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Energy Storage Controllers and Optimization Schemes Integration to Microgrid: An Analytical Assessment Towards Future Perspectives

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ABSTRACT Several important advancements in the integration of energy storage into microgrids have fueled a lot of research and development over the last ten years to achieve the global decarbonization goal by 2050. The effective integration of the energy storage system in the microgrid is essential to ensure a safe, reliable, and resilient operation. Nevertheless, the utilization of energy storage in microgrids brings several issues, including poor power quality and intermittence characteristics. To address these concerns, appropriate energy storage controllers and optimization schemes are required to manage and optimize the power efficiently and securely. Although various research works have been performed and published over the years, the analytical assessment of energy storage controllers and optimization schemes integration into microgrids has not been carried out yet. Thus, this paper presents a comprehensive analytical evaluation of energy storage controllers and optimization schemes in Microgrid by recognizing and evaluating the highly influential 110 manuscripts using the Scopus database within the year 2010-2021. The analytical analysis emphasizes the current research trends, keyword evaluation, research classification, country analysis, authorship, and research collaboration. The paper also discusses and compares 24 controllers and 21 optimization schemes in the highly cited 110 manuscripts. Besides, critical discussion and assessment are conducted over 15 emerging subject areas. The constructive analysis identifies the existing limitations and research gaps in the selected 110 papers. By analyzing the existing issues, this manuscript provides several guidelines and suggestions for future improvement. This survey will help to deepen the development concepts to achieve improved power quality, economic prosperity, energy savings, and increased efficiency towards sustainable operation and management in the microgrid.

INDEX TERMS Battery storage, microgrid integration, control approaches, energy management system, optimization method, highly cited paper.

NOMENCLATURE

ACM =	Autonomous Control Method
ACY =	Average Citation Per Year
BA =	Bat Algorithm
BESS =	Battery Energy Storage Systems
BMS =	Battery Management Systems
BS =	Battery Storage
CC-CV =	Current-Constant Voltage
CCHP =	Combined cooling heating and power
CDM =	Clean Development Mechanisms
CS =	Charging Station
DER =	Distributed Energy Resources
DLC =	Dual Loop Controller

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DOI =	Digital Object Identifier
DPG =	Distributed Power Generation
DS =	Digital Storage
DSE =	Data Storage Equipment
DSM =	Demand Side Management
EA =	Economic Analysis
EB =	Electric Battery
EES =	Electric Energy Storage
EE =	Energy Efficiency
ELD =	Electric Loads Dispatching
ELF =	Electric Loads Flow
EMS =	Energy Management System
EPD =	Electric Power Distribution
EPG =	Electric Power Generation
EPS =	Electric Power System
EPT =	Electric Power Transmission
ER=	Energy Resource
ES=	Energy Storage
EST=	Energy Storage Technologies
ETS=	Emission trading system
EU=	Electric Utilities
EV=	Electric Vehicles
FC=	Fuel Cells
FLC=	Fuzzy logic controller
GA=	Genetic Algorithm
HES=	Hybrid Energy Storage
HRES=	Hybrid Renewable Energy Systems
HS=	Hybrid Systems
HV=	Hybrid Vehicles
H2V=	Home to Vehicle
IB=	Intelligent Buildings
IF=	Impact Factor
IP=	Integer Programming
JI=	Joint Implementation
MG=	Micro Grid
MGCC=	Microgrid Central Controller
MPC=	Model predictive control
MILP=	Mixed-Integer Linear Programming
PEV=	Plug-in Electric Vehicles
PSO=	Particle Swarm Optimization
PIC=	Proportional Integral Controller
PM=	Power Markets
PV Cells=	Photovoltaic Cells
PVS=	Photovoltaic System
QL=	Q-learning method
RE=	Renewable Energies
RES=	Renewable Energy Source
RER=	Renewable Energy Resources
SB=	Secondary Batteries
SDG=	Sustainable Development Goals
SE=	Solar Energy
SG=	Smart Grid
SM=	Storage Management
SOC=	State of Charge
SPG=	Solar Power Generation
SS=	Stochastic Systems
TES=	Thermal energy storage
T&DLMP=	Transmission and Distribution Locational Marginal Price
UA=	Uncertainty Analysis
VS=	Virtual Storage
V2H=	Vehicle to Home
V2G=	Vehicle to Grid
WP=	Wind Power
WT=	Wind Turbines
2PEM=	Two-Point Estimation Method

I. INTRODUCTION

Energy storage and microgrid integration are promising solutions to the 21st century's environmental and energy challenges [1]–[3]. However, the incorporation of energy storage in microgrids exhibits several concerns. Due to the intermittent nature of renewable energy supplies and varying load profiles, the power supply in microgrids occasionally fails to meet load needs, resulting in system frequency fluctuations [4]. In order to supply high-power quality, fluctuating renewable energy sources must be smoothed with storage devices [5]. In addition, energy storage in microgrids connected to current electric grids poses technical challenges in terms of managing the power efficiently and securely. Hence, proper management between the energy storage and microgrid is required to optimize the system's overall effectiveness, reduce the electricity bill, and lengthen the lifetime of its components (e.g., fuel cells, batteries, converters). Normally, the energy management system (EMS) of a microgrid includes controllers and optimizations that may be utilized to reduce power utilization and enhance the performance of the battery storage system while enhancing the quality of services provided to consumers [6].

The most important feature of a microgrid, when compared to a traditional power distribution system, is its ability to be controlled and behaved as a coordinated module when connected to the power distribution system [7]. To enhance the efficiency of the microgrid, all components must be monitored, controlled, and optimized [8]. However, the incorporation of battery storage controllers and optimization schemes in microgrid EMS is very complex due to a large number of parameters and complicated algorithm execution [9]–[13]. The microgrid controllers have a few fundamental operational targets, such as the microgrid should be capable to start through a black start in case of general failure, disconnection and reconnection processes should happen flawlessly, uninterruptible operations should be guaranteed for sensitive loads. Nevertheless, microgrid energy storage controllers have several operational challenges, including power conversion mechanism, reliability and protection from dangers, charging and discharging, power electronic interfaces, and efficient energy storage management. Optimization schemes play another vital role in the energy storage integration in microgrid applications that can deliver the optimal size, cost, power quality, intermittencies, and scheduling. Nonetheless, the execution of the optimization algorithms exhibits

TABLE 1. Top most cited bibliometric analysis manuscripts and their limitations in microgrid applications.

Focused topics	Research gaps	Year	Ref.
Presented a bibliometric analysis on selected topmost cited 120 papers focusing on optimal algorithms of EES in microgrid applications.	Critical discussion and comparative analysis of the optimization schemes and control algorithms was not discussed elaborately.	2022	[14]
Examined various EES and EMS control techniques in the Microgrid applications.	The comparison among different control algorithms was not covered.	2021	[15]
Reviewed the control and operation techniques applied in electric vehicle, energy storage systems, and distributed energy resources in the microgrids.	The state-of-the-art controller and operation techniques comparison was not mentioned in detail.	2021	[16]
Provided a constructive review of various EES for microgrid applications.	The critical issues and challenges was not explored.	2021	[8]
Discussed various microgrid network strategies highlighting overview of centralized, decentralized, intelligent, and multiagent control strategies for controlling and managing distributed energy storage.	The in-depth evaluation of different controller techniques was not reported.	2021	[7]
Surveyed different EES, which are widely utilized in the Microgrid applications.	The constructive comparison among the different energy storage systems was not highlighted.	2021	[17]
Performed a review on various EES and demand-side management in microgrid applications.	The detailed discussion of issues and challenges was not covered.	2021	[18]

several concerns, including a large number of variables, complex computation, time-consuming operation, premature convergence, and inability to attain the global optimum solutions [19]–[21]. Therefore, further exploration is necessary to develop improved controllers and optimizations for microgrid energy storage systems.

Analytical assessment is a sort of research paper that combines the library and information science with statistics and quantitative methods to provide data and analysis in a number of formats [22], [23]. Emerging trends and analytical evaluation are critical areas because they give historical and comprehensive data that can be used to address future difficulties and make appropriate suggestions [24], [25]. Researchers, higher education institutions, and their students and lecturers can utilize analytical assessment to assess the quality of a journal article using a variety of critical indicators such as citations, h-index, impact factors, and quartiles. Gingras [26] examined the impact of analytical assessment on research objectives and provided a set of principles and criteria for developing an appropriate assessment technique for a particular research plan and analysis size. Andres [27] discussed the techniques, importance, and effects of analytical analysis in real-world situations. Hence, we believe that it is an appropriate time to evaluate the current trends and examine the significance of analytical evaluation in the field of battery storage controllers and optimization schemes in microgrid applications.

Various authors performed different reviews on energy storage strategies that are related to microgrid applications [7], [8], [14]–[21], [28], [29]. Reza *et al.* [14] conducted a bibliometric review on optimal algorithms of the energy storage system (EES) in microgrid applications. The authors performed the bibliometric analysis on selected topmost cited 120 papers. However, the authors did not discuss the optimization schemes and control algorithms in detail. Chaudhary *et al.* [15] reviewed EES and EMS control techniques in microgrid applications. The authors examined various EES that have a great potential for penetration and integration in microgrids. Nevertheless, the comparison among different control algorithms was not covered in detail. Nikam *et al.* [16] outlined various control systems for microgrid application and electric vehicles, ESS, and distributed energy resources. The authors explored the state-of-the-art control and operation techniques, which are widely utilized in the electric vehicle, energy storage systems, and distributed energy resources in microgrids. However, the comparative analysis among different controller strategies was not performed comprehensively. Oliveira *et al.* [8] presented a constructive review of various EES for microgrid applications. This manuscript delivered a detailed review of the current EES, which specially focused on the microgrid. Nonetheless, the critical evaluation of optimization techniques was not highlighted. Al-Saadi *et al.* [7] studied various microgrid network strategies which are related to EES. The authors provided an overview of centralized, decentralized, intelligent, and multiagent control strategies for controlling and managing distributed energy storage. Nonetheless, the in-depth evaluation among different controller techniques was absent. Georgious *et al.* [17] surveyed different EES, which were widely utilized in Microgrid applications. However, the constructive comparison among the different energy storage systems was not highlighted in this paper. Groppi *et al.* [18] overviewed various EES and demand-side management in microgrid applications. Nevertheless, the detailed analysis of issues and challenges was not discussed thoroughly. Table 1 presents a discussion on the various reviews by numerous scholars on energy storage integrated into microgrid applications, highlighting focused areas and research gaps.

