Power Management Strategies in Hybrid AC/DC Microgrid: A Review

[1*]Anil N Navle, [2]Naimish K Zaveri

[1]*Research Scholar, Gujarat Technological University Ahmedabad and Asst. Professor, Government Engineering College Dahod, Gujarat India*

[2]*Professor, Electrical Engineering Department C. K. Pithawalla College of Engg. & Tech., Surat Gujarat India*

**Corresponding author: anil.navle@gmail.com*

Abstract.

The future of power system is 'Smart Grid' for which microgrids are the building blocks. Renewable energy sources, such as solar, wind and various distributed generation (DG) units, and as well various energy storage systems (ESS) are encouraged to integrate with grid. Since they incorporate the benefits of AC and DC distribution networks and which do not entail any unnecessary changes to the distribution network, which emerge hybrid microgrids as a promising solution. They need more complex control techniques, though, since they must handle the alternating current and direct current networks at the same time as well as interface the power converters. This paper examines power management strategies in grid-connected and grid-disconnected operational modes in hybrid microgrids with renewable energy sources.

Keywords. Hierarchical control, Hybrid Microgrids, Interconnected converters, unidirectional/bidirectional power flow, Distributed Energy Resources, Energy Storage Systems.

1. INTRODUCTION

The definition of micro-grids with classification schemes, including controllable loads in addition with energy storage systems, are found in several literature, for instance in [1] – [4]. Microgrids are operated in a dependently when connected to grid and independently when isolated from grid.

There are three microgrid structures available: AC microgrid, DC microgrid, and hybrid microgrid [5], [6]. While AC system is the most prevalent configuration of micro-grids, there has been a lot of interest in DC micro-grids because of some advantages, such as the lack of the requirement for reactive power or synchronisation, also the growing number of electric vehicles, smart DC devices and DC loads that are available. The hybrid micro-grid, on the other hand, combines the greatest features of both designs. A hybrid microgrid is a design that merges a greater number of separate AC microgrids and DC microgrids using bidirectional power electronics interlinking converters (ICs). Here, ICs provide power management with neighbouring AC-DC microgrids. The DC microgrid is connected to the main utility grid by voltage source or back-to-back converters [7], [8] and it is adjacent to AC subgrids via bidirectional ICs. The IC serves as the foundation for hybrid microgrid management and control. IC is largely accountable for the efficient regulation of transmission of power between the AC microgrids and DC microgrids. The IC controller may also be set to function in island mode to guarantee identical loading of the AC microgrid and DC microgrid based on their capacity, minimum load peeling and renewable power reduction in the hybrid microgrid as a whole in addition appropriate reserve and loadability buffer intended for the overloaded microgrid.

Advanced hybrid microgrids can also balance renewable energy demand, plan resource dispatch, and maintain system dependability. It is also capable of controlling the inter connection and interactivity of complicated distributed generation arrangement, demand response, storage as well controlled loads, and energy management systems [9]– [13]. The operation of hybrid micro-grids comprises secure and suitable power management strategies, mostly based on droop control, to govern load contribution between AC and DC sources.

The layout of the paper is divided as follows: Section two is a concise description of the hybrid microgrid definition, here the key characteristics as well as related control and operation issues are stated. In section three, challenges and research findings are discussed.

2. HYBRID MICROGRID CONTROL

An AC microgrid and a DC microgrid, as well as an interface between the two power converters that regulates power flow connecting these microgrids and the main grid comprise hybrid microgrids. The AC microgrid mostly have AC dispersed energy resources (DERs) and AC loads in the hybrid structure, whereas the DC microgrid primarily consists of DC dispersed energy resources and DC loads [7]. Every extra energy generated in a DC microgrid is normally stored in storage systems, such as batteries. Simultaneously, excess energy generated in the AC subgrid can be stored in AC ESSs such as flywheels. In Fig. 1, A typical hybrid microgrid arrangement is shown as both AC microgrid and DC microgrids connected through interlinking bidirectional converters to the utility grid [14].

The hybrid AC-DC microgrid's topologies and power management strategies are discussed in [15]– [17]. The hybrid AC-DC microgrid plan and design representation is suggested in [18], [19], which can evaluate the dispersed energy capability, and study the effect of the load ratio of AC-DC. Here, in aforementioned literatures, however, the work is focused on the single optimization problem of AC-DC hybrid microgrids, except there is a short of efficient coordinated optimization idea in terms of economics, dependability, and other difficulties.

