Microgrid Operation Mode and Architectures

Subjects: Engineering, Electrical & Electronic

Contributor: Ritu Kandari , Neeraj Neeraj , Alexander Micallef

Energy security and the resilience of electricity networks have gained critical momentum as subjects of research. The challenges of meeting the increasing electrical energy demands and the decarbonisation efforts necessary to mitigate the effects of climate change have highlighted the importance of microgrids for the effective integration of renewable energy sources. Microgrids (MGs) can operate in grid-connected and islanded operation. MG architectures are categorised as alternating current microgrid (ACMG), direct current microgrid (DCMG) and hybrid microgrid (HMG).

distributed energy sources | energy storage | microgrids

1. Introduction

A microgrid is an interconnected group of loads, energy storage systems (ESSs) and distributed generators that can exchange power with the main grid through a single point of common coupling (PCC) [1]. Microgrids (MGs) have the capability of working together with the main grid, and as separate entities (i.e., as islands). Therefore, MGs can be deployed to provide electricity in remote areas, thereby facilitating the generation, distribution, and regulation of the power flow to the local consumers. MGs are being considered as one of the key concepts that will enable the deployment of high penetrations of renewable energy sources (RESs) in our electricity networks [2]. Amongst present and emerging RESs, RES integration in MGs typically consists of technologies including photovoltaic (PV) modules, small-capacity hydro units, ocean energy, and wind turbines. MGs can improve the energy security and reliability of the local energy network through the integration of complimentary distributed renewable sources. MGs are the key enablers for future smart grids, which have the potential to transition the present, centralised electricity networks into fully distributed architectures. MG architectures are categorised as alternating current microgrid (ACMG), direct current microgrid (DCMG) and hybrid microgrid (HMG). The HMG combines the advantages of the ACMG and DCMG architectures since the AC and DC buses are interlinked by a power electronic converter.

Power generation from RESs is typically intermittent and variable as the output power depends on the environmental conditions. Examples of this type of behaviour are the fluctuations in PV generation due to cloud coverage and the variable output characteristics of wind turbines. These uncertainties in RES generation can disrupt conventional planning by utilities. Any large unplanned fluctuations in non-dispatchable generators (i.e., RESs) can potentially affect the stability of the system [3][4][5][6]. Novel dispatch strategies are essential to maintaining the balance between generation and demand in scenarios with high penetrations of distributed RESs. Due to their hierarchical control architecture, MGs can maintain the voltage, phase angle, and frequency changes under permissible levels during fluctuations in RES generation. The hierarchical architecture enables the integration and management of distributed energy storage technologies that can provide the required additional reliability and energy security. High penetrations of distributed energy sources also cause power imbalances in the LV distribution network and can affect the transient stability. Local MG control strategies can maintain the voltage and frequency as stable, thus providing a reliable electricity supply to consumers during all possible modes of operation (islanded operation, grid-connected, and transitions between the two modes of operation) [7]. It is also a known phenomenon that high penetrations of distributed energy sources can also cause power imbalances, especially in cases where there are single-phase residential prosumers [8].

The authors in [9] examine the impact of integrating a PV system, an ESS, and electric vehicles into the distribution network of a campus. The authors applied an EMS to the campus microgrid while considering future integrations of RESs. A linear optimisation approach implemented in MATLAB was used to investigate the optimal PV and ESS scenarios. Without the local PV system, the utility provided for the entire energy needs of the campus under a time-of-use (ToU) tariff system. The integration of the PV and ESS, determined from the linear optimisation approach, predicted a reduction of up to 44.80% in the daily energy consumption costs. Investigations were also conducted into the effects of additional local issues such as power outages.

In [10], the authors mapped the interval forecast data from a PV system to the solution space with various weight assignment schemes for day-ahead optimisation. A thorough case study was conducted that shows a significant increase in the hybrid vessel’s operational flexibility. The dispatching system that was used in this study uses a multi-objective function to schedule the ship operation in scenarios with competing objectives. The operational cost is the main objective that is addressed by the optimisation scheme while the degradation in the lifetime of the ESS is minimised.

