STM JOURNALS
International Journal of
Electrical Machine Analysis and Design
Volume 3, Issue 1, 2025
January–June
DOI (Journal): 10.37591/IJEMAD
https://journals.stmjournals.com/ijemad
Review IJEMAD

A Review on Energy Storage System Enhancing the Stability of Microgrids

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Abstract

Microgrids constitute decentralized energy systems that rely on a variety of distributed renewable energy sources, such as solar panels, wind turbines, and power and heat production plants. Energy storage systems (ESS) help improve the stability and reliability of microgrids by decreasing the intermittent nature of renewable energy sources. This analysis looks at how microgrids are classified and how ESS might help improve power quality and system dependability. It explores the many stability difficulties that microgrids encounter, such as voltage and frequency fluctuations, as well as control solutions for ensuring stability. Furthermore, this paper emphasizes advances in ESS technology and their importance in optimizing energy management in microgrids. By tackling critical stability challenges, ESS helps to design durable, efficient, and long-term microgrid systems. Future study areas are also proposed to increase the incorporation and performance of stored energy in microgrids.

Keywords: Microgrid, energy storage system (ESS), stability issues, ESS application, power supply

INTRODUCTION

In addition to the growing worry over conventional fuels, environmental concerns are putting greater emphasis on distributed generation using renewable energy sources. A new concept called a "microgrid" is produced by linking parallel distributed generators (DGs) to a group of loads in the energy system. Microgrids (MGs) are used in distribution businesses at both high voltage and low voltage levels [1]. The idea of MGs initially appeared in. A low voltage MG can operate in two modes:

1. *Connected mode:* The MG is linked to the main high voltage network and can inject or absorb electricity from it.
2. *Mode:* When the upstream network fails, the MG creates an island and powers the loads using a power management approach.

Microgrids are currently classified into three types: alternating current (AC) grids, direct current (DC) grids, and hybrid AC/DC (HACDC) grids. This is because electrical energy is generated in both AC and DC modes from several renewable sources [2]. AC microgrids connect AC generating sources directly to power electronic interfaces, whereas DC generating sources, that include solar panels and fuel cells, undergo conversion to AC via DC/AC conversion [3]. In contrast, in DC microgrids, AC-generating sources are transformed into DC via AC/DC converters. These many changes, however, result in financial losses. A hybrid MG, which reduces repeated conversions and losses, provides an instant answer to the issues described above [4]. Electrical power capacity and system reliability are the two significant and important factors related to hybrid systems. Classification of MGs is in Figure 1. The most efficient and consistent system design is required, and it may be achieved with the help of the system's apparatus, which should be chosen with care.

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Received Date: February 23, 2025
Accepted Date: February 27, 2025
Published Date: April 07, 2025

Citation: Salman Ahmed Khan, Vivek Tiwari, Reeha Chauhan. A Review on Energy Storage System Enhancing the Stability of Microgrids. International Journal of Electrical Machine Analysis and Design. 2025; 3(1): 1–6p.

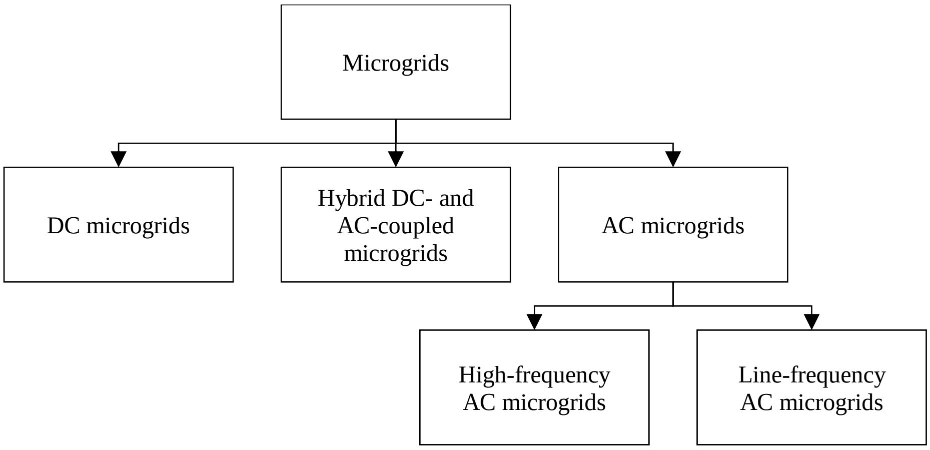

Figure 1. Classification of microgrids.