The organized approach that administers all such devices connected to the network is one of the mainly distinguishing types that distinguish microgrids from traditional distribution networks. Because microgrids are distributed, this strategy is crucial for effective management [20].

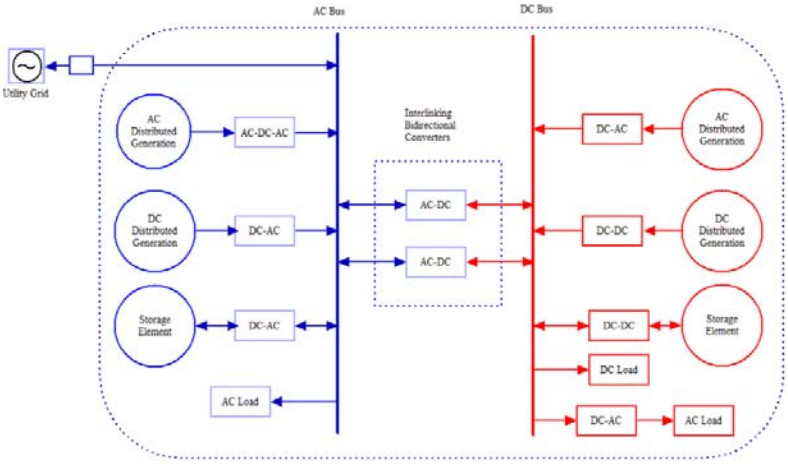

Figure 2.1. A Typical Hybrid AC-DC microgrid

Microgrids may function in both grid-tied and grid isolated operational modes, allowing for the effective integration of Dispersed Energy Resources (DER).

The microgrid control structures have following major roles [21]-[28]

- Microgrid synchronization with utility grid;
- Power transfer between the microgrid and utility grid;
- Active and reactive power management of microgrid at different operating modes;
- Smooth transition among different modes of operation of microgrid —i.e., grid-connected to isolated mode or island mode to grid-tied.
- Proper coordination between DER and load;

These requirements have different definitions and time scales, and thus require a hierarchical management system to handle each requirement in a different hierarchy of management. There are three level of hierarchical power management policy, namely primary, secondary, and global/tertiary controls.

2.1 Primary Control

The primary control is a self-regulating main/local control approach which permits each DG unit to function separately. It is essential to offer unique active and reactive power contribution regulations for DERs in the existence of both linear and nonlinear loads. Furthermore, power sharing regulation limits the circulation of undesirable currents. This main level of control consists of simple control circuitry, sometimes referred to as zero-level, that contains DERs' internal voltage as well current control loops. In the literature primary management strategies implemented are namely grid-feeding and grid-forming as expressed in [29], [30]. While some research on main control mechanisms is available, it typically focuses on AC microgrids or DC microgrids [4], [31]. In this case, grid-forming as well grid-following management approaches are being examined for execution [32].

2.1.2 Grid-following control

To be grid-connected, the microgrid must adhere to the network's distribution requirements. Local control, which comprises fundamental control hardware such as DG inner voltage as well current control loops, keeps DGs stable by sensing and adjusting local signals. It is essential to supply autonomous active and reactive power contribution management for DGs/RESs in addition to limit undesirable circulating currents using the accessible current, voltage, and frequency feedback signals. While in grid-tied operation mode, the main grid sets the voltage as well frequency of microgrid, so that local DER device controllers generally function in current-control mode to take out maximum power as feasible from energy resources [4].

2.1.2 Grid-forming control

In the case of any aberrant operation or situation affects the grid, the microgrid should be unplugged and switched to grid-isolated operating mode. During these situations, DG and ESS systems must maintain balance of active and reactive power of the microgrid's AC and DC networks. In this case main control provides reference inputs to the voltage and current control loops of DERs referred as zero-level control. To accomplish zero-level control, PQ or voltage control modes are typically employed [31]. Depending on the needs, several DG units may operate to regulate voltage of the network, i.e., in grid-forming mode, and the remaining will remain in the grid-following mode [4].