Economic load dispatch was also proposed in [11] to meet the load demand while reducing the overall operational costs by distributing power across several ESSs. In [11], the authors propose a multi-agent consensus-distributed control strategy that was designed to achieve multiple goals simultaneously. The multi-agent consensus-distributed control strategy considers the frequency/voltage droop controllers and the battery-based energy storage systems (BESSs)’ hierarchical control architecture. The presented results show that with this strategy, several BESSs tracked the time-of-use-based pricing-generated SoC reference trajectories during a 24 h period with a variable load. The multi-agent consensus strategy also distributes the load active and reactive power, and simultaneously achieves frequency and voltage management (using the leader-follower consensus approach). However, each BESS requires information from nearby BESSs, in addition to the local information. The suggested communication strategy includes plug-and-play functionality and robustness against communication-link failure and transmission delays of up to 15 ms.

A mixed-integer, nonlinear programming model for PV-battery systems was proposed by the authors in [12], which considers long-term battery deterioration. The main objective was to minimise the lifecycle cost by using a novel two-layer optimisation method that takes into account the self-consumption ratios, optimum battery capacity, and two types of tariff systems. The results showed that the battery degradation could cause an increase in operational costs. By taking the battery degradation into account in the optimisation strategy, the resulting battery capacities and lifecycle costs show a significant increase when compared to the scenario without the battery degradation effects.

In [13], a methodology is created which enables the efficient and effective management of the numerous measurements and uncertainties that come with renewable energy sources. By characterizing the measured data by representative days, clustering algorithms were employed to address these two problems. Historical data was used to reflect the specificities of the considered grid. The architecture that was created can successfully govern across various time horizons. HOMER Pro® (Boulder, CO 80301, USA) was employed for planning purposes, while other pertinent indicators were gathered through a day-ahead optimal scheduling tool. A case study shows that the proposed methodology can be used to identify the best battery technology and DOD strategy. The selection criteria for the battery storage were based on parameters such as the lifetime and annual operating costs of each battery technology. Results for the specific case study have shown that, even though NiCd batteries have the best operational costs, their profitability is limited due to their high fixed costs. From an economic standpoint, Li-ion batteries have shown similar behaviour. On the other hand, lead-acid and NaS batteries appeared to be profitable alternatives for the considered microgrid. However, further studies on various microgrid and nanogrid configurations are necessary in order to further corroborate these results.

The authors in [14] examined current research topics that are crucial for the planning, control, and operation of campus microgrid architectures. Several approaches for different types of campus microgrids were studied and compared. These campus microgrids were investigated using a variety of optimisation methodologies, modelling tools, and energy storage technology types. It was determined that different campus microgrids throughout the world lack effective energy management strategies. Most of the evaluated campus microgrids have outdated energy management methods as there have been several advancements in this field that can be deployed to further improve the energy management of their systems.

In [15], the authors identify a trade-off between minimizing energy usage and maximizing user comfort caused by the existing scheduling systems’ disregard for user activities. The trade-off between user comfort and electricity cost was alleviated by directly involving user actions in a proposed load-optimisation technique. This trade-off was taken into account, and optimisation models for various home appliances were designed and implemented. An analysis of the simulation’s outcomes was performed in terms of occupancy, cost, and energy-consumption reduction.

In [16], the authors discuss energy-efficient power grid technologies. A thorough analysis was performed that takes into account the numerous difficulties in smart-grid demand-side management. The authors propose that line planning and low-cost scheduling make up the first two tiers of the demand-side load management architecture. Demand response is at the third level and is a topic which has seen considerable research activity in the past decade.

2. Microgrid Operation Mode and Architectures

2.1. Modes of Operation

2.1.1. Grid-Connected Operation

In this mode, the MG is connected to the main grid through a single PCC. The MG exchanges power with the main grid depending upon the mismatch in the load power and the power generated by the RESs. Any excess power generated by the RESs (i.e., when the load demand is low, and the generation is high) can be used to charge the ESS. In scenarios where the ESS is fully charged, any excess power generated within the microgrid can be exported to the main grid. On the other hand, in case of partial shading or cloudy conditions (i.e., when the generation is lower than the load demand), the load may be supplied by the ESS, depending on the available SoC. When the ESS reaches its lower SoC limit, the required power may be imported directly from the main grid. Hence, the RES, ESS, and main grid need to work together to maintain the reliability and stability of the microgrid. Hence, the power flow through a PCC can be bidirectional.

