Mitigating Impacts of Distributed Generation on Power System Stability: A Review

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Abstract. The rising incorporation of Distributed Generators (DG) in power systems, propelled by escalating energy demands and the shift towards renewable energy sources, presents numerous benefits, such as diminished power losses, enhanced voltage profiles, environmental advantages, and postponement of transmission and distribution investments. This integration poses issues regarding control, protection, and stability, especially when distributed generators are inadequately modeled, coordinated, or optimally situated within distribution networks. These challenges may lead to problems including overvoltage, elevated fault levels, instability, and failures in protective systems, thereby impacting the overall reliability of the power system. This study is to examine the current literature about technologies and tactics employed to alleviate the negative effects of distributed generators on power system stability. The study comprised a review of 11 papers sourced from esteemed databases such as IEEE, Compendex, Science Direct, and Scopus, published in English from the years 2007 to 2023. The selection was predicated on keywords pertaining to distributed generation, stability, control methods, energy storage, reactive power control. Studies that failed to satisfy the inclusion criteria were excluded, leading to a thorough study of 11 studies. The study concentrated on identifying solutions such as energy storage systems (ESS), including batteries and reactive power regulation methods, which have proven useful in stabilizing networks with significant distributed generation (DG) penetration. The results indicate that the deployment of energy storage systems, in conjunction with sophisticated reactive power regulation schemes, is essential for mitigating problems such as overvoltage, load balancing, and overall network stability. Nonetheless, the expenses and ideal integration of these systems continue to pose issues that require additional investigation. The study suggests that although distributed generators (DGs) can offer substantial improvements to contemporary power networks, their effective integration necessitates meticulous planning, sophisticated control systems, and the implementation of auxiliary technologies to optimize benefits and mitigate potential adverse effects.

Keywords. Distributed Generation, Stability, Control Methods, Energy Storage, Reactive Power Control.

1. Introduction

The number of Distributed Generators (DG) units is increasing to meet the growing power demand. While this integration offers numerous advantages to consumers and power grids, it also introduces challenges related to control, protection, and stability(1,2).

In recent years, the growth of distributed generation from Renewable Energy Sources (RES) has further emphasized the need for potential reconfiguration of existing distribution networks. Such reconfiguration aims to reduce line congestion, ensure lower power losses, and correspondingly increase the system's reliability and efficiency(3).

Despite their advantages, including environmental benefits, remarkable flexibility, reduction in power losses, improvement of voltage profiles, and deferral of transmission and distribution investment timelines, poorly constructed DGs can lead to complications. The integration of distributed generation (DG) into distribution networks can adversely affect the stability indices of the power system if the DG is inadequately modeled, coordinated, scaled, and positioned, particularly owing to load sharing under fluctuating operating conditions(4).

Various energy storage systems utilized in a dispersed setting encompass batteries, ultracapacitors, flywheels, fuel cells, and superconducting magnetic energy storage can be used to minimize the effects that causes instability(5).

The aim of this study is to examine and evaluate in the literature the various tactics and mechanisms employed to alleviate the adverse effects of integrating Distributed Generation (DG) into electricity distribution networks. The study seeks to identify the primary challenges associated with stability, voltage regulation, and protection of the electrical system, while also assessing the efficacy of solutions like energy storage systems and reactive power management in enhancing the stability and efficiency of networks with significant distributed generation integration. A comprehensive literature review will be undertaken to choose articles that discuss these methodologies, aiming to facilitate the optimization of dispersed generation integration in contemporary electrical systems.

2. Research Methods.

For the completion of this work, 18 articles were previously selected based on the keywords: Distributed Generation, Stability, Control Methods, Energy Storage and Reactive Power Control. Subsequently, 7 were discarded as they did not meet the inclusion criteria. The 11 articles definitively selected for this work were researched in databases recognized by the scientific community: IEEE, Compendex, Science Direct and Scopus, in English, between the years 2007 and 2023. The inclusion criteria were articles that addressed topics relating Instability issues caused by distributed generation in distribution networks, and methods to mitigate these impacts. Studies that failed to satisfy the inclusion criteria were excluded

3. Results

3.1 Distributed Generation

Distributed generations are classified into four categories according to their provided capacity. Micro distributed generation covers capacities from 1W to under 5KW, small distributed generation ranges from 5KW to under 5MW, medium distributed generation spans from 5MW to under 50MW, and large distributed generation extends from 50MW to under 300MW (4).

