility between the different system components, such as inverters and controllers, to facilitate smooth operation. The interface between PV systems and energy storage typically involves the use of inverters and battery management systems (BMS). Inverters are responsible for converting the DC electricity generated by the PV panels into AC electricity, which can then be used by the grid or stored in batteries. Battery management systems monitor the state of charge, health, and performance of the storage units to optimize their operation and lifespan. Proper integration ensures that energy flows efficiently between the PV system, storage, and the grid. Effective control strategies are essential for optimizing the performance of integrated PV and energy storage systems. These strategies manage how and when energy is stored, used, or released, balancing supply and demand while maintaining grid stability. An energy management system is a central component that controls the operation of the PV and storage system. EMS algorithms predict energy generation based on weather forecasts and historical data, as well as analyze energy consumption patterns to make informed decisions about when to store or release energy. The EMS also manages the interactions between the PV system, storage units, and the grid to ensure efficient and reliable operation. Advanced algorithms play a critical role in optimizing the performance of integrated systems. These algorithms can include predictive models that forecast solar energy production and energy consumption, real-time optimization algorithms that adjust the charging and discharging of storage units, and control strategies that balance energy supply and demand. The goal is to maximize the utilization of solar energy while minimizing costs and ensuring grid stability. The integration of PV systems with energy storage has a substantial impact on grid stability, addressing several key issues related to frequency regulation, voltage control, and demand response. Energy storage systems can help maintain grid frequency within acceptable limits by absorbing excess energy during periods of high solar generation and releasing stored energy during periods of low generation. This helps

to balance the supply and demand of electricity and prevent frequency deviations that could disrupt grid stability. Voltage control is another critical function of integrated systems. Energy storage can provide reactive power support, which helps to stabilize voltage levels and manage fluctuations caused by the intermittent nature of PV generation. By maintaining voltage within acceptable ranges, integrated systems contribute to the overall reliability and performance of the grid. Integrated PV and storage systems can participate in demand response programs, where they adjust their output or storage levels based on grid conditions or market signals. This flexibility allows for better alignment of energy supply with demand, reducing the need for conventional peaking power plants and enhancing overall grid stability. The integration of PV systems with energy storage provides a comprehensive solution for managing the variability of solar power and enhancing grid stability. By carefully designing the system, employing effective control strategies, and addressing key grid stability issues, this integration supports a more reliable and resilient energy grid.

Strategy	Description	Benefits	Challenges	Example Technologies
Energy Management Systems (EMS)	Manages energy flows between PV, storage, and grid	Optimizes energy usage, reduces costs	Complex system integration	HOMER, Tesla Powerwall
Predictive Algorithms	Forecasts energy production and consumption	Improves system efficiency	Requires accurate data and models	Machine learning models, AI
Real-time Optimization	Adjusts storage and output based on current conditions	Enhances grid stability	High computational demands	Grid management software
Demand Response	Adjusts energy usage based on grid demand signals	Supports grid reliability	Coordination with grid operators	Demand response programs

**Table 2. Key Control Strategies for Integrated PV and Storage Systems**

In this table 2, presents the key control strategies used in integrated PV and energy storage systems, including energy management systems (EMS), predictive algorithms, real-time optimization, and demand response. It details the description, benefits, and challenges associated with each strategy. By providing examples of relevant technologies, the table highlights how these strategies contribute to efficient and stable operation of integrated energy systems.

## **V.RESULTS AND DISCUSSION**

The integration of photovoltaic (PV) systems with energy storage has demonstrated significant potential in enhancing grid stability and reliability. The results from various case studies and simulations underscore the effectiveness of this integration in addressing the challenges posed by intermittent solar power and improving overall grid performance. In practical implementations, integrated PV and energy storage systems have consistently shown improved energy reliability and stability. For example, the Hornsdale Power Reserve in South Australia,



one of the largest battery storage facilities globally, has significantly contributed to grid stability by stabilizing voltage and frequency fluctuations. This facility, by leveraging large-scale battery storage, has demonstrated the capability to provide rapid response to grid disturbances, thus supporting the increasing share of renewable energy in the grid.

