International Journal of Power System Operation and Energy Management

Volume 3 | Issue 3 Article 1

January 2022

Operation Control and Analysis of a Hybrid AC/DC Microgrid

Sanjay K. Bansal
Bikaner Technical University, skbansal30@gmail.com

Dhairya Gaur
Bikaner Technical University, dhairyagaur413@gmail.com

Kingshuk Roy
Bikaner Technical University, kingshukroy52@gmail.com

Apoorva Choumal
Bikaner Technical University, apoorvachoumal@gmail.com

Recommended Citation

Bansal, Sanjay K.; Gaur, Dhairya; Roy, Kingshuk; and Choumal, Apoorva (2022) "Operation Control and Analysis of a Hybrid AC/DC Microgrid," *International Journal of Power System Operation and Energy Management*: Vol. 3 : Iss. 3 , Article 1.
DOI: 10.47893/IJPSOEM.2022.1132
Available at: https://www.interscience.in/ijpsoem/vol3/iss3/1

Operation Control and Analysis of a Hybrid AC/DC Microgrid

Sanjay K. Bansal[1], Dhairya Gaur[2], Kingshuk Roy[3], Apoorva Choumal[4]
[1,2,3,4] Department of Electrical Engineering, BTU, Bikaner, India,
email: skbansal30@gmail.com, dhairyagaur413@gmail.com, kingshukroy52@gmail.com, apoorvachoumal@gmail.com
(Corresponding Author: - Sanjay K. Bansal, corresponding author email: skbansal30@gmail.com)

ABSTRACT**: Distributed renewable energy production is making smart microgrid concepts based on AC, DC, and hybrid-MG design more attractive (DRE). In light of the growing population and the pressing need to minimize the load, research into effective control techniques and architectural solutions is a hot topic right now. "However, a comprehensive and coordinated literature assessment of hierarchical control approaches based on diverse configurations of the microgrid (MG) architecture has been explored relatively little in the past.'' Primary, secondary, and tertiary methods to MG system control are outlined in this suggested method. Primary, secondary and third-tier techniques are examined for each MG structure in a short literature review. In addition, the paper offers the best and worst aspects of current control methods. In addition, a simulation research connected to the literature review's future trends in MG control is offered as a further contribution to this subject. Since renewable energy supplies are intermittent in nature, a hybrid microgrid is needed to minimize overall deficit inadequacies and increase system dependability. This is due to the depletion of natural resources and to the intermittent nature of renewable energy resources. Using a hybrid microgrid, the present distributed and concentrated load situations may be accommodated. In order to better understand how the hybrid microgrid may be integrated, optimized and controlled, there is a growing demand for research. It is necessary to do a thorough evaluation of the performance, efficiency, dependability, security, design flexibility, and cost-effectiveness of a hybrid microgrid. Issues such as AC and DC microgrids integrating into a single hybrid microgrid are discussed in this paper, as well as how to manage renewable energy resources in a cost-effective manner and how to place the optimal number of feeders in a microgrid. There is a quick overview of the primary research fields, with the goal of finding the research gap that may further enhance the grid's performance. ''New hybrid microgrid solutions are being offered in light of current study trends that have been determined to be the most effective and most-friendly." Research, comparative analysis, and further development of new methodologies related to hybrid microgrids will be aided by this study as the foundation for future work

Keywords: Microgrid (mg), AC/DC microgrid, AC/DC coupled hybrid microgrid, Optimization Technique, etc.

1 INTRODUCTION

Advanced communications, information technology, and semiconductor-based devices, together with enhanced management and sensing and measuring technologies are included in a 'smart grid,' which is an electric grid that has been modernized. Many enticing characteristics, such as reduced loss, demand-side response and control, greater power quality, and enhanced overall efficiency, are provided to satisfy the expanding energy demand. Besides the foregoing, the SMG initiation is driven by renewable energy integration, grid enhancement, smart protection & control, smart management system, and smart infrastructure system. However, in order to achieve all of its goals, a wide range of concerns and obstacles must be addressed and more development is needed. In order to ensure seamless, efficient, dependable, and secure operation, we need to pay greater attention to smart grid management. A substantial control gap exists between traditional and SMG systems when it comes to transitioning from centralized generation to distributed generation, restricted control to ubiquitous control, hierarchical to network control, and electromechanical to digital control. Control features must be provided in both grid-connected and isolated modes of operation, according to the MG viewpoint. Limiting SMG application control techniques as the manuscript's goal, a short technical explanation of motivation, problems and solutions is provided. Population growth, rising standards of living and infrastructure development have all contributed to a dramatic rise in energy consumption over the last several decades. A more efficient power grid and a greater use of classic producing units are thus necessary. Traditional energy sources, which are depleting in the form of fossil fuels at an alarming pace, are inefficient, and have environmental consequences that must be addressed, as does an outdated power infrastructure [1, 2]. When seen from this perspective, renewable energy sources have grown in popularity throughout time.