Analytical and bibliometric analysis in various energy storage fields has been reported in multiple manuscripts during the previous decade, like the nano-energy trend in the energy sector [30], solar energy technologies for energy production in the desert regions [31], carbon tax [32], energy storage device technology [33], hydrogen storage [34], microgrid protection and distribution [35], state-of-the-art of the thermal energy storage [36]. However, no such works related to battery storage controllers and optimization schemes towards microgrid EMS have been published to our knowledge. To bridge the existing research limitations mentioned in Table 1, this paper unveils new contributions with a detailed analytical assessment and constructive discussion of controllers and optimizations integrated into Microgrid applications. The innovative contributions of this review are summarized below.

- Energy storage controllers and optimization schemes integration to microgrids is reviewed comprehensively utilizing the highly cited 110 articles. The analytical evaluation has covered various key aspects, including current research trends, research paper distribution between 2010 and 2021, co-occurrence keywords analysis, research classification, most prominent authors, collaboration, and country analysis.
- Critical analysis of the state-of-the-art controllers and optimization schemes for microgrid energy management systems are presented, emphasizing objectives, strengths, and weaknesses in the selected top-cited 110 papers.
- An in-depth constructive analysis of various controller strategies and optimization techniques based on 15 emerging research areas is carried out, outlining objectives, key findings, and research gaps.
- The key issues and challenges are explored, highlighting several issues and concerns with regard to conducted bibliometric analysis, controller, and optimization techniques.
- Future perspectives and ideas are delivered for emerging battery storage and microgrid integration applications based on existing challenges and research gaps to overcome the future energy crisis.

The rest of the manuscript is arranged as follows: the detailed methodology of identifying the most relevant 110 papers from the Scopus database and analysis of the publishing trend and research characteristics are covered in section 2. Section 3 presents the analytical discussion related to the various field of research, study characteristics, most prominent journal, most prominent authors, and the co-occurrence keyword of the topmost cited manuscripts. Section 4 provides the state-of-the-art controllers and optimization schemes analysis for microgrid energy management systems in the most cited 110 papers. A critical investigation of controller and optimization techniques based on the various research areas is highlighted in Section 5. Section 6 underlines various issues and challenges related to the integration of battery storage controller strategies and optimization schemes integrated into microgrid EMS. Based on the critical analysis of various controller and optimization strategies, Section 7 delivers fruitful recommendations with concluding remarks for future studies.

II. SURVEYING METHODS

On the second week of December 2021, a brief search of the Scopus database was performed to select articles published in various journals from 2011 to 2021, to learn about the recent state of the art in the area of "Energy storage optimization and control" and "microgrid EMS integration." The primary aim of this study is to understand the features of a topmost cited publication and offer clearer insight into the evolution of battery storage controllers and optimization schemes as a form of microgrid EMS integration. For the aim of analysis, keywords like energy storage, optimization, control, microgrid integration, and energy management system were utilized to find the article. Due to resource constraints, the "English language" filter is imposed to limit the number of articles. The retrieved articles were reorganized using the "times cited highest to lowest" sorting criterion. Subsequently, the filter "exclude self-citations" was utilized to avoid the "self-citations" in the list of topmost cited manuscripts categorized from the Scopus Database to discourage irrelevant self-citation. After applying those filters, a wide range of papers was found in the database; among them, the 110 topmost articles were selected by analyzing numerous factors like citations, contributions, keywords, focus areas, abstract, and title of the article. Fig. 1 depicts the whole selecting procedure.

A. INCLUDING AND EXCLUDING CRITERIA

As the number of papers was high, some criteria were utilized to choose articles from Scopus. We predefined the conditions for manuscript removal and inclusion for the 110 topmost cited articles in the battery storage optimization and control towards microgrid EMS to overcome the next generation energy crisis, which are mentioned as follows:

- The criteria for inclusion are battery storage, optimization, control, microgrid integration, and energy management system.
- Few manuscripts are manually excluded based on the keywords such as composite materials, electrolytic analysis, battery chemistry, nanowires, ion exchange, and nanostructures.
- The manuscripts published between 2011 to 2021 are considered for this bibliometric survey.
- Some more articles are excluded by selecting the English language due to resource limitations.

B. PROCESS OF DATA SELECTION

- Based on the keywords, a sum of 2557 (n = 2557) articles were selected in the fundamental search from the Scopus database.
- The initial screening and evaluation were conducted by utilizing year limitations. The article published between 2011 and 2021 were only considered. In the Scopus database, a sum of 2523 (n = 2523) manuscripts were found.
- Then, the "English Language" filter was applied, and a total of 2430 (n = 2430) articles remained.

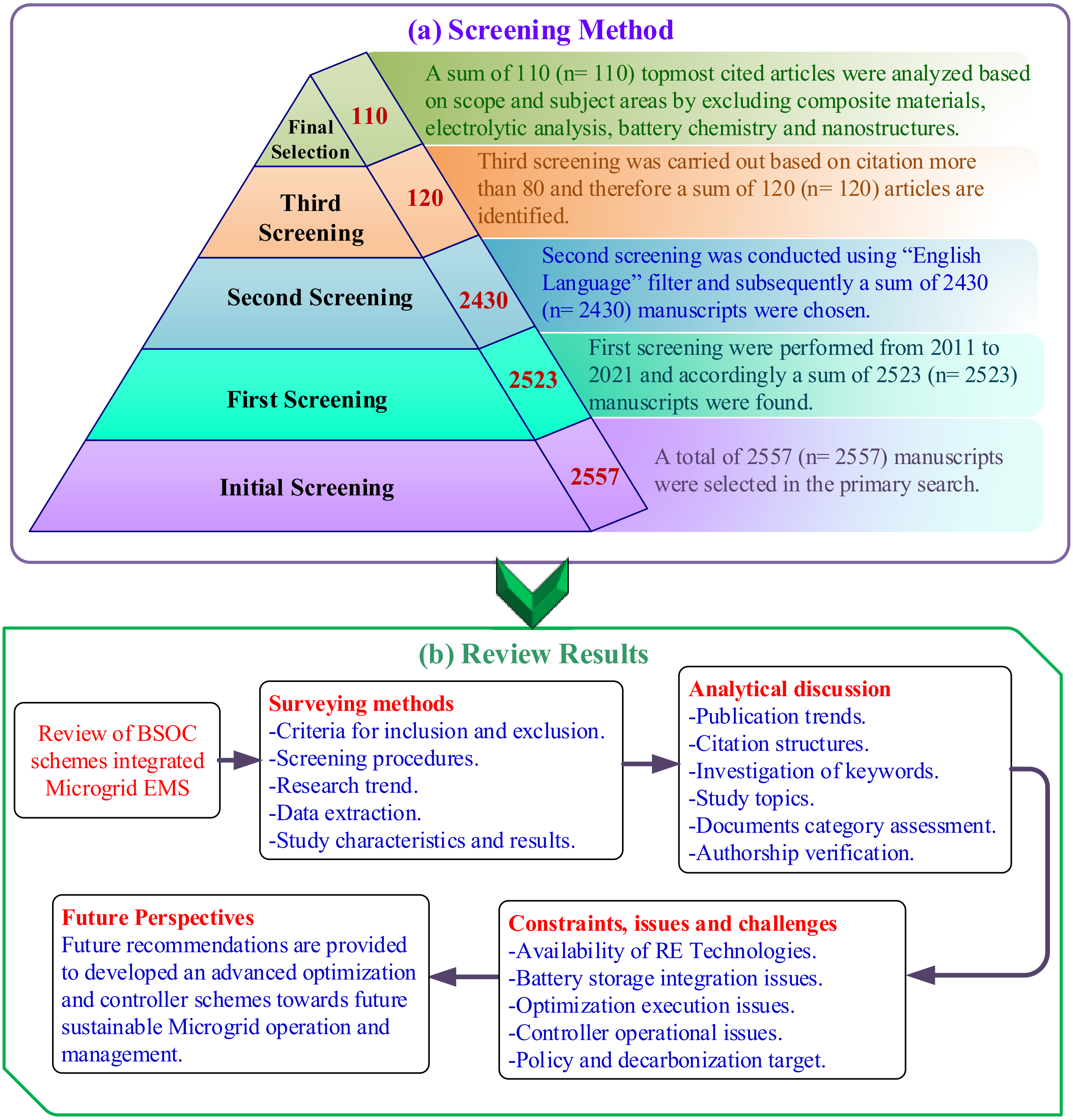

FIGURE 1. Methodology of extracting data and article selection from the Scopus database.

- In the 3rd step, the articles were selected based on the citation number. The articles with 80 plus citations were only included, and a sum of 120 (n = 120) articles was found.
- Then, 10 more articles were excluded manually based on the keywords such as composite materials, electrolytic analysis, battery chemistry, nanowires, ion exchange, and nanostructures.
- Finally, a sum of 110 (n = 110) topmost cited manuscripts was chosen, published in various sources like journal articles, review papers, and conferences for the main survey.

C. PUBLICATION TREND

Researchers are increasingly enthusiastic about building an efficient energy storage system that integrates existing microgrids [37]–[39]. The first publication on microgrid integration was recognized in the Scopus database in 2006 [40]. Following that, different scholars create different methods for incorporating the battery storage controllers and optimization and microgrid EMS with the current system. The quantity of manuscripts published in the field of battery storage controllers and optimization schemes and microgrid EMS integration from the elementary search is provided in Fig 2. The exponential growth of papers indicated in Fig. 2 illustrates that researchers are becoming more interested in this field. A sum of 1096 manuscripts was published from 2019 to 2020. However, the published articles in this specific field were below 100 before 2015. The statistics reveal that the battery storage integration to microgrid EMS is a comparatively new hot research field for future analysis and investigation. The graph shows that more than 50% of papers were published in recent three years.

D. DATA COLLECTION

The topmost cited papers were chosen separately for this bibliometric survey based on the Scopus database. The data was taken from the topmost cited 110 manuscripts based on the following features: a) 110 topmost cited articles published between 2011-2021, b) Types of study (core research/review), c) Research area, d) Publisher's name, e) Name of the Journal, f) Journal Impact Factor (IF), g) Affiliated country name, h) Authors with 2 or more articles, and i) title of the article. An observation is highlighted to represent a clear idea of energy storage integration for microgrid EMS based on the analysis of the topmost cited 110 manuscripts.