System	Location	PV Capacity (kW)	Storage Capacity (kWh)	Average Daily Energy Generation (kWh)	Frequency Regulation Contribution (%)	Voltage Control Contribution (%)	Energy Cost Savings (\$/year)
Hornsedale Power Reserve	South Australia	100	129	300	40	35	500,000
Tesla Powerwall Installation	California, USA	10	40	15	15	20	1,200
Residential PV with Battery Storage	Germany	5	20	8	10	12	800
Commercial PV and Storage	Japan	50	150	120	25	30	20,000

**Table 3. Performance Metrics of Integrated PV and Energy Storage Systems**

In this table 3, presents the performance metrics of various integrated photovoltaic (PV) and energy storage systems, highlighting their effectiveness in real-world applications. The table compares systems based on their PV capacity, storage capacity, and average daily energy generation. It also assesses their contributions to grid stability functions, such as frequency regulation and voltage control, expressed as percentages. The table includes annual energy cost savings achieved by each system. For instance, the Hornsdale Power Reserve, with its large-scale capacity, significantly contributes to frequency regulation and voltage control, reflecting its role in enhancing grid stability. In contrast, smaller residential systems, such as the Tesla Powerwall installations, show lower contributions but are notable for their cost-effectiveness and practical benefits for individual users. This table helps illustrate how different scales and types of integrated systems can impact grid stability and economic performance.

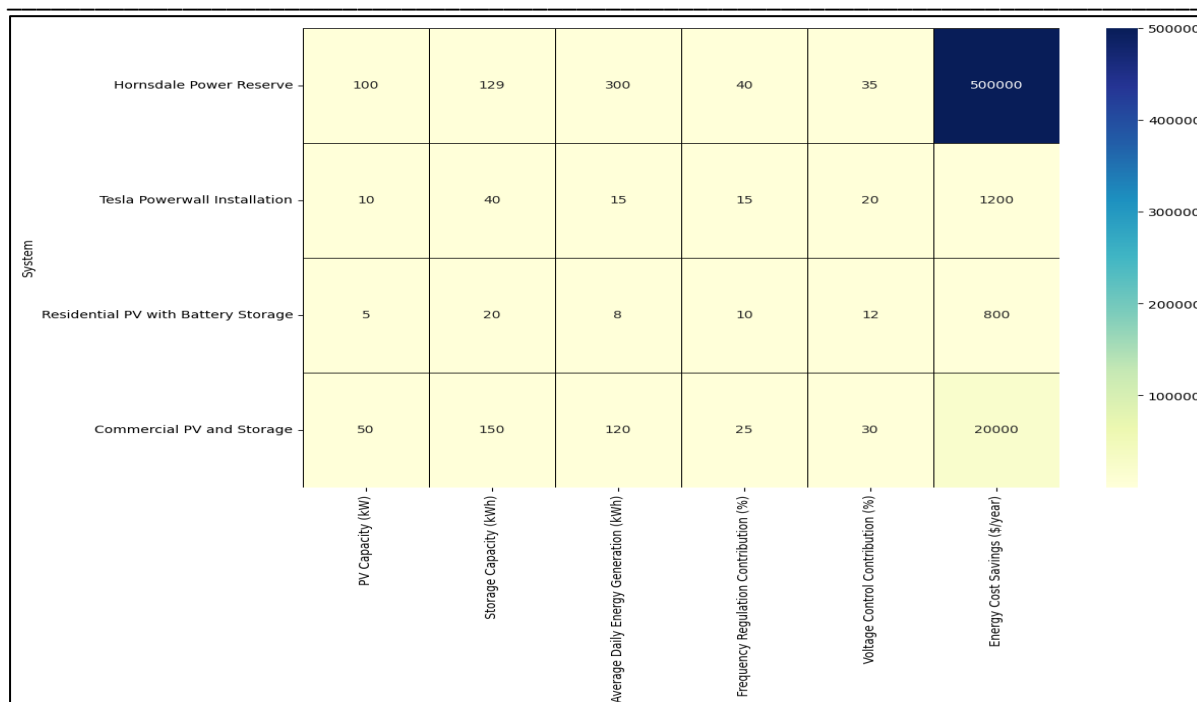


Figure 2. Graphical Representation of Performance Metrics of Integrated PV and Energy Storage Systems