It's important to note that renewable sources of energy include renewable sources such as renewable sources such as biofuels and small hydropower facilities. Often referred to as 'distributed energy resources,' these systems are often coupled at the distribution level. The utility grid's integration with distributed energy resources is an interesting option. A microgrid consists of a low-voltage distribution system, distributed generation, energy storage devices, and loads all combined into one system. It's the best way to decentralize a power grid, in my opinion. Increased system stability, lower investment costs, the green impact of renewable sources, improved power quality, and reduced losses in the distribution network are all benefits of a microgrid's capacity to connect and disengage from the main grid. AC, DC, and hybrid microgrids may be classified into three main categories depending on their topology. Microgrids based on the AC microgrid architecture are the most common and widely utilized. Distributed generation (DG) units must be synchronized and losses due to reactive power circulation are some of its downsides. Adding to this challenge is the fact that DC sources must be converted to AC, which reduces overall efficiency. DC microgrids have been made possible by the rising use of DC-based distributed energy resources such as PV and fuel cells, energy storage systems, and loads. But it demands a major overhaul of the existing electricity infrastructure. In both AC and DC microgrids, numerous DC/DC, AC/DC, and DC/AC conversions result in inefficiency. An ideal way to implement smart grids in traditional distribution networks is via a hybrid microgrid. There is no synchronization, no complex transformation, and it is economically feasible since it incorporates the benefits of both AC and DC microgrids [3–7, 9]. Hybrid microgrids may be defined as either 'an integrated AC/DC microgrid system or a hybrid low-voltage microgrid, unless otherwise stated,' according to this definition.

The hybrid microgrid offers a plethora of possibilities for further study. A thorough assessment of the most recent advancements in the hybrid microgrid sector is essential for any future research [22]. By summarizing the findings and allowing the reader to discover research gaps, review articles make this process simpler. An overview of research on hybrid microgrids, beginning with the topology and progressing through optimization and control methods, is presented in this study. In this review study, all important aspects of the hybrid microgrid, such as problems, optimization, power production, and sharing control, are compared with prior evaluations of the hybrid microgrid. If you're a researcher, here is your one-stop shop for all the information you need to go forward in your studies.

According to this study, a comparison of plausible alternatives and the level of research concentrated on each option is provided. Additionally, it will offer the most recent trends and research gaps in the field of hybrid microgrids, making it easier to locate relevant information. It is essential to have this thorough information in order to illuminate the way for future study.

2. OBJECTIVES

The main contributions of this paper are as follows:

- Subgrid integration and interconnecting converters are discussed in this study. It brings together the most current studies on interlinking converters and seeks to synthesize the results of the most explored part of integration and the existing research gap and the most recent trend in this area of study.

- The paper presents a critical analysis of all the optimization techniques employed in hybrid microgrids regarding power flow, power generation, minimizing the uncertainty issues, and the design and topology of the hybrid microgrid. It also finds the recent trends in optimization techniques, finds the efficiency of each area of techniques used, and suggests the latest areas of research where significant progress can be achieved regarding hybrid microgrids.
- The control methods for power flow and generation, as an important aspect of hybrid microgrid, are taken into understudy for this review. It encompasses all the recent control methodologies and proposes novel strategies which are being researched and found more cost-effective

- The paper presents a comprehensive comparative analysis with the existing surveys in all the relevant fields and establishes a novel framework regarding the review of all the major research studies in one paper.

3. STRUCTURE OF HYBRID AC/DC MICROGRID

AC, DC, utility grid, and interface stage are common components of the hybrid microgrid construction. A hybrid AC/DC microgrid contains both independent AC and DC microgrids through interface stages [12-14]. 'The hybrid microgrid may be classified into three topologies based on the connection of distributed generators and energy storage systems to the main bus and the coupling of the main bus with the utility grid. The key distinction between them is that there is a different kind of grid. With the aid of ***iHOGA*** software, writers in assess several batteries for optimum functioning of renewable energy resources in a hybrid microgrid [23]. It indicates that the current methods for predicting the life lifetime of batteries are inaccurate, and lithium batteries display a lower cost of energy compared to other types of batteries. In, a more in-depth examination of hybrid AC/DC microgrid power management techniques is offered.

3.1. AC Coupled Hybrid Microgrid

Distribution generators, energy storage devices, and a utility are all linked to the main AC bus in an AC-coupled microgrid. "Bidirectional interface converters are used to link the energy storage system and the DC loads." It is the most widely utilized topology in the world because of the ease with which AC generating equipment can be procured. However, interfacing converters are responsible for the topology's current inefficiency.

3.2. DC Coupled Hybrid Microgrid

To link the AC distributed generators to the main grid through the main DC bus interface converter, as illustrated in Figure 1, the DC-coupled microgrid is connected to distributed generators, energy storage elements, and loads.

3.3. AC-DC Coupled Hybrid Microgrid

In this topology, as shown in Figure 1, both AC and DC buses relate to Distributed generators, energy storage systems, and load. The interlinking converters have been employed as an interface between AC and DC subgrids [11, 15-16]. This configuration limits higher interfacing, which in turn reduces the cost and enhances the overall efficiency. This topology is the most attractive solution for a paradigm of future smart grids.