E. RESEARCH CHARACTERISTICS

Based on the elementary search, the Scopus database found a sum of 2557 articles. After various phases of the filtering, the topmost cited 110 articles were identified and summarized in Table 2 along with the digital object identifier (DOI), authors name, publisher name, journal name, year of publication, origin country, the total number of citations, and recent five years citation, respectively. The sum of the citations for the selected publications is 17718. (Mean 161.07; median 122; range from 81-807). Moreover, among 110 articles, 80 papers obtained citations more than 100 times. The top-cited article in the list was published by Zakeri *et al.* [41] in 2015 in "Renewable and Sustainable Energy Reviews" journal with a citation of 807 and an impact factor of 14.982. The current affiliation of Behnam Zakeri is International Institute for Applied Systems Analysis, Austria.

III. ANALYTICAL DISCUSSION AND ASSESSMENT

The number of citations in any specific research area is vital for understanding and classifying the latest research developments and delivering a clearer insight into the specific journals or publications' impact. In this survey, we intend to deliver elementary ideas about the topmost important area of research articles as well as current research trends in battery storage and microgrid integration to overcome the next generation energy crisis.

A. RESEARCH TRENDS OF THE HIGHLY INFLUENTIAL MANUSCRIPTS

Table 2 demonstrates the topmost cited 110 manuscripts on the subject of BS integrated with microgrid EMS, as compiled from the selected database and evaluated to provide current research trends for upcoming scholars. Based on the summary of Table 2, the citation counts for the topmost 110 papers is ranged from 81 to 807, while the first six articles each had more than 400 citations, and the first 80 articles each had more than 100 citations. The top-cited article in the list was published by Zakeri *et al.* [41] in 2015 with a citation of 807, while Wang *et al.* [42] published the article with the least number of citations in 2018 with 81 citations. The top-cited article titled "Electrical energy storage systems: A comparative life cycle cost analysis" in the area of battery storage integration to microgrid EMS was published by Zakeri *et al.* [41] in 2015 in "Renewable and Sustainable Energy Reviews" journal with the citation of 807 and an impact factor of 14.982. This manuscript reviews the current literature on analyzing utility-scale power storage system life cycle costs, giving an updated database for the financial aspects (replacement expenses, maintenance, operational costs, and capital expenses). In addition, the Levelized cost and lifecycle costs of power provided by electrical energy storage are investigated, with the Monte Carlo technique utilized to account for uncertainties. The article titled "A review of energy sources and energy management system in electric vehicles" achieved the second position in this list. This review manuscript is published by Tie *et al.* [43] citation of 722. This study examines the current state of the art in terms of power converters, storage devices, and energy sources utilized in electric vehicles (EVs). Besides, patterns of EV driving cycles and benefits and drawbacks are addressed. "Review of energy system flexibility measures to enable high levels of variable renewable electricity" [44] was the 3rd highly referenced publication published in the "Renewable and Sustainable Energy Reviews" in 2015. Lund *et al.* conducted the aforesaid study, which gained a total citation of 693. The article investigates several techniques, technologies, and tactics for managing large-scale renewable energy projects such as wind and solar, considering both demand and supply-side factors.

B. RESEARCH PAPER DISTRIBUTION OF HIGHLY CITED 110 MANUSCRIPTS FROM 2010 TO 2021

In Fig. 3, the allocation of the selected 110 topmost cited articles in battery storage controllers and optimization schemes and microgrid EMS from 2011 to 2019 is presented, with the number of manuscripts published in 2011 and 2012 being just 4 and 2, respectively. According to Fig. 3, the number of articles produced in 2016 was the greatest, while it was the minimum in 2012; the values are 28 and 2, correspondingly. With 16 and 17 articles, the number of manuscripts published in the year 2015 and 2017, respectively. The number

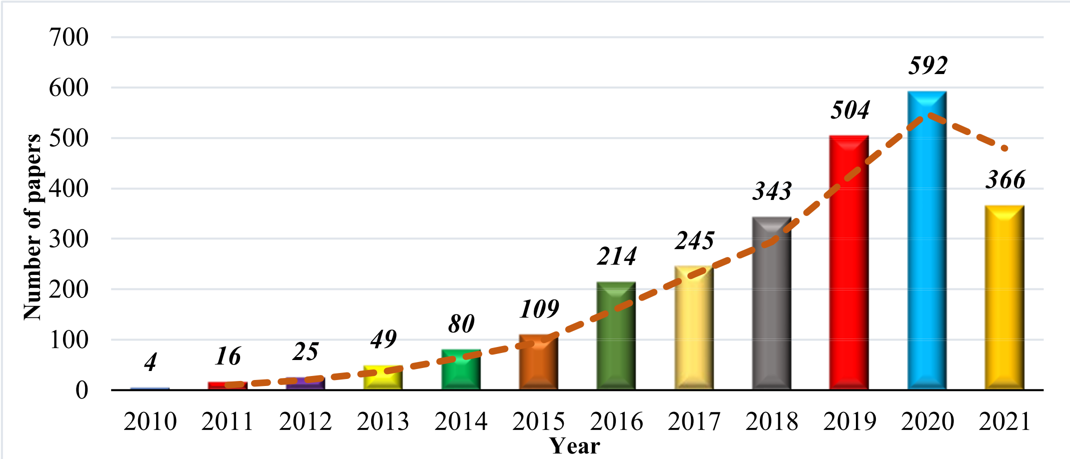

FIGURE 2. Research trend between 2010 and 2021 in battery storage controllers and optimization schemes towards Microgrid EMS.

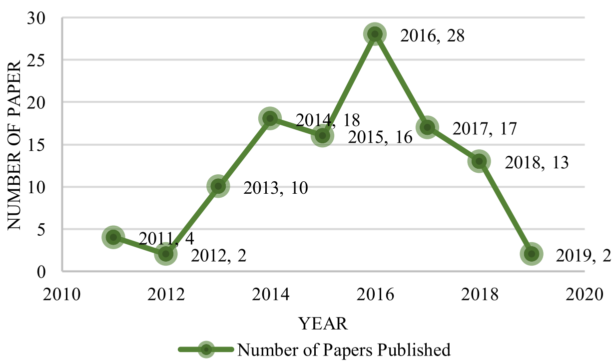

FIGURE 3. Distribution of topmost 110 papers over the period 2011 to 2019.

of articles published between 2012 and 2016 reveals an upward trend, but the manuscripts produced between 2016 to 2019 demonstrate a downward trend, reaching 2 in 2019.

C. CO-OCCURRENCE KEYWORDS ANALYSIS IN TOP 110 PAPERS

Table 2 provides a broad idea about the mentioned study topic, and Fig. 4 provides a co-occurrence keyword network from the topmost 110 referenced papers. Fig. 4 depicts the connective network of authors' keywords created in the VOSviewer software. The effect of the keyword defines the area of the labels and circles, while the connecting line between the keywords is shown as a connective connection. Distinct colors are utilized to designate various individual clusters based on the research interest. The strongest cluster is represented by red color, which includes the keywords such as demand-side management, energy management systems, electric power distribution, microgrid, electric power transmission networks, renewable energies, wind power, smart grid, smart power grids, storage management, photovoltaic system, solar power generation, hybrid systems, hybrid vehicles, intelligent buildings, uncertainty analysis, battery energy storage system, electric load dispatching, electric load flow, hybrid renewable energy systems, hybrid energy storage, and particle swarm optimization. The red cluster demonstrates the various storage types and control like battery energy storage, capacitors, data storage equipment, dc-dc converter, electric power generation, energy efficiency, policy, hydrogen storage, flywheel, linear programming, and power quality. The keywords like control system, demand response, electric power transmission network, energy management, planning, forecasting, and optimization are signified by the green cluster. The blue cluster represents the optimization and control parts. The main components in the blue clusters are electric utility, energy resources, genetic algorithms, intelligent systems, Monte Carlo methods, scheduling, and uncertainty analysis. The yellow cluster denotes the keywords like electric power system, economic analysis, fuel cells, intelligent building, plug-in-electric vehicles, and stochastic algorithms. Moreover, the sky-blue cluster represents the components related to the cost analysis, such as commerce, costs, power markets, digital storage, and integer programming. Finally, the orange cluster shows the connection among microgrid, electric load dispatching, and various algorithms.

The topmost utilized three keywords are "Energy storage," "Electric batteries," and "optimization." The keyword "Energy storage" was utilized 51 times, whereas the keywords "Electric batteries" and "optimization" were utilized 39 and 37 times, respectively. "Energy storage management" and "microgrid EMS" are also widely used keywords from the recent 2-3 years, which indicates that the researchers are currently working on the battery storage controllers and optimization schemes and microgrid EMS integration to overcome the next generation energy crisis and utilize the energy more efficiently. The in-depth allocation of keywords and

TABLE 2. Detailed comparison of the topmost cited 110 manuscripts.