Decentralization, digitization, and an increase in the use of artificial intelligence (AI) and automation have replaced the top-down, centralized operations of traditional power utility networks in response to climate change action and the urgent need to decarbonize. Better power generation, as well as more effective transmission and distribution, are possible with smart grids [1]. A hierarchy of MGs that are connected to one another to build a larger smart grid can be used to enable extensive digitization and automation of an electrical network [2]. The smart grid's common key goals include grids monitoring and situation awareness, system efficiency improvements, dependability, resilience, and safety enhancements, improved economic operations, and dispersed real-time intelligent management and protection of system components. The fundamental goal of both European and non-European countries seeking a clean energy environment is to increase the use of energy from renewable sources, which smart grids also enable [3, 4].

The energy storage system (ESS) is considered as a vital enabler in providing efficient buffering against the inherent intermittency of renewable energy sources in an intelligent, autonomous, and decentralized microgrid system [5]. Because of the necessity for effective power distribution management, microgrid regulation, including ESSs, is a critical branch in the field of intelligent energy transmission lines.

LITERATURE REVIEW

This paper begins by explaining MG architecture and its challenges. Then, important ESS types are discussed, along with a brief overview of their characteristics. Arani et al. [6] examined ESS operating conditions and control techniques. The study looks at the benefits and drawbacks of various set-up and control strategies. A discussion of ESS control mechanisms and impending trends is also provided. Numerous studies have shown that the control of ESSs has a substantial impact on MGs' stability, economics, and other aspects.

Kumar and Biswal [7] investigated a critical MG component while also testing alternative battery energy management system (BEMS) techniques. It also clarifies the battery energy storage system’s (BESS's) useful actions in relation to how the MG functions.

Mehta et al. [8] offered a comprehensive analysis of the stability components mentioned above in the overall setting of the MG system, which has not been identified in the published literature.

The study by Chaudhary et al. [9] looks at a variety of technologies for storing energy that can be tightly connected and included in microgrids. Chaudhary et al. [9] investigated operational methodologies and features. This paper also shows how to use distributed energy storage systems to govern microgrid energy management systems.

Ekanayake and Navaratnr [10] investigated with several degrees of communication, particularly during island operations. This article focuses on the issues, concerns, and future projects. Arani et al. [6] provided an introduction to the design and uses of flywheel energy storage systems (FESS) in power systems and MGs; it can act as a catalyst for the invention of FESS applications and provides direction on how to use its benefits in a variety of situations. According to the findings of various studies, FESS, an emerging technology, may be effective in the operation of present and future power systems, as well as MG.

The study begins with a succinct introduction to micrograds and discusses forecasting techniques for both load demand and power supply side. Following their analysis, Ma and Ma [5] present distributed, decentralized, and centralized control systems for the micro grid. The top energy management algorithms for centralized controllers are found using data from short-term forecasting, and a generalized centralized control scheme is then presented. This paper addresses a consensus mechanism for dealing with the cooperative problem in a distributed energy system that is based on a multi-agent system. Finally, future strategies for energy management and forecasting are discussed. This study looks at MG components, the many renewable energy resources that make up a hybrid system, and the numerous controls, operational strategy, and goal settings available in an energy management system (EMS). Zahraoui et al. [4] classified MGs into three stages: primary, secondary, and tertiary. The purpose of this article is to augment the legislation, standards, protection plans, transactive markets, and load restoration in MGs produced by various nations.

The primary purpose of this research, which represents contemporary advances in digitalization and machine intelligence, is to concentrate on control systems that rely on multivalent communications and reinforcement learning. Al-Saadi et al. [3] suggested decentralized, centralized, multivalent, and intelligent control systems for managing and controlling distributed energy storage, which are thoroughly reviewed in this study. Additionally, it emphasizes the variety of services that these storages may offer, their control challenges, and suggested solutions. The summary of developing areas and the presentation of possible future directions come at the paper's conclusion.