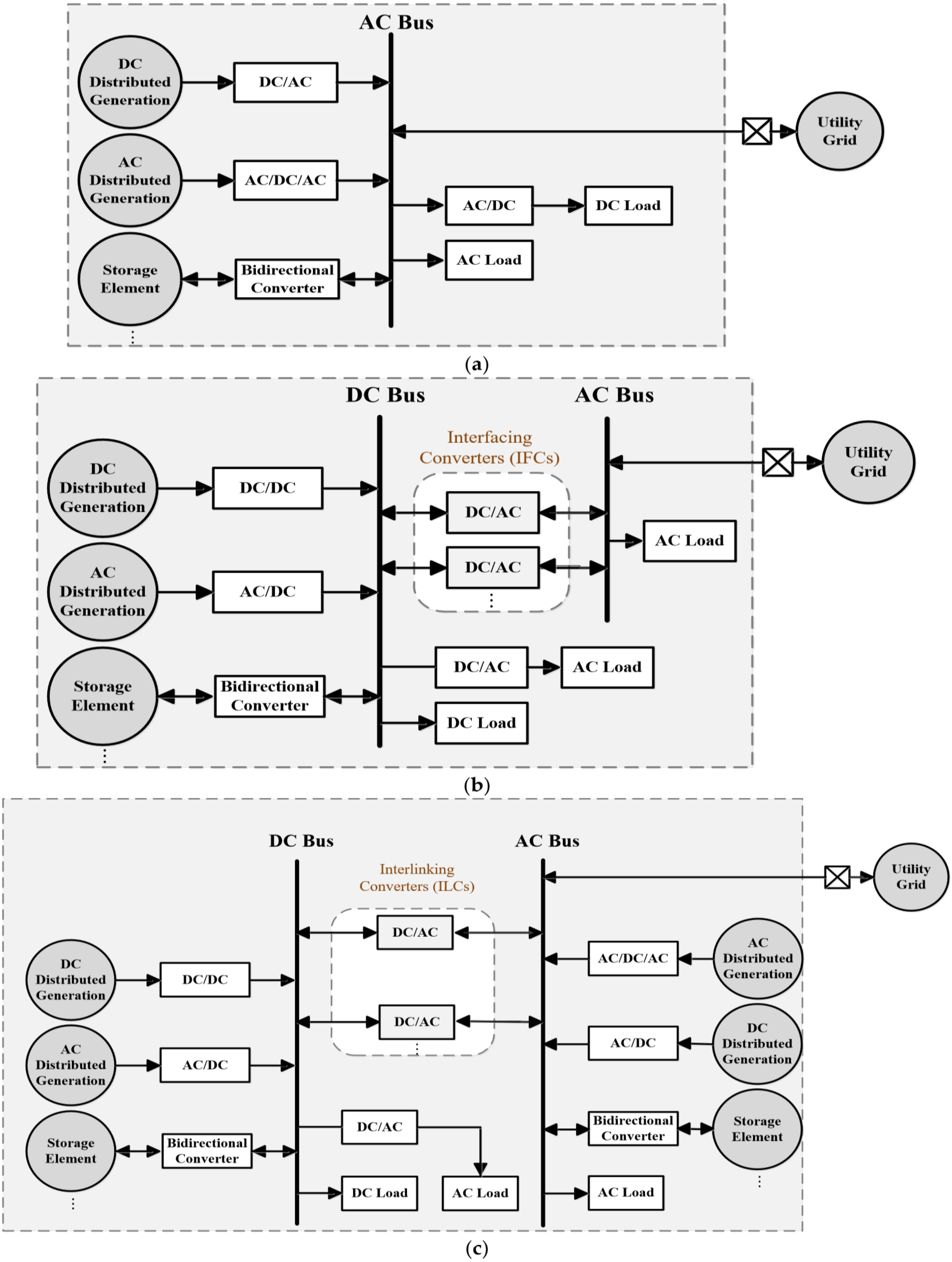

Figure 1. . (a) AC coupled, (b) DC coupled, and (c) AC-DC coupled hybrid microgrid

.

4. CHALLENGES AND ISSUES IN HYBRID AC/DC MICROGRID

Decentralized and smart grid paradigms may be realized with the help of AC/DC microgrids. When compared to other microgrids and utilities, it offers a slew of benefits. But there are other practical concerns, including operational obstacles like coordination control, protection issues, stability and energy management system stability and market trends in producing efficient and realistic future networks [17, 21]. Figure 2 summarizes the difficulties of hybrid AC/DC microgrids and outlines the steps taken to overcome them.