Rank	Ref. no.	Authors	Controller	Optimization	Abbreviated Journal name	Publisher	Article Type	Year	Country of Origin	Cited by	Citations in the last five years
1	[41]	Zakeri et al.	-	Monte Carlo method	RSERF	Elsevier Ltd	Review	2015	Finland	808	720
2	[43]	Tie et al.	Supervisor Control Algorithms	-	RSERF	Elsevier Ltd	Review	2013	Malaysia	720	521
3	[44]	Lund et al.	Model Predictive Control	-	RSERF	Elsevier Ltd	Review	2015	Finland	692	635
4	[45]	Sun et al.	-	-	ITPEE	IEEE	Article	2011	China	480	273
5	[9]	Gür et al.	Autonomous Control Method	-	EES	Royal Society of Chemistry	Review	2018	United States	466	465
6	[46]	Su et al.	Model Predictive Control	-	TSG	IEEE	Article	2014	South Korea	437	368
7	[47]	Brekken et al.	Artificial Neural Network	-	TSTE	IEEE	Article	2011	United States	388	179
8	[48]	Brahman et al.	-	A Multi-Objective Optimization	ENEBD	Elsevier Ltd	Article	2015	Iran	298	266
9	[49]	Shi et al.	-	A Nonlinear Optimization	TSG	IEEE	Article	2015	China	289	262
10	[50]	Suberu et al.	Frequency Controller	-	RSERF	Elsevier Ltd	Review	2014	Malaysia	261	214
11	[51]	Liu et al.	-	MILP	TSG	IEEE	Article	2016	United States	248	244
12	[52]	Bahmani et al.	-	Improved Bat Algorithm	IEPSD	Elsevier Ltd	Article	2014	Iran	240	199
13	[53]	Ru et al.	-	MILP	TSTE	IEEE	Article	2013	United States	238	150
14	[54]	Hesse et al.	-	Particle Swarm Optimization	Energies	MDPI AG	Review	2017	Germany	223	122
15	[55]	Sechilariu et al.	Frequency Controller	-	ITIED	IEEE	Article	2013	France	223	223
16	[56]	Yang et al.	Hierarchical Control	-	RSERF	Elsevier Ltd	Review	2018	Australia	213	213
17	[57]	Wu et al.	A Real-Time Control	-	JPSOD	Elsevier B.V.	Article	2016	United Kingdom	200	200
18	[58]	Merabet et al.	A Stochastic Optimal Control	-	TSTE	IEEE	Article	2017	United Arab Emirates	199	199
19	[59]	Ma et al.	Hydraulic Controller	-	ECMAD	Elsevier Ltd	Article	2014	Hong Kong	198	157
20	[60]	She et al.	-	MILP	TSG	IEEE	Article	2012	United States	183	99
21	[61]	Teng et al.	-	MILP	ITPSE	IEEE	Article	2013	Taiwan	182	130
22	[62]	Atia et al.	-	Linear Programming	TSG	IEEE	Article	2016	Japan	181	176
23	[63]	Bogdanov et al.	Dual Loop Controller	-	ECMAD	Elsevier Ltd	Article	2016	Finland	180	119
24	[64]	Mendes et al.	-	Three-Level Optimization Algorithm	RSERF	Elsevier Ltd	Review	2011	United States	180	171
25	[65]	Wang et al.	Generation Dispatch Control	-	APEND	Elsevier Ltd	Article	2015	United States	178	142
26	[66]	Serban et al.	-	A Receding Horizon Optimization Strategy	ITPEE	IEEE	Article	2014	Romania	178	142
27	[67]	Gee et al.	Frequency Controller	-	ITCNE	IEEE	Article	2013	United Kingdom	173	111

TABLE 2. ***(Continued.)*** **Detailed comparison of the topmost cited 110 manuscripts.**

28	[68]	Wang et al.	Frequency Controller	-	TSTE	IEEE	Article	2014	Australia	172	131
29	[69]	Aghamohammadi et al.	Fuzzy logic controller	-	IEPSD	Elsevier Ltd	Article	2014	Iran	170	124
30	[70]	Shivashankar et al.	Supervisory Control Algorithm	-	RSERF	Elsevier Ltd	Review	2016	Malaysia	169	163
31	[71]	Gu et al.	Conventional Droop Control Scheme	-	ITPEE	IEEE	Article	2015	China	166	134
32	[72]	Arani et al.	Fuzzy logic controller	-	RSERF	Elsevier Ltd	Review	2017	Iran	160	154
33	[73]	Venkataramani et al.	Robust nonlinear model predictive control	-	RSERF	Elsevier Ltd	Review	2016	United Kingdom	160	160
34	[74]	Zhang et al.	-	Stochastic Optimization	ITVTA	IEEE	Article	2014	United States	154	123
35	[75]	Yu et al.	Controlling Voltage	-	TSG	IEEE	Article	2014	United States	151	121
36	[76]	Hung et al.	Fuzzy logic controller	-	APEND	Elsevier Ltd	Article	2014	South Africa	151	110
37	[77]	Marra et al.	Dual Loop Controller	-	TSG	IEEE	Article	2014	Denmark	148	99
38	[78]	García et al.	Controlling Voltage	-	TII	IEEE	Article	2014	Spain	147	119
39	[79]	Jing et al.	ANFIS-Based Supervisory Control	-	RPG	IET	Review	2017	Malaysia	142	142
40	[80]	Li et al.	Model Predictive Control	-	ITIED	IEEE	Article	2019	United States	138	132
41	[81]	Hosseinalizadeh et al.	-	MILP and Particle Swarm Optimization	RSERF	Elsevier Ltd	Review	2016	Iran	138	138
42	[82]	Comodi et al.	-	MILP	APEND	Elsevier Ltd	Article	2015	Italy	136	99
43	[83]	Luna et al.	Fuzzy Logic Controller	-	ITPEE	IEEE	Article	2017	Spain	133	91
44	[11]	Zhou et al.		MILP	RSERF	Elsevier Ltd	Review	2013	China	133	133
45	[84]	Hassan et al.	-	MILP	APEND	Elsevier Ltd	Article	2017	United Kingdom	132	132
46	[85]	Arcos et al.	-	MILP	TSG	IEEE	Article	2018	Spain	130	129
47	[86]	Wu et al.	Frequency Controller	-	TSG	IEEE	Article	2018	China	127	127
48	[87]	Reddy et al.	-	Loss of load probability	JRE	Elsevier Ltd	Article	2017	South Korea	126	120
49	[88]	Khatib et al.	-	Particle Swarm Optimization	ECMAD	Elsevier Ltd	Review	2016	Malaysia	126	126
50	[89]	Wu et al.	Frequency Controller	-	JPSOD	Elsevier B.V.	Article	2017	China	125	125
51	[90]	Wang et al.	Model Predictive Control	-	TSTE	IEEE	Review	2016	Sweden	124	87
52	[91]	Tran et al.	-	Meta-heuristic optimization	TSG	IEEE	Article	2013	Singapore	124	122
53	[92]	Olabi et al.	-	Convex Programming	ENEYD	Elsevier Ltd	Editorial	2017	United Kingdom	123	85
54	[93]	Ding et al.	Hydraulic Controller	-	ITPEE	IEEE	Article	2014	China	123	123
55	[94]	Das et al.	-	Stochastic Optimization	RSERF	Elsevier Ltd	Article	2018	Australia	122	106
56	[95]	Akram et al.	-	Stochastic Dynamic Programming	RPG	IET	Article	2018	Saudi Arabia	122	118
57	[96]	Sachs et al.	Hierarchical Dispatch Model	-	TSTE	IEEE	Review	2016	Germany	122	121

TABLE 2. *(Continued.)* **Detailed comparison of the topmost cited 110 manuscripts.**

58	[97]	Nguyen et al.	-	A Cost-Based Multi-Objective Optimization	ITPSE	IEEE	Article	2016	United States	122	122
59	[98]	Pascual et al.	-	Improved particle swarm optimization	APEND	Elsevier Ltd	Article	2015	Spain	122	122
60	[99]	Liang et al.	Bus Voltage Control	-	ENERGIES	MDPI AG	Article	2014	Canada	120	66
61	[100]	Kyriakarakos et al.	-	Linear Program optimization	APEND	Elsevier Ltd	Article	2011	Greece	120	88
62	[101]	Jayasekara et al.	-	Linear Program optimization	TSTE	IEEE	Article	2016	Australia	118	86
63	[102]	Mahesh et al.	-	Stochastic Optimization	RSERF	Elsevier Ltd	Review	2015	India	118	100
64	[103]	Adika et al.	-	Stochastic Optimization	IEPSD	Elsevier Ltd	Review	2014	United States	118	115
65	[104]	Parra et al.	Distributed Energy Management controller	-	RSERF	Elsevier Ltd	Article	2017	Switzerland	117	95
66	[105]	Cau et al.	-	Stochastic Optimization	ECMAD	Elsevier Ltd	Article	2014	Denmark	117	117
67	[106]	Byrne et al.	-	Particle Swarm Optimization	IEEE ACCESS	IEEE	Article	2017	United States	112	112
68	[107]	Li et al.	-	Demand side management programs	TSTE	IEEE	Article	2016	United States	111	109
69	[108]	Yang et al.	Automatic generation control	-	RSERF	Elsevier Ltd	Article	2015	United Kingdom	110	96
70	[109]	Ju et al.	-	Particle Swarm Optimization	TSG	IEEE	Review	2018	Singapore	109	109
71	[110]	Wen et al.	Frequency Controller	-	ITPSE	IEEE	Article	2016	China	108	105
72	[111]	Beck et al.	-	Mixed-Integer Linear Optimization	APEND	Elsevier Ltd	Article	2016	Germany	108	108
73	[112]	Chaudhari et al.	Noncooperative Game Method	-	TII	IEEE	Article	2018	Singapore	107	59
74	[113]	Nguyen et al.	PIC	-	ITDSE	IEEE	Article	2015	South Korea	107	97
75	[114]	Beer et al.	-	Particle Swarm Optimization	TSG	IEEE	Article	2012	United States	107	107
76	[115]	Kuznetsova et al.	Central Controller	-	ENEYD	Elsevier Ltd	Article	2013	United Kingdom	104	85
77	[116]	Tushar et al.	-	MILP	TII	IEEE	Article	2018	Canada	103	96
78	[117]	Kamankesh et al.	-	Symbiotic Organisms Search	ENEYD	Elsevier Ltd	Article	2016	Iran	103	103
79	[118]	Liu et al.	Adaptive controller	-	APEND	Elsevier Ltd	Article	2018	China	102	102
80	[119]	Tankari et al.	Droop Controller	-	TSTE	IEEE	Article	2013	France	101	60
81	[13]	Akar et al.	-	Mixed-Integer Linear Optimization	ITVTA	IEEE	Article	2016	Turkey	99	99
82	[120]	Shaukat et al.	Model Predictive Control	-	RSERF	Elsevier Ltd	Review	2018	Pakistan	98	76
83	[121]	Malhotra et al.	-	Stochastic Optimization	RSERF	Elsevier Ltd	Article	2016	Switzerland	98	88
84	[122]	Tushar et al.	PIC	-	TITS	IEEE	Review	2016	United States	98	95
85	[123]	Ziadi et al.	-	Particle swarm optimization	TSG	IEEE	Article	2014	Japan	98	98
86	[124]	Reddy et al.	Frequency Controller	-	TSG	IEEE	Article	2015	United States	97	89

TABLE 2. *(Continued.)* Detailed comparison of the topmost cited 110 manuscripts.