2.1.2.1 Single Grid-Forming Unit

In the case of just one grid-forming unit availability in an isolated mode of microgrid, such unit stays with simpler voltage control with a predetermined reference voltage. Numerous grid-forming machines with the same specified reference voltage cannot be connected to a single distribution network. This will cause circulating currents, synchronisation problems, and inconsistencies in power contribution. Hereafter, all other units must be grid-following. The grid-forming unit will entirely remain dependable on power balance of the network [5].

2.1.2.2 Multiple Grid-Forming Units

If numerous dispatchable DG units are supplied into a microgrid, electricity must be swapped, for example, based on unit ratings. As a result, synchronisation is required for hybrid microgrid networks in such a way to assure voltage and frequency stability when performing balanced power sharing [4].

The droop control method is often utilised for main control in islanded microgrids. Droop control imitates traditional grid control in microgrids based on the well-known droop controllers of Q/V and P/f with many grid-forming DG interface converters, and did an exhaustive analysis of grid-forming control schemes [33].

2.2 Secondary control

In the case of secondary control, a communication-based approach for similar construction of DGs, provides power sharing by adjusting for voltage and frequency fluctuations induced by local control operation and load fluctuation. This type of control is meant to have a weak dynamics response than the main, that explains the decoupled dynamics of the primary and secondary control loops and simplifies their respective plans [4]. Secondary controls, also known as second layer control loops, help inner control loops by minimising steady-state defects and increasing power quality inside MGs. They work closely with both local and central command units. In grid-tied mode, all DGs and inverters in microgrids utilize grid electrical signals as references for voltage and frequency regulation. The DGs, however, lose the main grid's reference signal when operating in the islanding mode. In this circumstance, they could collaborate to handle a simultaneous operation using single/multimaster operation approaches. Some of the secondary controls necessary to improve the performance of parallel operations for DGs are also included (or inverters). Many control systems for successful similar operation of DGs/inverters are known in the literature, including current or power sharing, master or slave, and generalised frequency and voltage droop control strategies [30].

Secondary control techniques are classified as either centralised or decentralised. In centralised techniques, the microgrid is administered by a tertiary control level as the microgrid central controller or MGCC [20], [25], [34]. In grid-tied mode, the secondary centralised control compensates for change in frequency and voltage in main control levels using the reference supplied by the higher tertiary level. In contrast, after an islanding process occurs, these references are generated internally [22]. The authors suggest a centralised secondary control mechanism for both hybrid microgrid networks.

Power management duties in generating and storage units are recalled in non-centralized control schemes. This suggests that they are included into the local controller rather than the MGCC, so that bypassing the communication network with higher-level control mechanisms [35]. The fundamental benefit of these control systems is that if a problem increase, the remaining part of the microgrid may continue to function normally after the malfunctioning unit is unplugged. Because it provides a simpler communication network with plug-and-play device connections, the non-centralized control method is considered as an interesting choice for microgrid integration at the power distribution level [20], [34], [35].

2.3 Tertiary control

Topmost degree of power management of numerous linked MGs and communicating needs with the utility grid is tertiary control. The tertiary control system, for example, might include coordination capabilities for active/reactive power control of a grid comprised of the utility grid and interconnected MGs [22]. In grid connected mode, the power transfer between the microgrid and the utility grid may be adjusted by varying the amplitude and frequency of DERs voltages. Tertiary control is the highest level of management coordination for the operation of many connected MGs and communicating demands with the utility grid. For example, the tertiary control system might incorporate coordination capabilities for active/reactive power control of a grid comprised of the utility grid and linked MGs [36]. In contrast, from a tertiary control standpoint, the MG may be programmed to cooperate with the distribution network as a dispatchable and constant impedance load.

Tertiary level control is concerned with aspects of an MG's overall responsibilities, such as power transfer between the utility grid in addition/or other linked MGs. In general, the most important tertiary control objectives are generation schedule optimization, improved overall system management and dispatch services, energy disparity correction, and spinning reserve function. MGs can also be coordinated with the MGCC to provide various ancillary services aimed at improving the utility grid's performance [4].