5. OPTIMIZATION TECHNIQUES

Microgrids are being injected with renewable energy resources at a rapid rate owing to increased demand for renewable energy resources, as well as the depletion of fossil fuel resources and awareness of environmental protection. Using a hybrid microgrid, these problems may be alleviated by improving system attributes and performance metrics. Local energy needs may be met more reliably and efficiently thanks to the improved dependability, power quality, stability, and overall stability of the system. Optimization strategies for hybrid AC DC microgrid issues are covered in this section. Power flow optimization, uncertainty optimization, and design optimization are some of the more specific categories into which the issues may be broken down and analyzed [8].

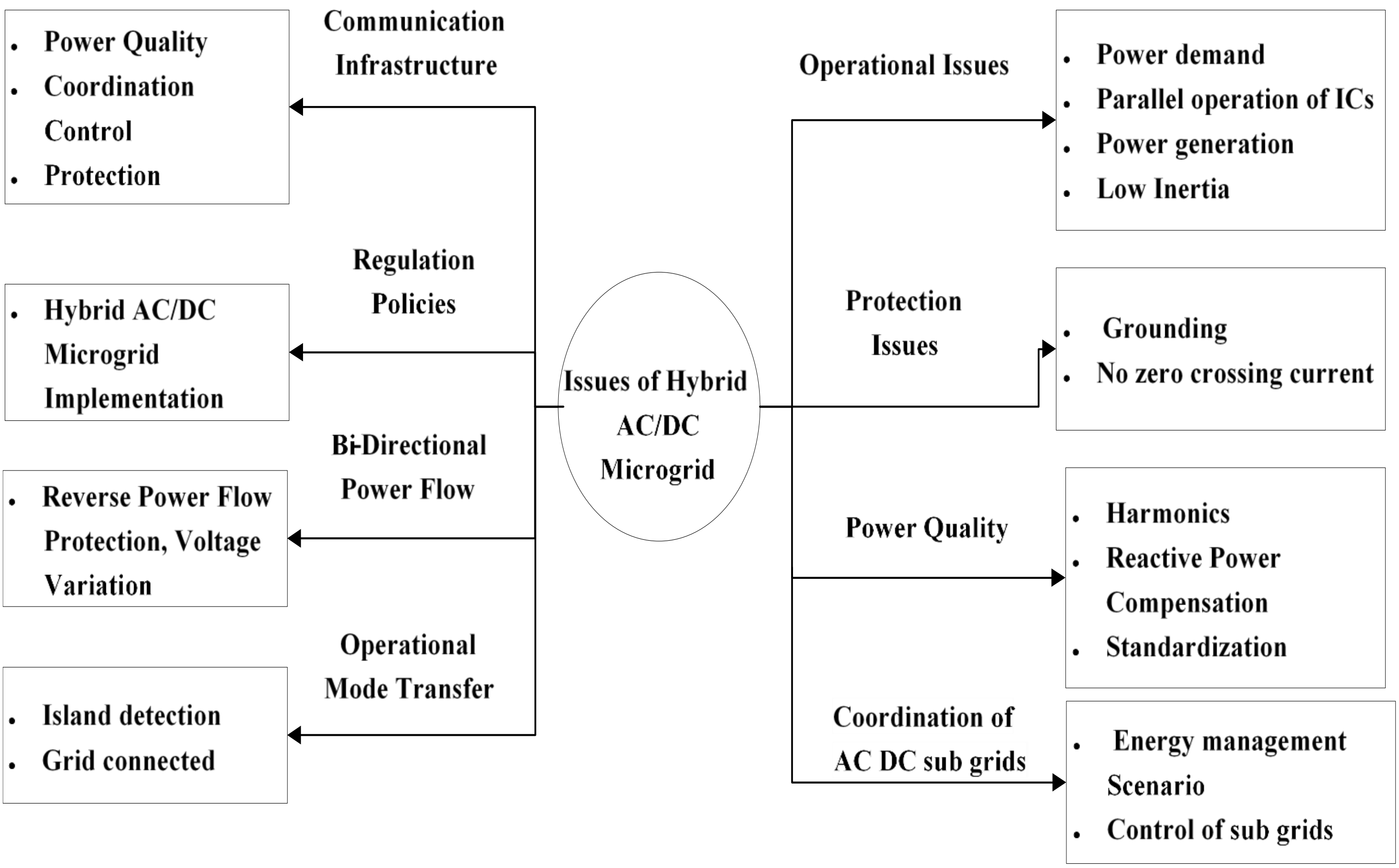

Figure 2 Challenges of hybrid AC/DC microgrid.