The majority of distributed generators are small to medium-scale units connected to low or medium voltage networks (LV or MV)(6) (7).

The distributed generators are primarily designed to link to the distribution system near consumption centers. The prevalent distributed generation technologies encompass photovoltaic arrays, solar thermal systems, hydro turbines, wind turbines, fuel cells, biomass gasification, battery storage, and geothermal energy. These technologies can be grouped into three types of distributed generation: static power electronic converters, which include microturbines, fuel cells, and photovoltaic systems; rotating machines, such as small hydro turbines, gas turbines, and diesel engines; and induction machines, like wind turbines (4)(7).

3.2 Distributed Generation’s Impact

Numerous government incentive programs promote the installation of small-scale, roof-mounted photovoltaic panels by individuals and businesses, driving a consumer-led transformation in modern electricity delivery systems. While increased photovoltaic penetration offers many benefits, research indicates it can lead to voltage level issues within the grid (2).

Thus, if these distributed generation systems are not properly installed and integrated with the electric power infrastructure, their potential benefits may be entirely negated. Significant penetration can impact the operation and control of transmission and distribution systems, resulting in technical challenges that require thorough identification and analysis (7). But usually, the primary worry is the potential of overvoltage resulting from reverse power flow in distribution feeders, particularly under light load conditions(2).

Connection of the DG to distribution networks can raise a certain number of technical problems, as follows: overshooting thermal limits of conductors, under- or over-voltage on the network, increase in the network fault levels, non-operation of the protection system, non reception of the tariff signal raise of voltage harmonics distortions, stability and ability of DG to remain synchronized with the network(7).

Transient disturbances, including failures, load switching, and load shedding, can alter system states and potentially induce system instability. Indicators of system disturbances typically employed for transient stability include rotor angle, rotor speed, terminal voltage, and frequency. The type and amount of the distributed generators or storage within the system can affect the amplitude and frequency of these oscillations (5).

3.3 Minimizing the Impact

To prevent integration-related issues, numerous utilities restrict GD penetration levels. However, this passive method results in a substantial loss of potential GD output (2).

Storage devices can facilitate power stabilization in conjunction with biomass, particularly for rural combined heat and power applications. These devices accumulate energy during times of elevated power or diminished demand and utilize the stored energy to meet excess loads during periods of reduced power. Various energy storage systems utilized in a distributed context including batteries, ultracapacitors, flywheels, fuel cells, and superconducting magnetic energy storage (5).

To assist the DGs during high demand, the storage devices may also enhance the overall stability of the entire system. These energy storage systems are linked to the electric grid through appropriate power conversion devices (5).

Another option suggested by the literature is reactive power absorption; this approach addresses overvoltage problems and also results in a diminished feeder power factor (2).

3.4 BESS

The implementation and management of Battery Energy Storage Systems (BESS) to mitigate power losses in the distribution grid have gained considerable appeal in recent years, thanks to significant technological advancements and anticipated reductions in installation costs. Additionally, BESS is increasingly recognized as an effective solution for the smooth integration of Distributed Generations (DGs) into the grid (3)(8).

BESS can provide various functions, including mitigating peak-shaving effects, contributing to voltage management in smart grids with high renewable energy source penetration, and generating reactive power through their inverters to reduce power losses and voltage drops in distribution networks. Additionally, this integration between BESS with substantial photovoltaic (PV) installations offers other benefits such as capacity support, congestion management, delaying upgrade investments, mitigating peak demand charges, and enhancing power quality (2)(3)(8).

The primary obstacle to the use of batteries currently is their cost. Consequently, optimal integration and a comprehensive understanding of the capabilities and function of BESS in the capacity mix are essential to achieve maximum techno-economic advantages for the grid while enhancing battery cost competitiveness (8).