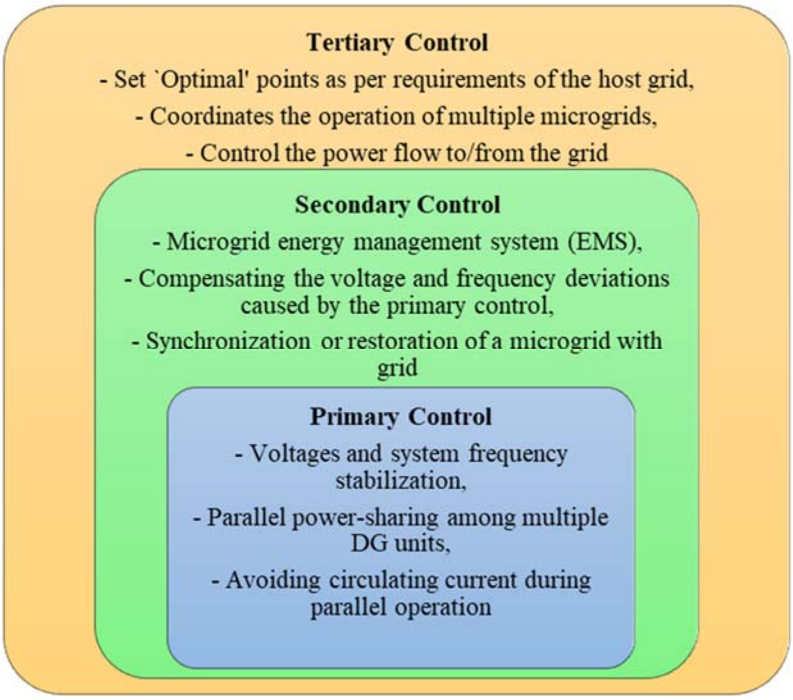

Figure 2.2: Hierarchical microgrid control structure

Furthermore, by including ESSs into the MG, these services might be expanded even further. In this circumstance, tertiary management will give functionalities like effective reserve capability extension, largely peak shaving, frequency regulation, backup of determined electrical islands, and increased control of day-by-day renewable energy cycles [37].

3. CHALLENGES ASSOCIATED WITH HYBRID MICROGRID

Microgrid protection and control systems must overcome operational problems in order to maintain adequate levels of dependability and take out possible benefits from DER. Some of the issues originate from incorrect assumptions, which might lead to system instability. When it comes to replicating power system control within a microgrid, the majority of the problems originate from the traditional distribution and transmission systems that still exist in today's power networks. The following are some of the microgrid control challenges [38]-[40]:

- *Bidirectional power flows:* The existing power system, as well as the distribution feeders that go with it, are built for unidirectional power flow. In such system use of DG units in low voltage networks is projected to necessitate bidirectional power flow, with customers acting as prosumers. If existing feeder systems are maintained during availability of DG units in distribution networks, complications like as reverse power flow, unexpected power flow patterns, imbalanced voltage levels, and fault current flow may occur.

- *Low inertia*: Solar modules and fuel cells like renewable energy sources have no inertia, while others, such as wind turbines, have a low inertia. In contrast to huge power systems with thousands of synchronous generators assuring high inertia, these power electronic based DG units in microgrids have low inertia characteristics. In spite of the fact that power electronics-based DG units have higher dynamic performance; their low-inertia features may cause frequency variations in the islanded operation mode if proper administration mechanisms are not implemented.
- *Stability issues*: Because of the interaction between the different control dynamics of the DG units, local oscillation may develop. A comprehensive small signal and transient stability study is also required for a smooth transition between microgrid grid-connected and isolated mode of operation.
- *System modelling*: In a typical power system at the transmission level, assumptions such as a low X/R ratio, balanced three-phase condition, and steady power loads might be assumed valid. However, when considering a microgrid with low voltage distribution networks, these assumptions are incorrect. As a result, new modelling is necessary.
- *Cyber-physical security*: Because prosumers and DG units are scattered, controllers must connect through communication networks. Malware and data theft are both threats to cyber networks. Cyber-physical security is becoming increasingly essential as the number of microgrids and their related controllers grows.
- *Uncertainty*: The most renewable DG units are linked with uncertainty, intermittency, non-linearity, and unpredictability. To enable effective and consistent microgrid operation, specific levels of coordination across multiple DG units are necessary. Especially in the isolated mode of microgrids, where maintaining generation-consumption balance is more difficult owing to the high incidence of component failures and the unpredictability associated with load profile and weather prediction. Due to the presence of strongly correlated output fluctuations of available energy sources, known as the restricted averaging effect, the unpredictability rate in a microgrid is actually higher than in a big power system.