2.1.2. Islanded Mode of Operation

Faults occurring in the main grid may cause abnormal conditions at the PCC of the microgrid. In this scenario, the microgrid can be isolated from the main grid and continue to operate as an islanded microgrid. In this mode of operation, the local frequency and voltage are regulated by the distributed RESs (e.g., wind and solar PV) and ESSs [17]. In this mode, ESSs are critical elements of the MGs that can maintain the energy balance, minimise power fluctuations, and improve the reliability and system efficiency [18]. The ESSs absorb excess RES generation when the generation exceeds the demand. The ESSs can be used to supply power to the MG in periods where the demand exceeds the local generation. This minimises any instances where RES power curtailment and/or load shedding should be carried out. In addition, ESSs can also be used to improve the voltage and frequency regulation of the islanded microgrid.

2.2. Microgrid Architectures

As described in an earlier section, MG architectures can be categorised into ACMGs, DCMGs, and HMGs. This section provides a brief overview of the main characteristics of each architecture.

2.2.1. AC Microgrids (ACMGs)

In ACMGs, the local RESs, ESSs, and loads are all connected to a common AC bus. Any DC generating units (e.g., PV panels) and ESSs (e.g., batteries) must connect to the common AC bus through dedicated DC-to-AC inverters [19]. The control and management of ACMGs is difficult due to the presence of critical and non-critical loads that require harmonic currents [20]. In ACMGs, harmonic suppression is achieved either by the introduction of passive/active filters or through the addition of special functionality in the primary control loops of the power electronic converters in the microgrid. While AC microgrids can be easily integrated into the main grid, re-synchronisation of the ACMG with the main grid is complex. Synchronisation of the MG involves matching the voltage amplitude, frequency, and phase at the PCC with that of the main grid. In the literature, there are three main AC distribution architectures for microgrids, namely, single-phase, three-phase with neutral, and three-phase without neutral.

2.2.2. DC Microgrids (DCMGs)

In these MGs, the local RES generation, ESSs, and loads are connected to a common DC bus. Any AC sources and loads must be connected to the common bus through dedicated AC-to-DC passive/active rectifiers. In the literature, one can find three main types of DC microgrids: monopolar, bipolar, and homopolar distribution systems. A monopolar DC grid consists of a two-wire distribution system, between which the DC bus voltage is defined. On the other hand, the bipolar and homopolar DC grids are three-wire DC distribution systems. In addition to the ground return conductor, the bipolar DC grid has two low-voltage conductors with different polarities, while the homopolar DC grid has two low-voltage conductors with the same voltage polarity. DCMGs have several advantages over their AC counterparts. These include greater reliability, higher efficiency (fewer power electronic converters), and improved stability. DC microgrids have been recently employed in special applications, such as shipboard microgrids, EVs, and telecommunication systems. However, the main limitation of DC microgrids is the complexity and high cost of the protection system when compared to AC microgrids [21].

2.2.3. Hybrid Microgrids (HMGs)

In HMGs, the AC sources and loads are connected to the AC bus, while DC sources and DC loads are connected to the DC bus. HMGs have the advantages of both ACMGs and DCMGs, and they result in fewer power conversion stages since these can simultaneously support both AC and DC sources/loads. The AC and DC sub-grids are interconnected via a bidirectional interlinking converter. This converter is the most important part of the HMG as it manages and coordinates the power flow between and within the sub-grids. The HMG uses a transformer to convert voltage on the AC side and a DC–DC converter for voltage conversion on the DC side [21][22]. Depending upon the load requirement and the condition of main grid, HMGs can also be made to work in grid-connected or islanded mode.

References

1. Rajesh, K.S.; Dash, S.S.; Rajagopal, R.; Sridhar, R. A review on control of ac microgrid. Renew. Sustain. Energy Rev. 2017, 71, 814–819.
2. Mohammed, A.; Refaat, S.S.; Bayhan, S.; Abu-Rub, H. AC microgrid control and management strategies: Evaluation and review. IEEE Power Electron. Mag. 2019, 6, 18–31.
3. Roslan, M.; Hannan, M.; Ker, P.J.; Uddin, M. Microgrid control methods toward achieving sustainable energy management. Appl. Energy 2019, 240, 583–607.
4. Chandak, S.; Rout, P.K. The implementation framework of a microgrid: A review. Int. J. Energy Res. 2021, 45, 3523–3547.