In most literature, battery systems are utilized solely for peak shaving. Nevertheless, installation for peak support does not address overvoltage (the principal limiting element of distributed generation) or low voltage concerns. Furthermore, it significantly amplifies system losses. Consequently, the issue must be resolved to improve system voltages for enhanced DG absorption. Optimal tradeoffs are attained while installing a battery, given its capacity to deliver various services concurrently. The extent of trade-offs regarding voltage management, peak shaving, loss reduction, and battery specifications is significantly influenced by the installation location (8).

The adoption and optimal integration of Battery Energy Storage Systems (BESS) in the next-generation grid would enhance resource usage and decentralize management, hence boosting the grid's capacity to accommodate increased demand and host greater amounts of Distributed Generation (DG) (8).

3.5 Control with Reactive Power

Voltage and reactive power regulation in traditional distribution systems were established on the premise of a planned centralized generation and the assumption that current consistently flows from the transmission network to the high-voltage/medium-voltage (HV/MV) substation and subsequently to the MV feeders (9).

The advent of distributed generation (DG) renders this premise invalid. Distributed Generation modifies power flows, therefore affecting feeder voltage profiles and influencing voltage and reactive power regulation in distribution systems. This indicates that integrating the distributed generation (DG) into a distribution system requires coordination with the existing voltage and reactive power control apparatus to maintain adequate voltage regulation within the distribution system (9).

Furthermore, capacitor control set-points must be adjusted in the presence of distributed generation (DG) (10).

The inverter is one of the devices employed for local control of reactive power. In microgrids, inverter-connected devices, such as photovoltaic and wind generators, are crucial and require regulation to ensure system stability and keep frequency and voltage within acceptable parameters. Droop control is a prevalent method for managing frequency and voltage in inverters within microgrids (11).

In conventional grid-connected systems, local voltage regulation via distributed generators is increasingly prevalent. As distributed generators (DGs) are typically utilized to inject maximum active power into the grid, these solutions predominantly focus on reactive power management. To counteract undesirable voltage fluctuations, the distributed generators can consume or generate reactive power (11).

4. Discussion

To mitigate these impacts, studies suggest the use of energy storage systems, such as batteries (BESS), which can help stabilize the grid by accumulating energy during periods of low demand and releasing it during peak times (5), moreover, BESS can provide multiple functions, such as load peak management and voltage support in networks with high penetration of renewable sources (3).

However, the high cost of these batteries remains a challenge, making proper integration and planning essential to maximize the technical and economic benefits for the electrical system (8).

Another proposed strategy is reactive power control to regulate voltage and minimize overvoltage issues, the use of devices, such as inverters connected to microgrids, allows for the absorption or generation of reactive power, helping to maintain stable voltage profiles (11).

The coordinated integration of reactive power control with existing distributed generation is essential for maintaining grid stability, as the distribution of generation modifies power flows and, consequently, the voltage profile of the distribution system (9).

5. Conclusion

The growing prevalence of distributed generation (DG) in electrical networks presents considerable challenges to the stability and operation of the distribution system, particularly due to problems such as overvoltage, voltage fluctuations, and ineffective protective mechanisms. While distributed generation (DG), especially from renewable sources, presents prospects for decentralizing energy production and minimizing system losses, insufficient integration may result in technical issues that compromise the quality and reliability of energy supply.

Given these issues, the implementation of energy storage technology, such as batteries, and reactive power regulation schemes has demonstrated efficacy in alleviating the effects of distributed generation. Batteries, nevertheless their elevated expenses, are essential for grid stabilization, demand management, and voltage support. Moreover, the synchronized management of reactive power, especially in systems with significant inverter integration, aids in preserving system stability and regulating voltage profiles.

Consequently, to optimize the advantages of dispersed generation and mitigate its adverse effects, it is imperative to invest in effective integration techniques and storage technologies. A cohesive and strategically designed approach will facilitate enhanced integration of distributed generation into the grid, so advancing the modernization of the electrical system and augmenting the reliability of energy supply.References

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