4. CONCLUSION

The review focused on current work on hybrid microgrid integrated with renewable energy sources. The primary problem, especially for those operating in the islanded mode, is power management and control strategy. This is mostly owing to the microgrid's necessity to control voltage, frequency, and power delivery in addition to power supply. In the literature, many methodologies for analysing power-sharing possibilities for AC and DC microgrids have been given. The authors highlight three major study areas: hybrid microgrid convergence, system control, and distribution network modelling. This research investigated power management strategies in hybrid microgrids, as well as the benefits, difficulties, and solutions interfaces together AC microgrids and DC microgrids. Such systems' unidirectional/bidirectional power flow capabilities, as well as changes in frequency and methods, were explored.

5. REFERENCES

[1] C. Jin, P. Wang, J. Xiao, Y. Tang, and F. H. Choo, “Implementation of hierarchical control in DC microgrids,” IEEE Trans. Ind. Electron., vol. 61, no. 8, pp. 4032–4042, 2014, doi: 10.1109/TIE.2013.2286563.

[2] F. Martin-Martínez, A. Sánchez-Miralles, and M. Rivier, “A literature review of Microgrids: A functional layer-based classification,” Renew. Sustain. Energy Rev., vol. 62, pp. 1133–1153, 2016, doi: 10.1016/j.rser.2016.05.025.

[3] A. Mehrizi-Sani, “Distributed Control Techniques in Microgrids,” Microgrid Adv. Control Methods Renew. Energy Syst. Integr., pp. 43–62, 2017, doi: 10.1016/B978-0-08-101753-1.00002-4.

[4] A. Bidram and A. Davoudi, “Hierarchical structure of microgrids control system,” IEEE Trans. Smart Grid, vol. 3, no. 4, pp. 1963–1976, 2012, doi: 10.1109/TSG.2012.2197425.

[5] M. Shahparasti, M. Mohamadian, P. T. Baboli, and A. Yazdianp, “Toward power quality management in hybrid AC-DC microgrid using LTC-L utility interactive inverter: Load voltage-grid current tradeoff,” IEEE Trans. Smart Grid, vol. 8, no. 2, pp. 857–867, 2017, doi: 10.1109/TSG.2015.2480717.

[6] E. Planas, J. Andreu, J. I. Gárate, I. Martínez De Alegría, and E. Ibarra, “AC and DC technology in microgrids: A review,” Renew. Sustain. Energy Rev., vol. 43, pp. 726–749, 2015, doi: 10.1016/j.rser.2014.11.067.

[7] X. Liu, P. Wang, and P. C. Loh, “A hybrid AC/DC microgrid and its coordination control,” IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 278–286, 2011, doi: 10.1109/TSG.2011.2116162.

[8] R. Majumder, “A hybrid microgrid with dc connection at back to back converters,” IEEE Trans. Smart Grid, vol. 5, no. 1, pp. 251–259, 2014, doi: 10.1109/TSG.2013.2263847.

[9]T. P. Kumar, N. Subrahmanyam, and M. Sydulu, “Power Management System of a Particle Swarm Optimization Controlled Grid Integrated Hybrid PV/WIND/FC/Battery Distributed Generation System,” Distrib. Gener. Altern. Energy J., Jun. 2021, doi: 10.13052/dgaej2156-3306.3624.

[10] S. S. Venkata and M. Shahidehpour, “Microgrid controllers: The brain, heart, & soul of microgrid automation,” IEEE Power Energy Mag., vol. 15, no. 4, pp. 16–18, 2017, doi: 10.1109/MPE.2017.2690526.

[11] I. Colak, E. Kabalci, G. Fulli, and S. Lazarou, “A survey on the contributions of power electronics to smart grid systems,” Renew. Sustain. Energy Rev., vol. 47, pp. 562–579, 2015, doi: 10.1016/j.rser.2015.03.031.

[12] A. Mohammed, S. S. Refaat, S. Bayhan, and H. Abu-Rub, “AC Microgrid Control and Management Strategies: Evaluation and Review,” IEEE Power Electron. Mag., vol. 6, no. 2, pp. 18–31, 2019, doi: 10.1109/MPEL.2019.2910292.

[13] B. Han, M. Li, J. Song, J. Li, and J. Faraji, “Optimal Design of an On-Grid MicroGrid Considering Long-Term Load Demand Forecasting: A Case Study,” Distrib. Gener. Altern. Energy J., Apr. 2021, doi: 10.13052/dgaej2156-3306.3546.