APPLICATIONS OF ENERGY STORAGE SYSTEM

The ESSs are crucial components of the MGs and power system. Different ESS kinds have recently been developed and put to use. 1.4 GW of ESS capacity was added globally in 2017 [7]. Battery energy storage systems (BESSs), a long-established, well-developed, and still-evolving technology, have been utilized for a variety of purposes, including load balancing, the usage of electrical cars, and ancillary services. Compressed air energy storage (CAES), super magnetic energy storage (SMES), super capacitors (SC), and flywheel energy storage system (FESS) are further major ESSs with various applications and topologies. Figure 2 demonstrates some ESS uses in MGs and power systems.

Because ESSs frequently generate DC voltage, they need power electronics connections for connection to the AC power system and AC MG [7]. Some energy users may utilize DC power. Power electronics connections with semiconductor switches and ESSs offer increased controllability.

Energy storage strategies are utilized to quickly switch between high power sources while also meeting peak power requirements. The typical configuration's peak power supply consists of power plants that can flip on and off briefly. Modern power systems necessitate the usage of energy storage technologies. Typical peak power sources include gas turbines and hydroelectric power facilities [11]. These systems have significant initial costs and generate greenhouse gases due to the usage of natural gas as a fuel. Alternatives involve integrating sources of clean energy with energy storage devices, as well as utilizing energy storage alone in conjunction with conventional power plants. Energy storage alternatives provide a substantial alternative to these systems [12].

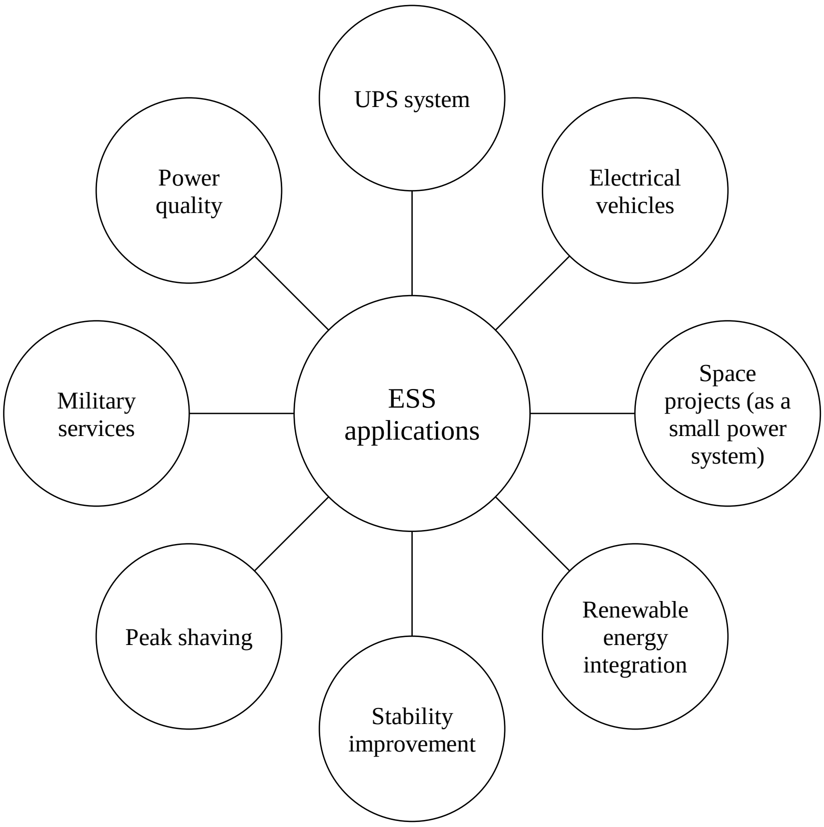

Figure 2. Applications of energy storage system (ESS).

Energy storage solutions can benefit consumers and electrical systems. These advantages include those for end consumers, energy from renewable sources, and the functioning and infrastructures of the electric grid. Energy storage advantages are classified into three types: distribution or bulk power, power-oriented, and capacity-oriented [13]. When employed as a resource, energy storage provides two substantial benefits. There are two examples: time-shifted electrical power and electric resource capacity.