87	[125]	Bordin et al.	Transactive Controller	-	JRE	Elsevier Ltd	Article	2017	United Kingdom	96	64
88	[126]	Koohi et al.	-	Linear Programming	ECMAD	Elsevier Ltd	Article	2014	Saudi Arabia	96	96
89	[127]	Caraman is et al.	-	Robust Optimization	IEEPA	IEEE	Article	2016	United States	95	93
90	[128]	Zhang et al.	-	Hybrid harmony search algorithm	APEND	Elsevier Ltd	Article	2016	China	94	92
91	[129]	Guo et al.	-	Robust Optimization	TSG	IEEE	Article	2016	United States	94	93
92	[130]	Rubino et al.	PIC	-	APEND	Elsevier Ltd	Article	2017	Italy	93	86
93	[131]	Zhang et al.	PIC	-	SRENA	Elsevier Ltd	Article	2015	China	93	93
94	[132]	Alharbi et al.	Phase-locked loop	-	TSTE	IEEE	Article	2018	Canada	92	92
95	[133]	Ratnam et al.	-	Hybrid Harmony Search	JRE	Elsevier Ltd	Article	2015	Australia	90	71
96	[134]	Kazemi et al.	Model Predictive Controller	-	TSTE	IEEE	Article	2017	Iran	89	89
97	[135]	Haruni et al.	Model Predictive Controller	-	TSTE	IEEE	Article	2013	Australia	88	59
98	[136]	Ou et al.	-	Robust Optimization	Energies	MDPI AG	Article	2017	China	87	82
99	[137]	Petrolles e et al.	Model Predictive Controller	-	APEND	Elsevier Ltd	Article	2016	Spain	87	87
100	[138]	Alsaidan et al.	Model Predictive Controller	-	ITPSE	IEEE	Article	2018	United States	86	63
101	[139]	Bracco et al.	-	Stochastic Optimization	ECMAD	Elsevier Ltd	Article	2015	Italy	86	86
102	[140]	Skjong et al.	-	Linear Programming	TTE	IEEE	Article	2016	United States	85	84
103	[141]	Wang et al.	PIC Derivative Linear Controller	-	TSG	IEEE	Article	2016	China	85	85
104	[142]	Morstyn et al.	A Multi-Agent Control Strategy	-	ITPSE	IEEE	Article	2016	Australia	84	79
105	[143]	Khorram del et al.	PIC	-	TII	IEEE	Article	2016	Italy	84	84
106	[144]	Bocklisc h et al.	Model Predictive Controller	-	Energy Proc.	Elsevier Ltd	Article	2015	Germany	84	83
107	[145]	Siano et al.	PIC	-	JSYST	IEEE	Confer ence Paper	2019	Spain	83	83
108	[146]	Hemmat i et al.	-	Meta-Heuristic Optimization Algorithm	JCROE	Elsevier Ltd	Retract ed	2017	Iran	82	82
109	[147]	Lupangu et al.	-	Particle Swarm Optimization	RSERF	Elsevier Ltd	Article	2017	South Africa	82	82
110	[42]	Wang et al.	-	MILP	ENEBD	Elsevier Ltd	Article	2016	Australia	81	75

the graphical illustration are depicted in Fig. 6. By analyzing co-occurrence keywords provided in Fig. 5 and Table 2, the following conclusions are:

- Currently, scholars are concerned about the efficient ES management system and are equally focused on the integration of battery storage controllers and optimization schemes and microgrid EMS to provide more efficient energy supply and consumption.
- Additionally observed, there has been a remarkable rise in microgrid EMS and battery storage EMS research.

D. CRITICAL ANALYSIS OF TOP-CITED TEN MANUSCRIPTS

Table 4 illustrates the topmost ten manuscripts based on their average citation per year (ACY) along with the target, validation, advantages, and limitations. The paper by Gur *et al.* [9] has the greatest ACY of (233) and is placed 5th in the total number of citations. The 2nd greatest ACY manuscript was published by Zakeri *et al.* [41], with an ACY of 161.6. Zakeri *et al.* [41] critically examine the current literature on cycle expenses of the utility-scale electricity storage system. The authors found the following benefit:

reduction of power production cost and hydrogen storage in different power systems. Along with the benefits, still, there are some lacking in performance, which can be further improved by considering more parameters like dependencies among charge and discharge, optimal life cycle numbers, and life cycle numbers. Tie *et al.* [43] especially focus on low-level control energy management schemes, power converters, storage devices, and state of the arts of energy resources. The optimum performance of fast-charging stations is highlighted in this article. Still, the following shortcoming remains as battery electric vehicles can only travel a small distance, and BEV is only suitable for stop-and-run driving like city driving. Hence, further attention is essential to resolve the above-mentioned concerns. Lund *et al.* [44] review various technologies and schemes to manage large-scale integrations of variable renewable electricity, where the authors found the following advantages: a flywheel has a longer lifetime, higher power and energy density, higher efficiency, and is cost-effective. On the contrary, performance decreases with an increasing number of cycles; hence further investigation is required. Sun *et al.* [45] proposed a way to tackle the large-scale incorporation of intermittent energy resources without significant disturbances to the grid. The proposed technique has the benefits like improved grid reliability, facilitating full incorporation of intermittent renewable resources, and efficiently managing power generation. On the other hand, this suggested model still consists of the following limitations like low energy density and thermal conductivity or specific heat. Hence, further exploration is mandatory to solve the above-mentioned issues. Gür *et al.* [9] introduced a technique to enhance reliability and efficiency, particularly for photovoltaic power production. This strategy can reduce the cost and enhance reliability. Su *et al.* [46] recommended a model to deal with the operational issues associated with these technologies and energy resources. This model can be further extended by adding uncertainties like load and customer behavior. Brekken *et al.* [47] suggest a model that enhances wind power generation's predictability and fossil-fuel or hydro power reserve generation. Moreover, the outcome also demonstrates the more efficient control and management of energy storage systems. The authors found that the predictability of wind plant outcomes can be improved, and the expense of incorporation related to reserve conditions can be diminished. But lack of this study, long-term storage capacity was not considered. Hence, further attention is required to enhance efficiency.

E. RESEARCH CLASSIFICATION IN THE TOP-CITED 110 PAPERS

Table 3 presents the research categories of the articles that were chosen as the most referenced. Most of the selected papers are published under the category of simulation analysis and problem formulation. The ratio and the citation range under this category are 66.63% and 81-480, respectively. The second-highest category is the systematic and non-systematic review has 20% of manuscripts with a citation range of 98 to 809. The State-of-the-Art Technical category is 3.63%, whereas the lowest category is around 3%, with a citation range of 97-298. There is a connection between citation ranges, the range of years, keywords, and research types. Based on Table 3, most authors nowadays focus on original work to overcome the energy crisis. The Review (Systematic/Nonsystematic) manuscripts are also taken seriously to let the researchers know about the research trend in this specific field of research. Moreover, the researcher is currently focused on battery storage controllers, optimization schemes, and microgrid EMS integration. Fig. 4 represents the distributions of articles according to the type of publications of selected topmost selected 110 manuscripts.

TABLE 3. Topmost cited manuscripts distribution over the types of study.

Article Types	Frequency of Publications	Range of Years	Range of Citations
Problem formulation and Simulation Analysis	73	2011-2019	81-480
Review (Systematic / Nonsystematic)	22	2011-2018	98-809
Performance assessment, development, and experimental work	8	2012-2019	87-388
State of the Art Technical	4	2013-2017	110-223
Observational	3	2014-2018	97-298

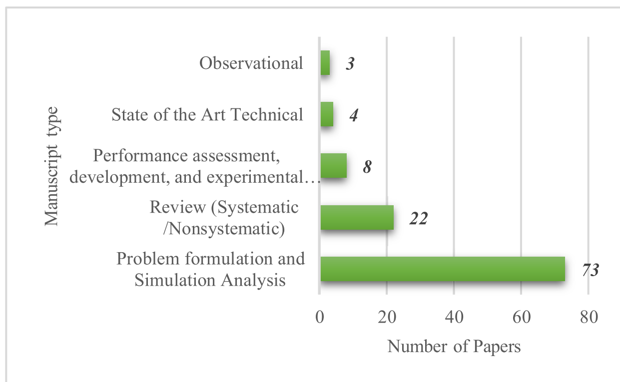

FIGURE 4. Percentage-wise article distribution of topmost selected 110 manuscripts.

F. BIBLIOMETRIC ANALYSIS OF THE MOST PROMINENT AUTHORS

Table 5 lists the authors who have published two or more papers, along with their position on the author's list, h-index, total citations, number of publications in the chosen 110 manuscripts, present institution, and country of origin. Vassilios G. Agelidis from Danmarks Tekniske Universitet is the leading author with four publications on the top-cited list of manuscripts. Xiaosong Hu from Chongqing University published three articles. Xiaohua Wu also published three

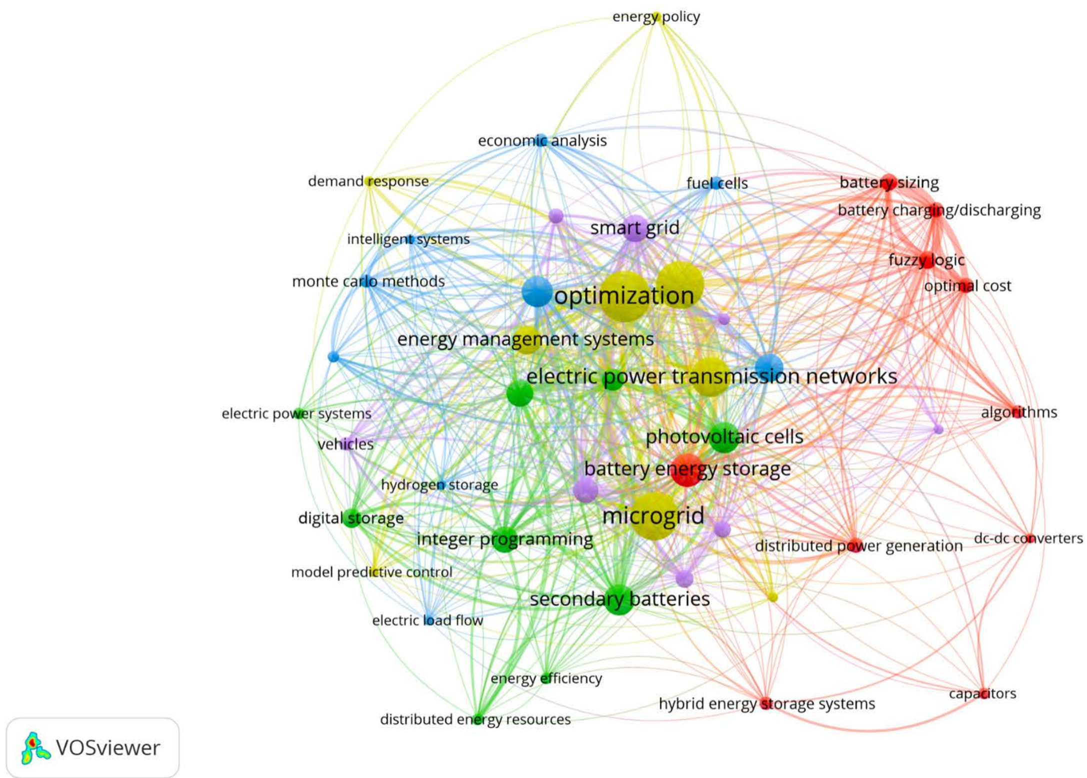

FIGURE 5. Bibliometric analysis of co-occurrence keywords by VOSviewer.

articles under affiliation with Xihua University. The USA has the most authors (3), while China, Denmark, and Italy have two authors on the list of the top 10 most prolific authors. Josep M. Currently, Guerrero of the Aalborg Universitet in Denmark consists of the highest citations (50400) and the topmost h-index (101). Followed by Zhu Han from the University of Houston, USA, with 33718 citations and an h-index of 88. In contrast, the lowest number of citations is owned by Xiaohua Wu, with an h-index of 7.