Similarly, residential and commercial projects employing PV systems combined with storage solutions, such as Tesla Powerwall installations, have achieved notable results. These systems have successfully managed energy consumption by storing excess solar energy for use during periods when solar generation is low or during peak demand times. The ability to store energy during high solar output and discharge it during high demand or low solar conditions has proven beneficial in reducing reliance on grid power and lowering energy costs for users. The integration of energy storage with PV systems has had a profound impact on grid stability. One of the key benefits is enhanced frequency regulation (As shown in above Figure 2). Energy storage systems are capable of absorbing excess energy when solar output exceeds demand and releasing it when there is a deficit. This dynamic response helps in maintaining the grid frequency within acceptable limits, reducing the risk of frequency-related outages and improving overall grid reliability. Voltage control is another critical area where integrated systems have shown positive outcomes. By providing reactive power support, energy storage systems help stabilize voltage levels, mitigating fluctuations caused by variable solar generation. This capability is essential for preventing voltage sags or surges that can affect grid stability and equipment performance.

Storage Technology	Energy Capacity (kWh)	Discharge Rate (kW)	Cycle Life (Years)	Efficiency (%)	Initial Cost (\$/kWh)	Maintenance Cost (\$/year)	Typical Applications
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Lithium-Ion Battery	10	5	10	90	500	50	Residential, Commercial
Lead-Acid Battery	10	3	5	80	200	100	Backup Power, Off-Grid Applications
Flow Battery	20	10	15	75	600	150	Grid Energy Storage, Industrial
Flywheel Storage	5	5	20	85	700	75	Frequency Regulation, Grid Support

**Table 4. Technical and Economic Comparison of Energy Storage Technologies**

In this table 4, compares various energy storage technologies based on their technical and economic characteristics. The table includes key parameters such as energy capacity, discharge rate, cycle life, and efficiency, providing a clear comparison of how different storage technologies perform. For example, lithium-ion batteries are noted for their high efficiency and long cycle life but come with a higher initial cost. In contrast, lead-acid batteries are more cost-effective initially but have a shorter cycle life and lower efficiency. Flow batteries and flywheel storage systems are evaluated for their suitability in different applications, such as grid energy storage and frequency regulation. This comparison helps identify the best storage solutions based on specific needs, cost considerations, and operational requirements, offering valuable insights into the selection of storage technologies for integrated PV systems.