CLASSIFICATION OF STABILITY ISSUES IN MICROGRIDS

There are three basic categories for considering stability issues in MGs: voltage stability, transient stability, and small-signal stability [14]. The main causes of the multiple issues are rapid load shifts, undervoltage load shedding, DER (distributed energy resources) loss, MG faults, islanding conditions, and so on. Stability in MGs is classified based on the physical origin of instability, the magnitude of the disruption, the physical elements involved, the duration of the period during which instability occurs, and the methodologies used to measure or predict the instability [15]. Because voltage and frequency are inextricably linked in microgrids, instability manifests as changes in all system parameters instead of distinct instability patterns in earlier systems. Stability issues in MGs are shown in Figure 3. Because of the complex interplay of system components, identifying instability occurrence as “voltage instability” or “frequency instability” based solely on relevant variable measures is very difficult. Table 1 summarizes these and discusses how each sort of instability may express itself in the system shown. Given this limitation, the more realistic approach proposed is based on the types of equipment and/or controllers involved in the instability process produced by a system shutdown [16].

The central controller used for MG stability enhancement displays its crucial importance by attempting to adjust for unbalanced/fluctuating voltages in an islanded MG due to an unknown load and power supply mismatch. Studies have investigated MG stability issues from a variety of perspectives, including distant, institution, and grid-connected MGs, as well as augmenting methods.

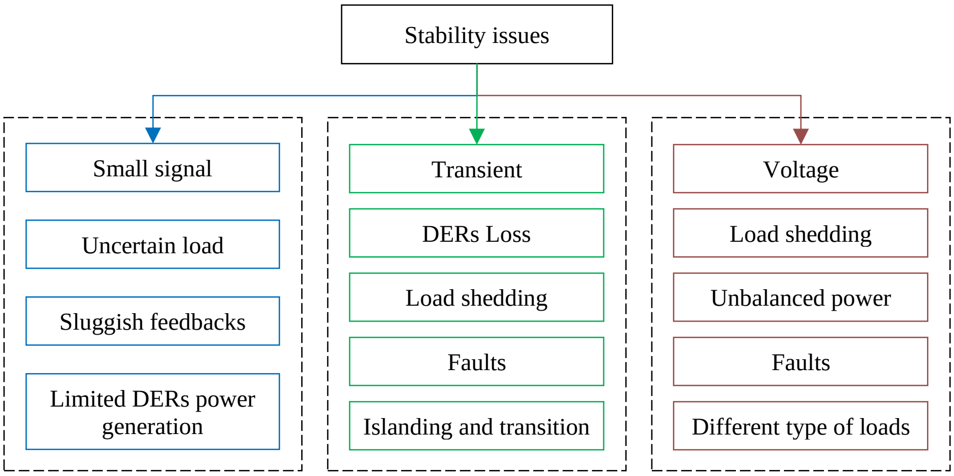

Figure 3. Stability issues in microgrids.

Table 1. Stability issues and how each sort of instability may express itself in the system.

Category	Manifestations	Root cause	Subcategory
Control system stability	Undamped oscillations, irregular voltage and/or frequency rise or drop	The controller was poorly tuned.	Electric machines are stable.
Power supply and balancing stability.	Low steady-state incidence, high power, and rapid frequency change. An amplitude swings.	Capacitor for the DC link. Active power limits, poor power sharing, and inadequate active power supply	Frequency stability
Power supply and balance stability	Major power surges, high DC-link voltage waves, and low steady-state voltages.	Limits to distributed energy resources (DERs) power, an insufficient reactive charger, poorly shared reactive power, voltage sensitivity under load	Voltage stability
Control system stability	Oscillations without a pause, high-frequency oscillations with low steady-state voltages.	Phased lock loop (PLL) bandwidth issues, poor controller synchronization, and poor controller tuning	Converter stability

CONCLUSION

A microclimate is an economic system that serves a specific geographic area, such as a neighborhood, business center, hospital complex, or college campus. MGs generate electricity from one or more scattered power sources. Furthermore, many current MGs have energy storage, usually in the form of batteries. This work presents microgrid taxonomy and examines the use of energy storage devices in MGs for improving power quality. We also addressed how to classify stability issues in MGs.