6. HYBRID AC/DC MICROGRID CONTROL STRATEGIES

Despite their numerous advantages, hybrid alternating current/direct current microgrids need very sophisticated control strategies due to their integration of AC and DC subgrids. Nonlinear control methods and other unique ways are being used to integrate hybrid microgrids effectively in the integration control center of current control research. For power management and control, AC/DC hybrid micro grids need more sophisticated methods than AC or DC micro grids because of the ICs controls. It focuses on hybrid microgrid power management solutions, emphasizes research trends, and indicates the specific research routes

7. COMPARISON WITH RECENTLY CONDUCTED REVIEWS

In recent years, a variety of reviews have been published on the subject of hybrid microgrids. As an example, in reference, a comprehensive evaluation of the uncertainties (only) associated with renewable energy resources-integrated hybrid AC/DC microgrids is presented in order to ensure their optimum performance. For AC/DC microgrids developed to provide a sustainable electrical supply, key obstacles were explored in. An overview of recognized mathematical optimization approaches applied to a complicated microgrid planning process is provided by reference. Referencing also shows that for microgrids with embedded hybrid energy systems (HES), a review of optimization techniques, including metaheuristics like ant colony optimization (ACO), GA, PSO, simulation annealing (SA), differential evolution (DE), and others, is described in order to ensure economical and reliable resource dispatch. For hybrid energy systems in microgrids, provides a detailed evaluation of power management approaches. Various versions (variants) and hybrid forms of PSO were examined to determine the economic dispatch issues. The strategies, challenges, and future perspectives for protecting distributed generating hybrid AC/DC microgrids are discussed in reference. Microgrid control strategies for isolated microgrids are thoroughly reviewed in [9-10, 22]. Details of all the procedures involved in cooperative control are thoroughly covered in this book. These review

for the future of hybrid microgrids protection issues, strategies for integrating microgrids with the help of interlinking converters and robust uncertainty optimization techniques, design techniques, nonlinear load handling, and droop control mechanisms are the popular research areas regarding the hybrid microgrids, established in this table with the help of comparison with other surveys. Protection issues, strategies for integrating microgrids with the help of interlinking converters and robust uncertainty optimization techniques, design techniques, nonlinear load handling, and droop control mechanisms are the popular research areas regarding the hybrid microgrids, established in this table with the help of comparison with other surveys.
articles focus on one of the most important aspects of microgrids at a time, as can be seen. All the important hybrid microgrid research fields are covered here, as well as related studies and future research plans [18-20]. It also helps

8. OPTIMAL OPERATION MATHEMATICAL MODEL

Coordination of Source-network-load

a) Load Side

i. Shift Load for Consuming Renewable Energy

The recalculation of load demand curves has been done based on renewable energy projection data and the DSR depending on the costs and incentive in order to prevent the abandonment of renewable energy. The production power of renewable energy differs from the load demand, and this discrepancy is what determines the value of shift-in load. Here is a breakdown of the particular steps:

$$L_{yr}(t) = \begin{Bmatrix} P_r(t) - L(t) & P_t(t) > L(t) \\ 0 & P_t(t) \le L(t) \end{Bmatrix} \quad (1)$$

$$L_{yc1}(t) = \begin{Bmatrix} \min\left(L_{py}(t), \sum_{t=1}^{T} L_{yr}(t) - \sum_{tt=0}^{t-1} L_{yc1}(tt)\right) & L(t) > P_t(t) \\ 0 & L(t) \le P_t(t) \end{Bmatrix} \quad (2)$$

$$L_{yr}(t) = \begin{cases} P_r(t) & P_t(t) > L(t) \\ 0 & P_t(t) \le L(t) \end{cases} \quad (3)$$

$$L_{yr1}(t) = \min\left(L_{py}(t), {P_t(t)} \Big/ {\textstyle\sum_{t=1}^{T} L_{yr}(t) - \sum_{t=0}^{T} L_{yc1}(t)} \right) \quad (4)$$

$$L_{yc1}(t) = \begin{cases} L(t) - L_{yc1}(t) & L(t) > P_t(t) \\ L_{yr}(t) + L(t) & L(t) \le P_t(t) \end{cases} \quad (5)$$

Where, $L(t)$ is a function of time, $L_{yr}(t)$ is the load demand at the start of the calculation. The greatest load shift at time t is represented by$L_{yr}(t)$. If you're interested in learning more about the $L_{yc1}(t)$ gene, go here. Loads $L_{yc1}(0)$ and $L_{yr}(t)$ are the shift in and shift out loads respectively at time t. $L_{yc1}(0) = 0$. The movable load at time t is denoted by$L_{py}(t)$. $P_r(t)$ At time t, $P_r(t)$ is the renewable energy's predicted output power; TT is the ideal cycle; Total renewable energy power $L_{yr}(t)$, when its output power is greater than that of the load, and load value $L_{j1}(t)$ after the load has been shifted, are represented by $L_{yr}(t)$.
The load curves of a hybrid AC/DC MG would be changed depending on the price of DSR for reduction of overall costs of the system. The load would be moved in accordance with the TOU pricing of the power grid in order to fulfil the limitations of balance of load-supply and the satisfaction of customer.

ii. Reduction of running cost of hybrid AC/DC microgrid by shift load

$$L_{jg}(t) = L_{j1}(t) - L_{yc2}(t) + L_{yr2}(t) \quad (6)$$

Where, $L_{jg}(t)$ is at time t load demand value while DSR in considering based on price; $L_{yr2}(t)$ and $L_{yc2}(t)$ represent the shift-in and shift-out load at time t. The base case load value is $L_{j1}(t)$. The net load demand at any instant is the net sum of base case load of that moment and the shift-in and shift out load. The pricing of DSR has been done using $L_{jg}(t)$.