Various authors take different approaches to the same problem. For example, Vassilios G. Agelidis works on Multi-Agent Control of Heterogeneous Storage Devices [142], Optimal scheduling of RE-based microgrid with PHEV charging demand [117], and large PV plant power smoothing utilizing HES [68]. He also wrote one review article on power electronics of utility-scale BESS for grid connection [90]. Xiaosong Hu published manuscripts on Stochastic optimal EM with PEV ES [86], integration of solar HES with PEV [89], and EM by Stochastic control with PEV, BES, and PV array [57]. All of his works are related to the plug-in electric vehicle, and he mentioned about nanogrid system in [89]. BES and PV Integration with commercial distribution systems [76] documented by Ramesh C. Bansal. He also published a review manuscript on various technical challenges related to the development of PV [147]. Fig. 7. presents the co-occurrence author's evaluation utilizing VOSviewer software from the Scopus data.

G. ORIGIN COUNTRY ANALYSIS OF THE SELECTED TOPMOST 110 MANUSCRIPTS

Both Fig. 8 and 9 represent the co-occurrence countries and a graphical presentation of the topmost ten articles producer that dominate battery storage controllers and optimization in microgrid EMSs, respectively, using VOSviewer software. The United States placed in 1st position with 27 papers, followed by China with 16 papers. With 12 articles, Australia placed in 3rd position. According to our chosen database, United Arab Emirates is ranked bottom with only one publication. Fig. 8 depicts the network of co-occurrences among all of the nations that published the 110 articles that were chosen. Furthermore, Fig. 9 shows that the United States has the most international connections, followed by Spain and China. The selected database shows that India and Taiwan have the fewest collaborative networks. The majority of articles from the selected topmost cited 110 manuscripts are sponsored by ''National Natural Science Foundation of China'' and ''National Science Foundation'' with the figure of 5 manuscripts each. Followed by ''Engineering and Physical Sciences Research Council'' and ''Government of

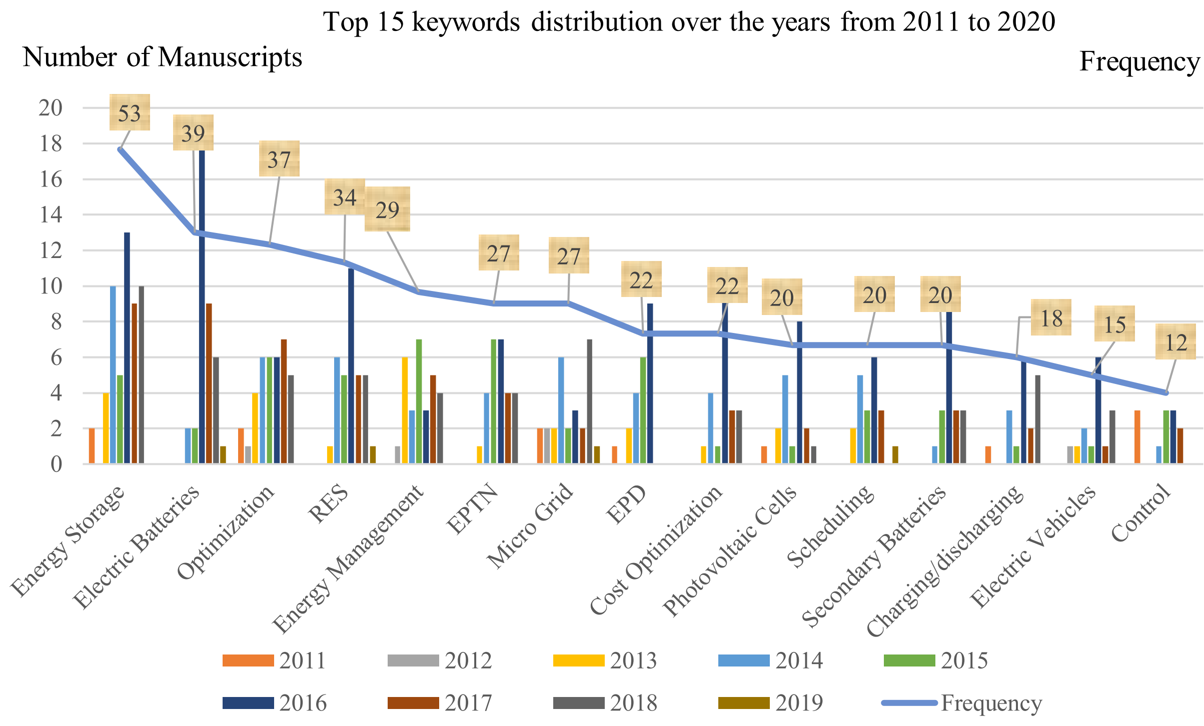

FIGURE 6. Top 15 widely utilized keywords distribution over the year 2011 to 2019.

Canada'' with 4 and 5 manuscripts, respectively. Based on the discussion and analysis from a different point of view on the selected topmost cited 110 manuscripts, it is noticed that the majority of the top-cited articles produced in recent years are ''core work'' instead of ''review'' type. According to recent trends, researchers are increasingly focusing on the development of efficient integration between BS and microgrid EMS. The cost is another important aspect to consider when integrating battery storage controllers and optimization schemes with microgrid EMS applications. Numerous optimization and control algorithms have been proposed in several publications to reduce cost [41], [45], [47], [51], [57], [69], [97], [109], [118], [131], [148], [149]. Various researchers perform different types of literature evaluations focused on energy storage optimization, control technologies, and efficient integration between BS and microgrid.

IV. STATE-OF-THE-ART CONTROLLERS AND OPTIMIZATION SCHEMES FOR MICROGRID ENERGY MANAGEMENT SYSTEM IN TOP CITED 110 PAPERS

This manuscript constructively discusses and compares 24 controller strategies and 21 optimization schemes in the highly cited 110 manuscripts. The selected controllers and optimization techniques are state-of-the-art models that perform better than the contemporary techniques in terms of strong computation capability, improved generalization performance, enhanced efficiency and precision. The analysis covers each optimization and controller strategy's objectives, advantages, and drawbacks.

A. CONTROLLER STRATEGIES USED IN THE SELECTED 110 MANUSCRIPTS

Appropriate controllers play the most crucial role in the microgrid energy management system. Fig. 10 represents the distribution controller techniques over 110 topmost cited papers. From the selected database, 24 types of controller techniques are utilized in the selected top cited 110 manuscripts. Among all the controllers, model predictive controllers are the most frequently utilized controller strategies in the microgrid EMS. Fig. 9 followed by frequency and proportional-integral controllers used in 8 and 7 manuscripts, respectively. Then the fuzzy logic controllers were used in 4 papers. Fig. 10 represents the distribution of controller techniques that are utilized in the selected 110 articles. Table 6 represents the top 10 controller strategies that are most frequently utilized in the selected topmost cited 110 articles and their advantages and disadvantages. Model predictive control (MPC) controller is the most frequently utilized controller in microgrid EMS. MPC is utilized to predict the system's future behavior over a finite time window, which contains advantages like cost-effective, enhanced energy-saving, multiple variables control, and enhanced transient response [96] [129]. Along with the benefits, MPC shows disadvantages, such as higher installation costs and

TABLE 4. "Highest average citation per year (ACY)" based on 10 manuscripts.