REFERENCES

1. Rokrok E, Shafie-Khah M, Catalão JPS. Review of primary voltage and frequency control methods for inverter-based islanded microgrids with distributed generation. Renew Sustain Energy Rev. 2018; 82: 3225–3235. doi: 10.1016/j.rser.2017.10.022.
2. Pabbuleti B, Somlal J. A review on hybrid AC/DC microgrids: optimal sizing, stability control and energy management approaches. J Crit Rev. 2020; 7 (2): 376–381. doi: 10.31838/jcr.07.02.72.
3. Al-Saadi M, Al-Greer M, Short M. Strategies for controlling microgrid networks with energy storage systems: a review. Energies. 2021; 14 (21): 7234. doi: 10.3390/en14217234.
4. Zahraoui Y, Alhamrouni I, Mekhilef S, et al. Energy management system in microgrids: a comprehensive review. Sustainability. 2021; 13 (19): 10492. doi: 10.3390/su131910492.
5. Ma J, Ma X. A review of forecasting algorithms and energy management strategies for microgrids. Syst Sci Control Eng. 2018; 6 (1): 237–248. doi: 10.1080/21642583.2018.1480979.
6. Arani AAK, Karami H, Gharehpetian GB, Hejazi MSA. Review of flywheel energy storage systems structures and applications in power systems and microgrids. Renew Sustain Energy Rev. 2017; 69: 9–18. doi: 10.1016/j.rser.2016.11.166.

7. Kumar V, Biswal M. Benign effects of battery energy storage system for efficient microgrid operation along with its management: a review. In: 2021 International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT), Bhilai, India, February 19–20, 2021. pp. 1–5. doi: 10.1109/ICAECT49130.2021.9392482.
8. Mehta S, Basak P. A comprehensive review on control techniques for stability improvement in microgrids. Int Trans Electric Energy Syst. 2021; 31 (4): e12822. doi: 10.1002/2050-7038.12822.
9. Chaudhary G, Lamb JJ, Burheim OS, Austbø B. Review of energy storage and energy management system control strategies in microgrids. Energies. 2021; 14 (16): 4929. doi: 10.3390/en14164929.
10. Ekanayake UN, Navaratne US. A survey on microgrid control techniques in islanded mode. J Electric Computer Eng. 2020; 2020: 6275460. doi: 10.1155/2020/6275460.
11. Muhtadi A, Pandit D, Nguyen N, Mitra J. Renewable energy based microgrid: role of the architecture in grid enhancement towards sustainable energy. In: 2020 IEEE Industry Applications Society Annual Meeting, Detroit, MI, USA, October 10–16, 2020. pp. 1–11. doi: 10.1109/IAS44978.2020.9334887.
12. Yoldaş Y, Önen A, Muyeen SM, Vasilakos AV, Alan İ. Enhancing smart grid with microgrids: challenges and opportunities. Renew Sustain Energy Rev. 2016; 72: 205–214. doi: 10.1016/j.rser.2017.01.064.
13. Ravichandran A, Malysz P, Sirouspour S, Emadi A. The critical role of microgrids in transition to a smarter grid: a technical review. In: 2013 IEEE Transportation Electrification Conference and Expo (ITEC), Detroit, MI, USA, June 16–19, 2013. pp. 1–7. doi: 10.1109/ITEC.2013.6573507.
14. Mina-Casaran JD, Echeverry DF, Lozano CA. Demand response integration in microgrid planning as a strategy for energy transition in power systems. IET renewable power generation. 2021 Mar;15(4):889-902.
15. Mohammadi F, Mohammadi-Ivatloo B, Gharehpetian GB, et al. Robust control strategies for microgrids: a review. IEEE Syst J. 2022; 16 (2): 2401–2412. doi: 10.1109/JSYST.2021.3077213.
16. Fathima AH, Palanisamy K. Optimization in microgrids with hybrid energy systems – a review. Renew Sustain Energy Rev. 2015; 45: 431–446.