b) Source Side

Diesel generator (DEG) and wind turbine (WT) in AC region, and photovoltaic (PV) and ES in DC area are studied in this study. Renewable energy is given precedence on the supply side of the equation. The cost function is dictated by insufficiency of renewable energy to fulfil demand of the conventional power sources output. Power production from PV and WT is mostly dependent on weather conditions. Our data shows that the Weibull distribution holds true for wind speed; Beta holds true for light intensity. When the output power of PV and WT is tends to zero and then it is difficult to satisfy the load demand, a complementary power supply of renewable energy between AC and DC areas may effectively boost the consumption rate of renewable energy by making up for these shortcomings.

$$If\ (R_{AC}(t) \le L_{AC}(t)) \cap \left(R_{DC}(t) \le L_{DC}(t)\right)$$

$$\begin{cases} R_{AC\to DC}(t) = 0 \\ R_{DC\to AC}(t) = 0 \\ P_{RAC}(t) = R_{AC}(t) \\ P_{RDC}(t) = R_{DC}(t) \end{cases} \quad (7)$$

$$If\ (R_{AC}(t) > L_{AC}(t)) \cap \left(R_{DC}(t) < L_{DC}(t)\right)$$

$$\begin{cases} R_{AC\to DC}(t) = \min(R_{AC}(t) - L_{AC}(t); L_{DC}(t) - R_{DC}(t)) \\ R_{DC\to AC}(t) = 0 \\ P_{RAC}(t) = L_{AC}(t) \\ P_{RDC}(t) = R_{DC}(t) \end{cases} \quad (8)$$

$$If\ (R_{AC}(t) \ge L_{AC}(t)) \cap \left(R_{DC}(t) \ge L_{DC}(t)\right)$$

$$\begin{cases} R_{AC\to DC}(t) = 0 \\ R_{DC\to AC}(t) = 0 \\ P_{RAC}(t) = L_{AC}(t) \\ P_{RDC}(t) = L_{DC}(t) \end{cases} \quad (9)$$

Where, renewable energy's maximum output power at the DC and AC area represented by $R_{DC}(t)$ and $R_{AC}(t)$, the load demand in DC and AC area are represented by $L_{DC}(t)$ and $L_{AC}(t)$, $R_{AC\to DC}(t)$ represents renewable energy's output power flowing from AC to DC area, $R_{DC\to AC}(t)$ represents renewable energy's output power flowing from DC to AC area and $P_{RAC}(t)$ represents output power supplied to the AC load by renewable energy in the AC area and $P_{RDC}(t)$ represents output power supplied to the DC load by renewable energy in the DC area;

c) Network side

In order to achieve supply-load parity, the hybrid AC/DC MG in this study is linked to the main grid. It is possible to compute the cost of acquiring energy from the power grid in order to fulfil the PCC's transmission capacity limitation, as follows:

$$F_{grid} = \sum_{t=1}^{T} \epsilon(t).P_{grid}(t) \qquad (10)$$

Where, electricity purchasing costs from main grid is denoted byF_{grid}; TOU price is denoted by $\epsilon(t)$ and purchased electricity is defined by $P_{grid}(t)$.

It is possible to sell excess renewable energy to the grid if the unit generating cost of renewable energy is lower than the selling price in a hybrid AC/DC MG.

$$F_S = \sum_{t=1}^{T}(\beta(t) - \chi(t)).R_s(t) \qquad (11)$$

Where, the profile of selling the excess electric power from the renewable sources to main grid is denoted by F_S; at time t selling price is denoted by $\beta(t)$, The renewable sources generation costs per unit is denoted by $\chi(t)$ and the sold surplus power to the grid is $R_s(t)$.

The proposed optimal hybrid AC/DC MG operations based on source-network-load coordination has been shown in Fig. 3.