Rank	Author's Name	Ref.	Year	Citation	Target	Validation	Advantages	Limitations/ Research Gaps
1	Zakeri et al.	[41]	2015	808	This review critically examines the current literature on cycle expenses of the utility-scale electricity storage system.	Compared with existing storage systems.	• Reduction of power production cost. • Hydrogen storages in various power system.	• The analysis can be further improved by considering more parameters like dependencies in between charging/ discharging, optimal life cycle numbers, and life cycle number.
2	Tie et al.	[43]	2013	720	This review especially focuses on low-level control energy management schemes, power converters, storage devices, and state-of-the-art of energy resources.	Compared with the existing vehicle technologies.	• Optimum performance of fast-charging stations.	• Battery electric vehicle (BEV) can only travel a small distance. • BEV only suitable for stop-and-run driving like city driving.
3	Lund et al.	[44]	2015	692	This paper reviews various technologies and techniques to manage large-scale integrations of variable renewable electricity.	Compared with more advanced methods like demand-side linked approaches and demand-side management.	• Price difference of electricity. • A flywheel has a longer lifetime.	• Energy and power density. • Efficiency and cost • Performance decreases with an increasing number of cycles.
4	Sun et al.	[45]	2011	480	To manage large-scale integration of variable energy sources without causing major grid disruptions.	Compared with existing strategies for the incorporation of intermittent energy sources.	• Efficiently manage power generation. • Facilitate full integration of intermittent renewable sources. • Improve grid reliability.	• Low energy density. • Specific heat or thermal conductivity.
5	Gür et al.	[9]	2018	466	To enhance the reliability and efficiency, particularly for photovoltaic power production.	Experiments results validate the effectiveness and practical feasibility.	• Cost reduction. • Reliability enhancement.	• A distributed control method can be employed in residential PV generation. • The distributed control method can be adopted for dc nano-grid and microgrids.
6	Su et al.	[46]	2014	437	To address the operational issues associated with these technologies and energy resources.	Simulation outcomes demonstrate the accuracy and effectiveness of the proposed stochastic microgrid energy scheduling model.	• The amount of charging power at any given time step.	• This model can be further extended by adding uncertainties like load and customer behavior.
7	Brekken et al.	[47]	2011	388	To improve the predictability of wind power generation and hydro or fossil-fuel reserve generation.	The results demonstrate more effective control and coordination of energy storage systems.	• Expenditure of integration related to reserve conditions can be reduced. • The predictability of wind plant outcomes can be enhanced.	• Lack of this study, long-term storage capacity was not considered.
8	Brahman et al.	[48]	2015	298	To optimally schedule key household electrical devices, production, and storage component.	The outcomes demonstrate the impact of incorporating thermal energy storages, demand response, and PHEV on energy price reduction.	• Energy cost reduction. • The potential of generating both power and heat simultaneously.	• Battery charging/ discharging limitation.
9	Shi et al.	[49]	2015	289	To solve the nonlinear optimization problem in microgrids.	Simulation findings show the validity and effectiveness of the proposed distributed EMS.	• Optimal power flow problem. • Fast convergence.	• This research can be further extended by implementing the proposed EMS in a real system
10	Suberu et al.	[50]	2014	261	To address the issue of energy scarcity, particularly in an off-grid system that is separated from the mainland.	Compared with existing energy storage technology.	• Ranges of sizes and shapes. • Higher open-circuit voltage compares. • Low percentage rate of self-discharge. • Lighter weight with high energy density.	• Lower electric power effectiveness. • Higher expenses. • Sensitivity to hydrogen contaminations.

TABLE 5. Top ten authors' profiles, along with their profile summary.

Rank	Name of the Author	Latest affiliation	Origin Country	No. of Articles	Citations	h-index	Author's position
1	Agelidis, Vassilios G.	Danmarks Tekniske Universitet	Denmark	4	15865	64	Senior Author= 3 Co-author= 1
2	Hu, Xiaosong	Chongqing University	China	3	11058	58	Co-author= 3
3	Wu, Xiaohua	Xihua University	China	3	601	7	First author= 3
4	Bansal, Ramesh C.	University of Sharjah	United Arab Emirates	2	7861	40	Senior Author= 2
5	Cau, Giorgio	Università degli Studi di Cagliari	Italy	2	1452	22	First author= 1 Co-author= 1
6	Chu, Chicheng	University of California	United States	2	1204	16	Co-author= 2
7	Cocco, Daniele	Università degli Studi di Cagliari	Italy	2	1334	20	Co-author= 2
8	Gadh, Rajit	University of California	United States	2	3658	32	Senior Author= 2
9	Guerrero, Josep M.	Aalborg Universitet	Denmark	2	50400	101	Senior Author= 2
10	Han, Zhu	University of Houston	United States	2	33718	88	Senior Author= 1 Co-author= 1

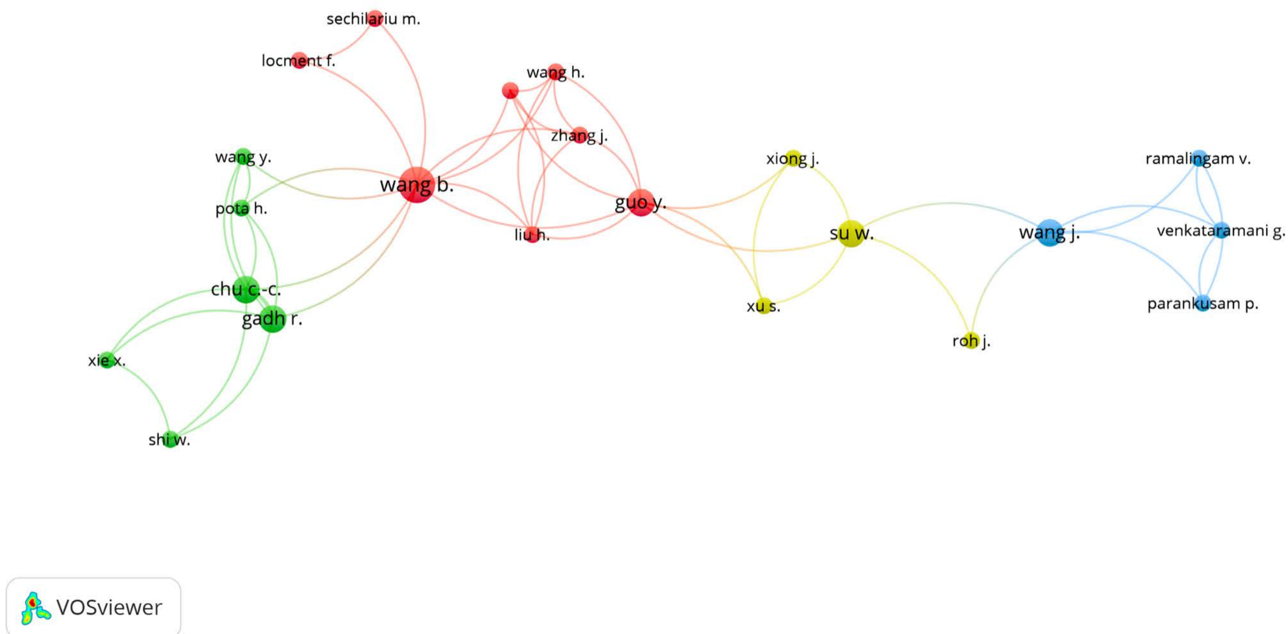

FIGURE 7. Authorship analysis using VOSviewer software based on Scopus data.

a complex algorithm. Hence, further attention is essential to address the above-mentioned concerns. A frequency controller is also utilized in many microgrid EMS, which is used for controlling the AC motor torque and speed by altering motor input voltage and frequency [75] [135]. This controller consists of the following benefits: cost-effective, smooth starting, smooth acceleration and deceleration time, motor reversal, and increased power factor. However, this controller still has some harmonics distortion and electromagnetic interference, which is required to be addressed in future research. The third most frequently used controller is the proportional-integral controller. This controller is commonly utilized in industrial control systems and other appliances that require constantly modulated control [136]. This controller has the following pros: good response to unmeasured disturbances, easy to tune by simple trial and error, robust to tuning mismatches, uses low resources, and is easy to implement. Further attention is required to tackle issues like hard to manage multiple constraints and performance optimization, hard to handle multiple variables with strong interaction, low

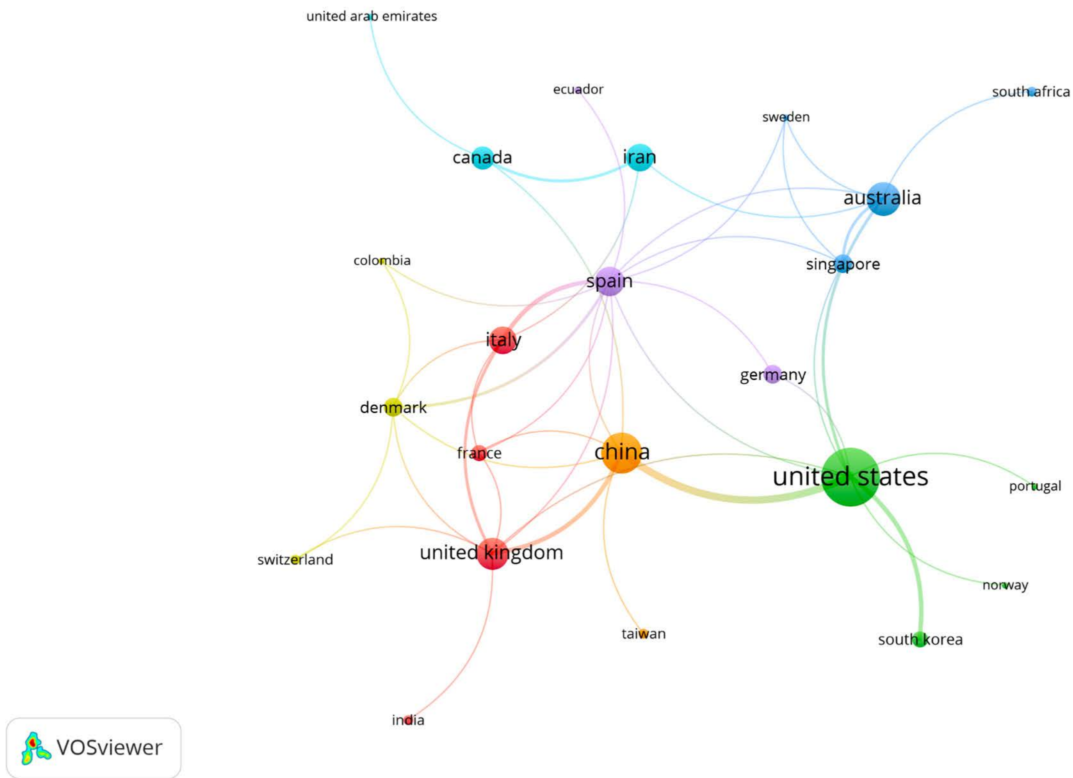

FIGURE 8. Co-occurrence country analysis using VOSviewer software.