5. Hartono, B.S.; Budiyanto, Y.; Setiabudy, R. Review of microgrid technology. In Proceedings of the 2013 International Conference on QiR, Yogyakarta, Indonesia, 25–28 June 2013; pp. 25–28.
6. Falahi, M.; Lotfifard, S.; Ehsani, M.; Butler-Purry, K. Dynamic model predictive-based energy management of DG integrated distribution systems. IEEE Trans. Power Deliv. 2013, 28, 2217–2227.
7. Liang, H.; Choi, B.J.; Abdrabou, A.; Zhuang, W.; Shen, X.S. Decentralized Economic Dispatch in Microgrids via Heterogeneous Wireless Networks. IEEE J. Sel. Areas Commun. 2012, 30, 1061–1074.
8. Tenti, P.; Caldognetto, T. Master/Slave Power-Based Control of Low-Voltage Microgrids. In Microgrid: Advanced Control Methods and Renewable Energy System Integration; Mahmoud, M.S., Ed.; Butterworth-Heinemann, Elsevier: Oxford, UK, 2017; pp. 101–135.
9. Nasir, T.; Raza, S.; Abrar, M.; Muqeet, H.A.; Jamil, H.; Qayyum, F.; Cheikhrouhou, O.; Alassery, F.; Hamam, H. Optimal Scheduling of Campus Microgrid Considering the Electric Vehicle Integration in Smart Grid. Sensors 2021, 21, 7133.
10. Hein, K.; Yan, X.; Wilson, G. Multi-Objective Optimal Scheduling of a Hybrid Ferry with Shore-to-Ship Power Supply Considering Energy Storage Degradation. Electronics 2020, 9, 849.
11. Ullah, S.; Khan, L.; Badar, R.; Ullah, A.; Karam, F.W.; Khan, Z.A.; Rehman, A.U. Consensus based SoC trajectory tracking control design for economic-dispatched distributed battery energy storage system. PLoS ONE 2020, 15, e0232638.
12. Wu, Y.; Liu, Z.; Liu, J.; Xiao, H.; Liu, R.; Zhang, L. Optimal battery capacity of grid-connected PV-battery systems considering battery degradation. Renew. Energy 2021, 181, 10–23.
13. Arévalo, P.; Tostado-Véliz, M.; Jurado, F. A novel methodology for comprehensive planning of battery storage systems. J. Energy Storage 2021, 37, 102456.
14. Muqeet, H.A.; Munir, H.M.; Javed, H.; Shahzad, M.; Jamil, M.; Guerrero, J.M. An Energy Management System of Campus Microgrids: State-of-the-Art and Future Challenges. Energies 2021, 14, 6525.
15. Rasheed, M.B.; Javaid, N.; Ahmad, A.; Jamil, M.; Khan, Z.A.; Qasim, U.; Alrajeh, N. Energy Optimization in Smart Homes Using Customer Preference and Dynamic Pricing. Energies 2016, 9, 593.
16. Balouch, S.; Abrar, M.; Muqeet, H.A.; Shahzad, M.; Jamil, H.; Hamdi, M.; Malik, A.S.; Hamam, H. Optimal Scheduling of Demand Side Load Management of Smart Grid Considering Energy Efficiency. Front. Energy Res. 2022, 10, 861571.
17. Mogaka, L.O.; Nyakoe, G.N.; Saulo, M.J. Islanded and Grid-Connected Control in a Microgrid with Wind-PV Hybrid. Int. J. Appl. Eng. Res. 2020, 15, 352–357.

18. Talapur, G.G.; Suryawanshi, H.M.; Xu, L.; Shitole, A.B. A Reliable Microgrid with Seamless Transition Between Grid Connected and Islanded Mode for Residential Community with Enhanced Power Quality. IEEE Trans. Ind. Appl. 2018, 54, 5246–5255.
19. Lotfi, H.; Khodaei, A. AC versus DC microgrid planning. IEEE Trans. Smart Grid 2015, 8, 296–304.
20. Planas, E.; Andreu, J.; Gárate, J.I.; de Alegria, I.M.; Ibarra, E. AC and DC technology in microgrids: A review. Renew. Sustain. Energy Rev. 2015, 43, 726–749.
21. Justo, J.J.; Mwasilu, F.; Lee, J.; Jung, J.-W. AC-microgrids versus DC-microgrids with distributed energy resources: A review. Renew. Sustain. Energy Rev. 2013, 24, 387–405.
22. Unamuno, E.; Barrena, J.A. Hybrid ac/dc microgrids—Part I: Review and classification of topologies. Renew. Sustain. Energy Rev. 2015, 52, 1251–1259.

Retrieved from https://encyclopedia.pub/entry/history/show/91350