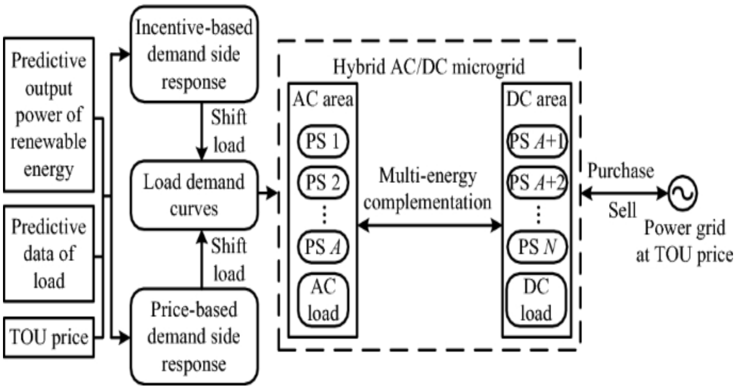

Figure 3. **Operation costs distributed situation**

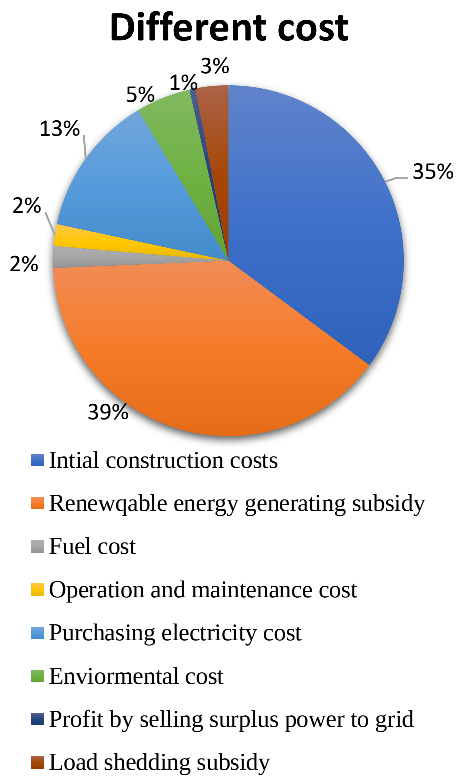

Figure 4. Different Cost

8. Conclusions

Various features of a hybrid microgrid, including its optimization and control topologies and difficulties encountered, are briefly discussed in this study. Decentralized power systems and smart grids may be realized using a hybrid microgrid. Due to its better dependability, the elimination of repeated conversions and auxiliary service, it has several benefits over conventional power networks. An investigation of the obstacles that hybrid microgrids encounter in integrating into the grid is described in this research, with various solutions to those issues being examined. Research into microgrid integration is focused on the non-linear regulation of interlinking converters, which is critical. It's critical to investigate new methods for protecting hybrid microgrids, and this is a research gap that needs filling. Optimization strategies have been guided by the power flow mechanism. Updated models and enhanced heuristic approaches have been employed to assure optimal power flow and decrease operating expenses. Stochastic, fuzzy logic, and resilient approaches were used to deal with the DC generator uncertainties. The cost-effective and efficient robust approaches have been established in this sector. Planning and designing the hybrid AC/DC is the initial stage in optimizing the hybrid grid's operating efficiency. Since the pace of hybrid microgrid research has been sluggish and stable in recent years, there is a tremendous need for further study in this field. Developing new equipment, modelling current equipment, and using enhanced heuristic methodologies for optimum storage and generator planning are all essential components of this field. "Additional consideration is needed in the hybrid grid system to bear in mind the high integration of DC generators, non-linear loads, and plugin hybrid automobiles." The droop control approaches have been extensively studied in relation to hybrid microgrid control systems. Improved droop control systems and non-linear control tactics utilising model predictive control have also recently become popular. It is important to thoroughly examine the various microgrids functioning in a hybrid microgrid environment in order to determine the best power management and control solutions. In addition, it provides suggestions for further study in this area.

This research proposes a multi-objective optimum operation technique for hybrid AC/DC microgrids based on source-network-load coordination to increase renewable energy consumption and reduce operating costs. MA's core design is upgraded while its test function proves its strong optimization efficiency. Running time is shorter and more optimal outcomes may be noticed in comparison to basic MA. Results show that both incentive-based DSRs and price-based DSRs are beneficial in terms of load side, the complementary use of renewable energy between alternating current and direct current (AC) areas, and the electricity trading between the hybrid AC/DC microgrid and the big power grid. In only 10.22 seconds, the IMA convergence time and renewable energy consumption rate may approach 100%. Using the same calculations, but excluding source-network-load coordination, the cost of a hybrid AC/DC microgrid is much lower than that of a conventional system.