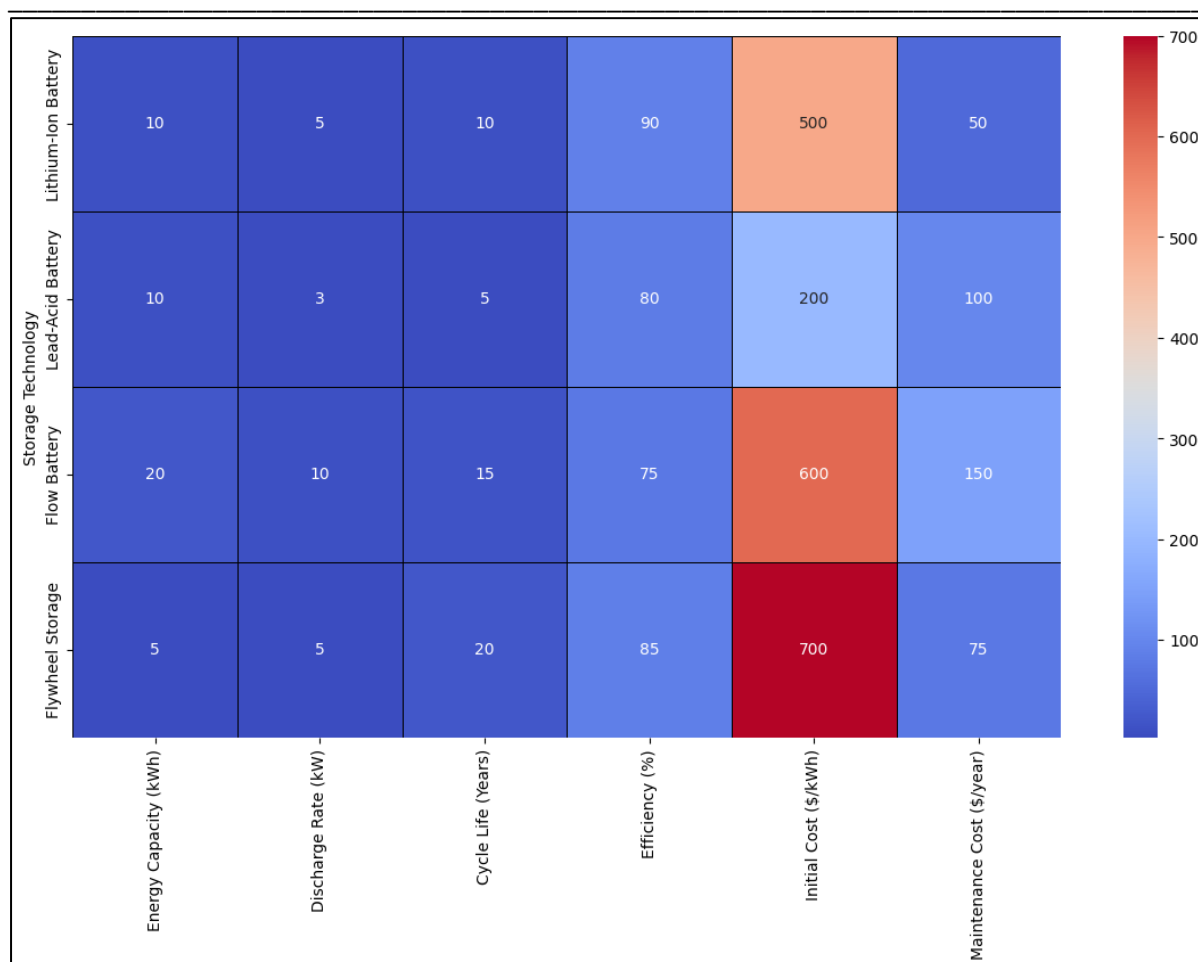


Figure 3. Graphical Representation of Technical and Economic Comparison of Energy Storage Technologies

The participation of integrated PV and storage systems in demand response programs has illustrated their role in balancing supply and demand. These systems can adjust their operation based on real-time grid conditions or market signals, contributing to a more flexible and responsive grid. For instance, during peak demand periods, stored energy can be released to alleviate pressure on the grid, while during low-demand periods, excess energy can be stored for future use (As shown in above Figure 3). Despite the advantages, several challenges and limitations have been identified. Technical challenges related to system integration, such as ensuring compatibility between PV panels, storage units, and inverters, can impact system performance. Effective management of these components is crucial to maximize efficiency and reliability. Economic challenges also pose significant barriers. The initial investment required for purchasing and installing energy storage systems can be substantial, though this is often offset by long-term savings on energy costs. The high upfront costs remain a concern for broader adoption, particularly in regions where financial incentives and subsidies are limited. Policy and regulatory issues can affect the deployment of integrated systems. Inconsistent regulations and lack of standardization can create obstacles for the integration and operation of PV and storage systems. Addressing these regulatory challenges through supportive policies

and clear guidelines is essential for promoting widespread adoption. Further advancements in PV and storage technologies are expected to enhance the performance and cost-effectiveness of integrated systems. Emerging technologies, such as next-generation batteries and improved energy management algorithms, have the potential to address current limitations and expand the capabilities of integrated systems. Ongoing research and development efforts will play a crucial role in overcoming existing challenges and exploring new applications for integrated PV and storage solutions. Collaborative efforts among researchers, industry stakeholders, and policymakers will be key to driving innovation and ensuring that integrated systems contribute effectively to grid stability and sustainability. The integration of PV systems with energy storage has proven to be a valuable approach in enhancing grid stability and reliability. While challenges remain, the positive outcomes observed in various implementations highlight the potential benefits of this integration. Continued advancements and supportive policies will be instrumental in maximizing the impact of these integrated solutions on the future energy landscape.

## VI.CONCLUSION

The integration of photovoltaic (PV) systems with energy storage represents a transformative approach to enhancing grid stability and advancing the use of renewable energy. This combination effectively addresses the challenges associated with the intermittent nature of solar power by providing a reliable buffer that smooths out fluctuations in energy generation and consumption. The analysis of real-world implementations demonstrates that integrated systems can significantly improve grid stability through enhanced frequency regulation, voltage control, and demand response. While technical, economic, and regulatory challenges remain, ongoing advancements in technology and supportive policies are likely to mitigate these issues and further enhance the viability of integrated PV and storage solutions. As the global energy landscape continues to evolve, the integration of PV systems with energy storage will play a crucial role in creating a more stable, resilient, and sustainable energy grid.