[14] C. 21 IEEE Standards Coordinating, IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems, no. July. 2011.

[15] N. Eghtedarpour and E. Farjah, “Power control and management in a Hybrid AC/DC microgrid,” IEEE Trans. Smart Grid, vol. 5, no. 3, pp. 1494–1505, 2014, doi: 10.1109/TSG.2013.2294275.

[16] E. Unamuno and J. A. Barrena, “Hybrid ac/dc microgrids—Part I: Review and classification of topologies,” Renew. Sustain. Energy Rev., vol. 52, pp. 1251–1259, Dec. 2015, doi: 10.1016/j.rser.2015.07.194.

[17] F. Nejabatkhah and Y. W. Li, “Overview of Power Management Strategies of Hybrid AC/DC Microgrid,” IEEE Trans. Power Electron., vol. 30, no. 12, pp. 7072–7089, 2015, doi: 10.1109/TPEL.2014.2384999.

[18] H. Lotfi and A. Khodaei, “Hybrid AC/DC microgrid planning,” Energy, vol. 118, pp. 37–46, 2017, doi: 10.1016/j.energy.2016.12.015.

[19] M. S. Rahman, M. J. Hossain, J. Lu, and H. R. Pota, “A Need-Based Distributed Coordination Strategy for EV Storages in a Commercial Hybrid AC/DC Microgrid With an Improved Interlinking Converter Control Topology,” IEEE Trans. Energy Convers., vol. 33, no. 3, pp. 1372–1383, 2018, doi: 10.1109/TEC.2017.2784831.

[20] C. Bordons, F. Garcia-Torres, and M. A. Ridao, “Microgrid control issues,” Adv. Ind. Control, pp. 1–23, 2020, doi: 10.1007/978-3-030-24570-2_1.

[21] P. Piagi and R. H. Lasseter, “Autonomous control of microgrids,” 2006 IEEE Power Eng. Soc. Gen. Meet. PES, 2006, doi: 10.1109/pes.2006.1708993.

[22] J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. De Vicuña, and M. Castilla, “Hierarchical control of droop-controlled AC and DC microgrids - A general approach toward standardization,” IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 158–172, 2011, doi: 10.1109/TIE.2010.2066534.

[23] A. S. Dobakhshari, S. Azizi, and A. M. Ranjbar, “Control of microgrids: Aspects and prospects,” 2011 Int. Conf. Networking, Sens. Control. ICNSC 2011, pp. 38–43, 2011, doi: 10.1109/ICNSC.2011.5874892.

[24] J. A. P. Lopes, C. L. Moreira, and A. G. Madureira, “Defining control strategies for microgrids islanded operation,” IEEE Trans. Power Syst., vol. 21, no. 2, pp. 916–924, 2006, doi: 10.1109/TPWRS.2006.873018.

[25] C. Yuen, A. Oudalov, and A. Timbus, “The provision of frequency control reserves from multiple microgrids,” IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 173–183, 2011, doi: 10.1109/TIE.2010.2041139.

[26] A. Mehrizi-Sani and R. Iravani, “Potential-function based control of a microgrid in islanded and grid-connected modes,” IEEE Trans. Power Syst., vol. 25, no. 4, pp. 1883–1891, 2010, doi: 10.1109/TPWRS.2010.2045773.

[27] Y. A. R. I. Mohamed and A. A. Radwan, “Hierarchical control system for robust microgrid operation and seamless mode transfer in active distribution systems,” IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 352–362, 2011, doi: 10.1109/TSG.2011.2136362.

[28] F. Katiraei, M. R. Iravani, and P. W. Lehn, “Micro-grid autonomous operation during and subsequent to islanding process,” IEEE Trans. Power Deliv., vol. 20, no. 1, pp. 248–257, 2005, doi: 10.1109/TPWRD.2004.835051.

[29] J. Rocabert, A. Luna, F. Blaabjerg, and P. Rodríguez, “Control of power converters in AC microgrids,” IEEE Trans. Power Electron., vol. 27, no. 11, pp. 4734–4749, 2012, doi: 10.1109/TPEL.2012.2199334.