REFERENCE

1. Babatunde, O.M.; Munda, J.L.; Hamam, Y. A Comprehensive State-of-the-Art Survey on Hybrid Renewable Energy System Operations and Planning. *IEEE Access* **2020**, *8*, 75313–75346. [CrossRef]
2. Gong, X.; Dong, F.; Mohamed, M.A.; Abdalla, O.M.; Ali, Z.M. A Secured Energy Management Architecture for Smart Hybrid Microgrids Considering PEM-Fuel Cell and Electric Vehicles. *IEEE Access* **2020**, *8*, 47807–47823. [CrossRef]
3. Bolgouras, V.; Ntantogian, C.; Panaousis, E.; Xenakis, C. Distributed Key Management in Microgrids. *IEEE Trans. Ind. Inform.* **2020**, *16*, 2125–2133. [CrossRef]
4. Yoldas¸, Y.; Önen, A.; Muyeen, S.M.; Vasilakos, A.V.; Alan, I. Enhancing Smart Grid with Microgrids: Challenges and Opportunities.˙ *Renew. Sustain. Energy Rev.* **2017**, *72*, 205–214. [CrossRef]
5. Cagnano, A.; De Tuglie, E.; Mancarella, P. Microgrids: Overview and Guidelines for Practical Implementations and Operation. *Appl. Energy* **2020**, *258*, 114039. [CrossRef]
6. Hirsch, A.; Parag, Y.; Guerrero, J. Microgrids: A Review of Technologies, Key Drivers, and Outstanding Issues. *Renew. Sustain. Energy Rev.* **2018**, *90*, 402–411. [CrossRef]
7. Unamuno, E.; Barrena, J.A. Hybrid Ac/Dc Microgrids—Part I: Review and Classification of Topologies. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1251–1259. [CrossRef]
8. García-Vera, Y.E.; Dufo-López, R.; Bernal-Agustín, J.L. Optimization of Isolated Hybrid Microgrids with Renewable Energy Based on Different Battery Models and Technologies. *Energies* **2020**, *13*, 581. [CrossRef]
9. Nejabatkhah, F.; Li, Y.W. Overview of Power Management Strategies of Hybrid AC/DC Microgrid. *IEEE Trans. Power Electron.* **2015**, *30*, 7072–7089. [CrossRef]
10. Malik, S.M.; Sun, Y.; Ai, X.; Chen, Z.; Wang, K. Cost-Based Droop Scheme for Converters in Interconnected Hybrid Microgrids. *IEEE Access* **2019**, *7*, 82266–82276. [CrossRef]
11. Loh, P.C.; Li, D.; Chai, Y.K.; Blaabjerg, F. Autonomous Operation of Hybrid Microgrid with AC and DC Subgrids. *IEEE Trans. Power Electron.* **2013**, *28*, 2214–2223. [CrossRef]
12. Loh, P.C.; Li, D.; Chai, Y.K.; Blaabjerg, F. Hybrid AC–DC Microgrids with Energy Storages and Progressive Energy Flow Tuning. *IEEE Trans. Power Electron.* **2013**, *28*, 1533–1543. [CrossRef]
13. Alsiraji, H.A.; El-Shatshat, R. Serious Operation Issues and Challenges Related to Multiple Interlinking Converters Interfacing a Hybrid AC/DC Microgrid. In Proceedings of the 2018 IEEE Canadian Conference on Electrical Computer Engineering (CCECE), Quebec City, Canada, 13–16 May 2018; pp. 1–5.
14. Zhao, B.; Qiu, H.; Qin, R.; Zhang, X.; Gu, W.; Wang, C. Robust Optimal Dispatch of AC/DC Hybrid Microgrids Considering

Generation and Load Uncertainties and Energy Storage Loss. *IEEE Trans. Power Syst.* **2018**, *33*, 5945–5957. [CrossRef]

15. Kaushik, R.A.; Pindoriya, N.M. A Hybrid AC-DC Microgrid: Opportunities Key Issues in Implementation. In Proceedings of the *2014 International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE)*, Coimbatore, India, 6–8 March 2014; pp. 1–6.
16. Li, C.; Chaudhary, S.K.; Vasquez, J.C.; Guerrero, J.M. Power Flow Analysis for Droop Controlled LV Hybrid AC-DC Microgrids with Virtual Impedance. *In Proceedings of the 2014 IEEE PES General Meeting Conference Exposition, National Harbor*, MD, USA, 27–31 July 2014; pp. 1–4.
17. Hossain, M.A.; Pota, H.R.; Hossain, M.J.; Blaabjerg, F. Evolution of Microgrids with Converter-Interfaced Generations: Challenges and Opportunities. *Int. J. Electr. Power Energy Syst.* **2019**, *109*, 160–186. [CrossRef]
18. Lotfi, H.; Khodaei, A. Hybrid AC/DC Microgrid Planning. *Energy* **2017**, *118*, 37–46. [CrossRef]
19. Noh, C.-H.; Kim, C.-H.; Gwon, G.-H.; Khan, M.O.; Jamali, S.Z. Development of Protective Schemes for Hybrid AC/DC Low-Voltage Distribution System. *Int. J. Electr. Power Energy Syst.* **2019**, *105*, 521–528. [CrossRef]
20. Mirsaeidi, S.; Dong, X.; Said, D.M. Towards Hybrid AC/DC Microgrids: Critical Analysis and Classification of Protection Strategies. *Renew. Sustain. Energy Rev.* **2018**, *90*, 97–103. [CrossRef]
21. Beheshtaein, S.; Savaghebi, M.; Vasquez, J.C.; Guerrero, J.M. Protection of AC and DC Microgrids: Challenges, Solutions and Future Trends. In Proceedings of the *IECON 2015—41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, Japan*, 9–12 November 2015; pp. 005253–005260.
22. Nejabatkhah, F.; Li, Y.W.; Tian, H. Power Quality Control of Smart Hybrid AC/DC Microgrids: An Overview. *IEEE Access* **2019**, *7*, 52295–52318. [CrossRef]
23. Ortiz, L.; Orizondo, R.; Águila, A.; González, J.W.; López, G.J.; Isaac, I. Hybrid AC/DC Microgrid Test System Simulation: Grid-Connected Mode. *Heliyon* **2019**, *5*. [CrossRef]