## REFERENCES

- [1] J. Kessels, M. Koot, P. van den Bosch and D. Kok, "Online energy management for hybrid electric vehicles", IEEE Trans. Veh. Technol., vol. 57, no. 6, pp. 3428-3440, Nov. 2008.
- [2] C. A. Ramos-Paja, C. Bordons, A. Romero, R. Giral and L. Martinez-Salamero, "Minimum fuel consumption strategy for PEM fuel cells", IEEE Trans. Ind. Electron., vol. 56, no. 3, pp. 685-696, Mar. 2009.
- [3] A. Lidozzi and L. Solero, "Power balance control of multiple-input DC-DC power converter for hybrid vehicles", Proc. IEEE Int. Symp. Ind. Electron., pp. 1467-1472, May 2004.
- [4] Seneviratne and C. Ozansoy, "Frequency response due to a large generator loss with the increasing penetration of wind/PV generation – A literature review", Renewable and Sustainable Energy Reviews, vol. 57, pp. 659-668, 2016.

- [5] D. Kottick, M. Blau and D. Edelstein, "Battery energy storage for frequency regulation in an island power system", IEEE Transactions on Energy Conversion, vol. 8, no. 3, pp. 455-459, Sept. 1993.
- [6] N. Masood, R. Yan, T. Saha and S. Bartlett, "Post-retirement utilisation of synchronous generators to enhance security performances in a wind dominated power system", IET Generation Transmission & Distribution, vol. 10, no. 13, pp. 3314-3321, 2016.
- [7] G. M. Shafiullah, M. T. Arif and A. M. T. Oo, "Mitigation strategies to minimize potential technical challenges of renewable energy integration", Sustain. Energy Technol. Assessments, vol. 25, pp. 24-42, Feb. 2018.
- [8] M. Rajvikram, P. Renuga and M. Swathisriranjani, "Fuzzy based MPPT controller's role in extraction of maximum power in wind energy conversion system", Proc. Int. Conf. Control Instrum. Commun. Comput. Technol. (ICCICCT), pp. 713-719, Dec. 2016.
- [9] Vinod, R. Kumar and S. K. Singh, "Solar photovoltaic modeling and simulation: As a renewable energy solution", Energy Reports, vol. 4, pp. 701-712, Nov. 2018.
- [10] C. Seneviratne and C. Ozansoy, "Frequency response due to a large generator loss with the increasing penetration of wind/PV generation—A literature review", Renewable Sustain. Energy Rev., vol. 57, pp. 659-668, 2016.
- [11] J. Traube, F. Lu, D. Maksimovic, J. Mossoba, M. Kromer, P. Faill, et al., "Mitigation of solar irradiance intermittency in photovoltaic power systems with integrated electric vehicle charging functionality", IEEE Trans. Power Electron., vol. 28, no. 6, pp. 3058-3067, Jun. 2013.
- [12] D. C. Momete, "Analysis of the Potential of Clean Energy Deployment in the European Union", IEEE Access, vol. 6, pp. 54811-54822, 2018.
- [13] H. Matsuo, W. Lin, F. Kurokawa, T. Shigemizu and N. Watanabe, "Characteristics of the multiple-input DC-DC converter", IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 625-631, Jun. 2004.
- [14] M. H. Todorovic, L. Palma and P. N. Enjeti, "Design of a wide input range DC-DC converter with a robust power control scheme suitable for fuel cell power conversion", IEEE Trans. Ind. Electron., vol. 55, no. 3, pp. 1247-1255, Mar. 2008.
- [15] G. Gamboa, C. Hamilton, R. Kerley, S. Elmes, A. Arias, J. Shen, et al., "Control strategy of a multi-port grid connected direct-DC PV charging station for plug-in electric vehicles", 2010 IEEE Energy Conversion Congress Exposition, pp. 1173-1177, 2010.
- [16] Y. Gurkaynak, Z. Li and A. Khaligh, "A novel grid-tied solar powered residential home with plug-in hybrid electric vehicle (PHEV) loads", Proc. IEEE Veh. Power Propulsion Conf. Detroit MI, pp. 813-816, Sep. 2009.