[30] T. L. Vandoorn, J. C. Vasquez, J. De Kooning, J. M. Guerrero, and L. Vandevelde, “Microgrids: Hierarchical control and an overview of the control and

reserve management strategies," IEEE Ind. Electron. Mag., vol. 7, no. 4, pp. 42–55, 2013, doi: 10.1109/MIE.2013.2279306.

[31] H. Han, X. Hou, J. Yang, J. Wu, M. Su, and J. M. Guerrero, "Review of power sharing control strategies for islanding operation of AC microgrids," IEEE Trans. Smart Grid, vol. 7, no. 1, pp. 200–215, 2016, doi: 10.1109/TSG.2015.2434849.

[32] B. Mirafzal and A. Adib, "On Grid-Interactive Smart Inverters: Features and Advancements," IEEE Access, vol. 8, pp. 160526–160536, 2020, doi: 10.1109/ACCESS.2020.3020965.

[33] T. L. Vandoorn, J. D. M. De Kooning, B. Meersman, and L. Vandevelde, "Review of primary control strategies for islanded microgrids with power-electronic interfaces," Renew. Sustain. Energy Rev., vol. 19, pp. 613–628, 2013, doi: 10.1016/j.rser.2012.11.062.

[34] E. Planas, A. Gil-De-Muro, J. Andreu, I. Kortabarria, and I. Martínez De Alegría, "General aspects, hierarchical controls and droop methods in microgrids: A review," Renew. Sustain. Energy Rev., vol. 17, pp. 147–159, 2013, doi: 10.1016/j.rser.2012.09.032.

[35] Q. Shafiee, J. M. Guerrero, and J. C. Vasquez, "Distributed secondary control for islanded microgrids-a novel approach," IEEE Trans. Power Electron., vol. 29, no. 2, pp. 1018–1031, 2014, doi: 10.1109/TPEL.2013.2259506.

[36] P. T. Baboli, M. Shahparasti, M. P. Moghaddam, M. R. Haghifam, and M. Mohamadian, "Energy management and operation modelling of hybrid AC-DC microgrid," IET Gener. Transm. Distrib., vol. 8, no. 10, pp. 1700–1711, 2014, doi: 10.1049/iet-gtd.2013.0793.

[37] L. Meng, T. Dragicevic, J. Guerrero, J. Vasquez, M. Savaghebi, and F. Tang, "Agent-based distributed unbalance compensation for optimal power quality in islanded microgrids," IEEE Int. Symp. Ind. Electron., pp. 2535–2540, 2014, doi: 10.1109/ISIE.2014.6865019.

[38] N. Mahmud, A. Zahedi, and M. Shamiur Rahman, Control of Renewable Energy Systems. Singapore: Springer Singapore, 2018, pp. 207~231.

[39] A. Bidram and A. Davoudi, "Hierarchical Structure of Microgrids Control System," IEEE Transactions on Smart Grid, vol. 3, no. 4, pp. 1963~1976, Dec. 2012.

[40] D. E. Olivares, A. Mehrizi-Sani, A. H. Etemadi, C. A. Canizares, R. Iravani, M. Kazerani, A. H. Hajimiragha, O. Gomis-Bellmunt, M. Saeedifard, R. Palma-Behnke, G. a. Jimenez-Estevez, and N. D. Hatziargyriou, "Trends in microgrid control," IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1905~1919, 2014.

Biographies

Anil Navle received the bachelor's degree in electrical engineering from Sarvajanik College of Engineering & Technology, VNSGU Surat Gujarat India in 2004 and the master's degree in electrical power engineering from M. S. University of Baroda, Vadodara Gujarat India in 2006. He is currently working as an Assistant Professor at the Electrical Engineering Department, Government Engineering College Dahod Gujarat India. His research areas include Renewable energy control and power management in microgrid. He is research scholar at Gujarat Technological University Ahmedabad Gujarat India.

Naimish K Zaveri received the bachelor's degree in electrical engineering from S.V.N.I.T, Surat, Formerly known as S.V.R.E.C,Surat Gujarat India in 1999, the master's degree in electrical engineering from B.V.M ,V.V.Nagar Gujarat in 2002 and PhD from SVNIT, Surat in 2012. He is currently working as a Professor at the Electrical Engineering Department, C.K.Pithawala College of Engineering and Technology Surat Gujarat India. His research areas include Power Quality in renewable energy and power management in microgrid.