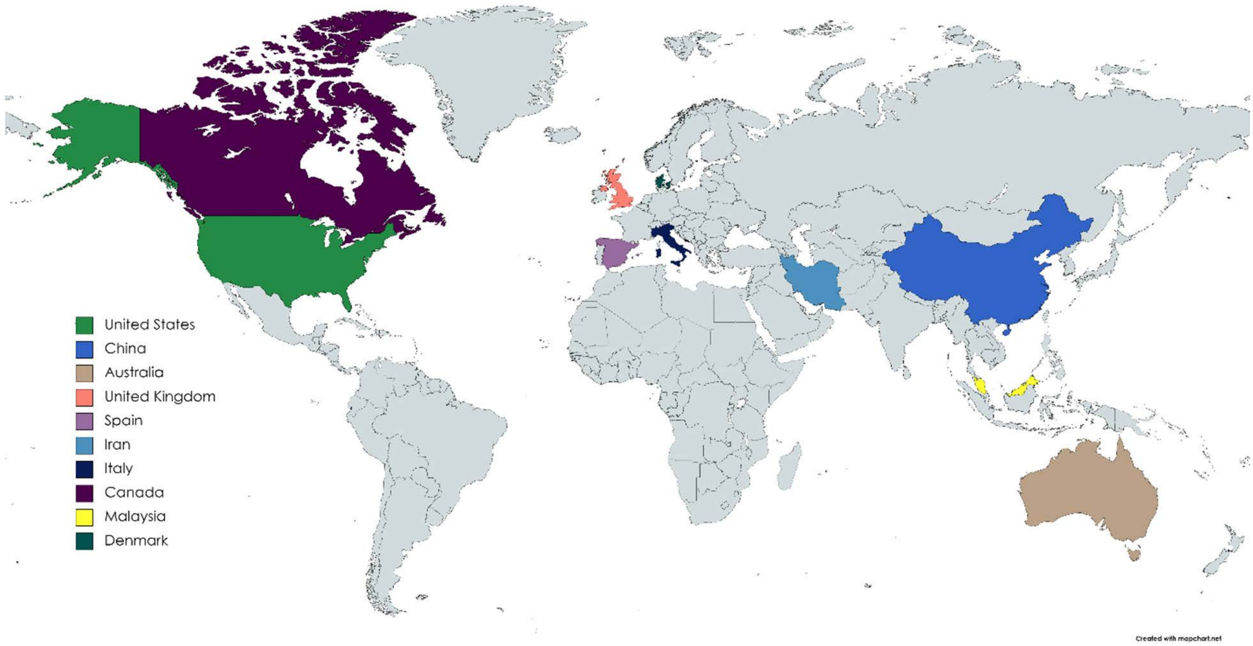

FIGURE 9. Top 10 countries graphical presentation that dominate the battery storage controllers and optimization for microgrid EMSs.

performance to handle strong non-linearities, and low performance in processes with long deadtime. The fuzzy logic controller is widely used in machine control due to the following advantages: high precision, rapid operation, integrated and complex systems, simple mathematics for nonlinear, similar to human reasoning, and efficient for HVAC systems.

Along with the benefits, this controller consists of the following drawbacks: lack of real-time response, the longer running time and slower speed of the systems, and limited number of usages of input variables [85]. Hence, further attention is mandatory to tackle the above-mentioned concerns.

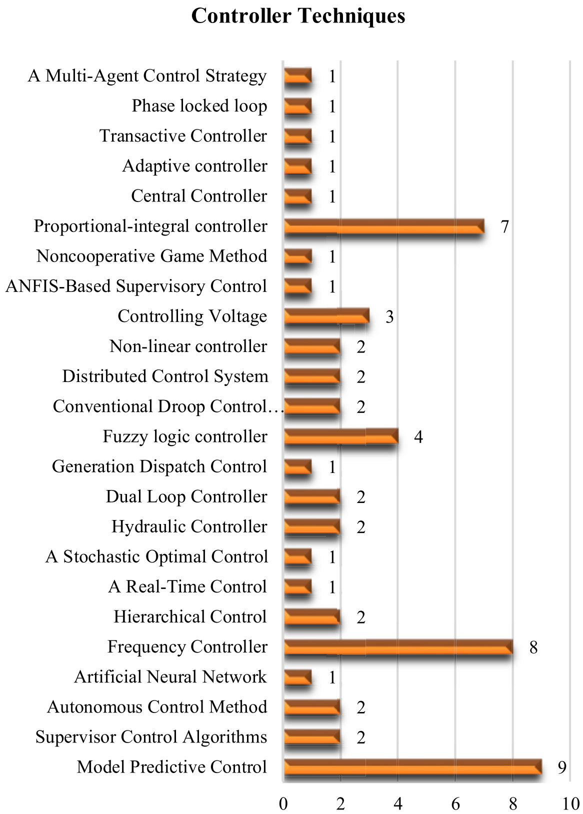

FIGURE 10. Controller techniques distribution over 110 topmost cited papers.

B. OPTIMIZATION SCHEMES FOR MICROGRID ENERGY MANAGEMENT SYSTEM IN TOP CITED 110 PAPERS

Apart from this, the selection of appropriate optimization techniques plays a vital role in microgrid EMS. Fig. 11 represents the optimization techniques distribution over 110 topmost cited papers. In the selected database, 21 types of optimization techniques are used in the top-cited 110 papers. Out of all the optimization techniques, Particle Swarm Optimization (PSO) and Mixed-Integer Linear Programming (MILP) algorithms are most frequently utilized in the selected manuscripts, with the figure of 10 papers each. Stochastic optimization techniques were used in the eight manuscripts. Fig. 11 represents the distribution of optimization techniques that are utilized in the selected topmost cited 110 articles. Table 7 represents the top 10 optimization techniques most frequently utilized in the selected topmost cited 110 articles and their advantages and disadvantages. Most of the researchers used MILP and PSO algorithms in the microgrid EMS. MILP is used to capture the discrete nature

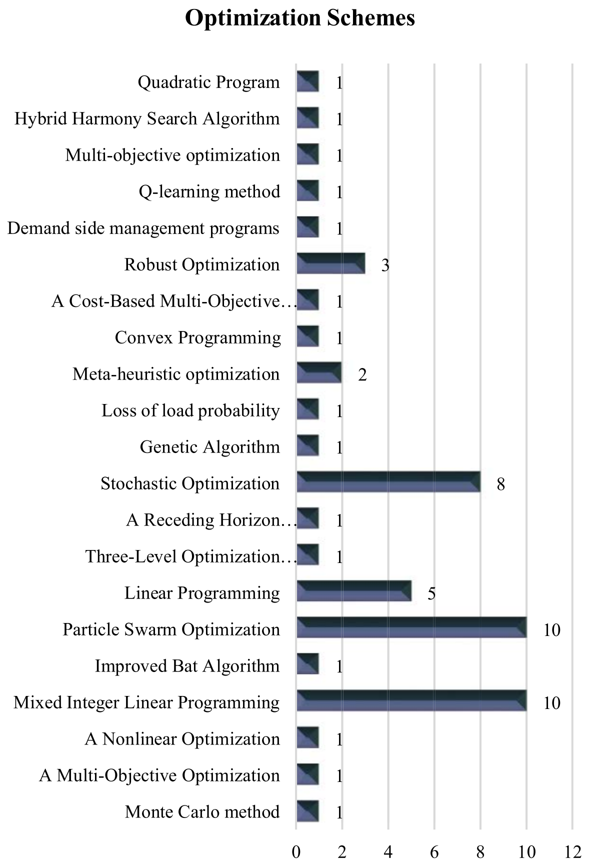

FIGURE 11. Optimization techniques distribution over 110 topmost cited papers.

of some decisions, consisting of the following advantages: requiring less computational time, and algorithms can be terminated early upon finding one integral solution [6]. But this algorithm has the following limitations: If they fail to discover a solution, it's impossible to tell whether it's because there is not one or because the algorithm just could not find one. This is why further investigation is required to solve the issues mentioned above. The PSO algorithm is the second most frequently utilized optimization technique used to efficiently solve numerous problems that arise in real life along with the following benefits: higher computational efficiency compared with a mathematical algorithm, robustness to control parameters, easy implementation, and simple concept [74]. However, issues like the low-quality solution need memory to update velocity, and early convergence still exists. To solve the above-mentioned issues, further attention is required.

Stochastic optimization is widely used to solve stochastic problems, integrating both meanings of stochastic optimizations, which contains benefits like rapid convergence towards a local minimum and a higher probability of avoiding local minima. But this algorithm has the following drawbacks: accuracy is not very good, and, without computer assistance, they are slow. Hence, further exploration is required.

Another most frequently utilized optimization algorithm is meta-heuristic optimization; this algorithm aims to find, generate, or select a heuristic that may provide a satisfactorily good solution. This algorithm consists of several advantages like, it can be applied to any problems that can be formulated as function optimization problems and have broad applicability. Moreover, this algorithm can be merged with more conventional optimization methods. But this algorithm is still struggling with the high computational requirements. Hence, further in-depth exploration is required.

V. EXPLORATION OF CONTROLLER AND OPTIMIZATION METHODS BASED ON RESEARCH AREAS

Table 8 represents the distribution of the topmost cited 110 manuscripts over the different subject areas. The topmost cited 110 manuscripts distributed over 15 specific subject areas. Subject areas further classify the selected article to the more unique research interests. According to Table 8. most of the selected papers belong to the subject area of ''Battery storage integration and technology'' and ''Battery storage optimal design and sizing,'' with the figure of 14 articles. Followed by ''Dynamic pricing and electricity market'' and ''EV, PHEV and optimal charging'' with the figure of 10 and 9 manuscripts, respectively. On the other hand, the lowest number of manuscripts belongs to the category of ''Vehicle to Grid (V2G) application'' and ''Building energy management,'' with three articles each. Table 9. represents the summary of controllers and optimizations schemes used in the topmost cited 110 articles based on subject areas. Table 7. also highlights the specific objectives of controllers and optimization techniques along with their key findings and research gaps.

A. MICROGRID INTEGRATION AND DEVELOPMENT

Shi *et al.* [49] introduce distributed energy management strategies (EMS) in which the microgrid central controller (MGCC) and local controllers collaborate to find the best timetable. The authors also show how to put the planned distributed EMS based on IEC 61850 into practice. The simulation results show that the proposed distributed EMS effectively converges quickly. At the same time, Teng *et al.* [61] propose a mathematical model for battery storage systems (BSSs) that may utilize to replicate charging methods such as the widely utilized constant current-constant voltage (CC-CV) charging model, as well as discharging operations and state of charge (SOC). Test results validate the suggested topology and optimal charging or discharging scheduling for BSS.

Serban *et al.* [66] propose an improved control approach for battery energy storage systems (BESS) to support MG frequency while also being able to disengage from the MG and serve a local consumer in the island mode. The BESS active power transfer is governed by a frequency controller (FC) that combines a traditional droop control with an inertia emulation function during the primary frequency control level. The simulation and experimental findings are used to determine the viability of the suggested control solutions.

B. BATTERY STORAGE INTEGRATION AND TECHNOLOGY

Merabet *et al.* [58] present a laboratory-scale microgrid energy management and control system based on hybrid energy resources such as wind, solar, and battery. For the microgrid's efficient functioning, power converters and control algorithms, as well as specific energy supplies, were utilized. The suggested laboratory-scale microgrid can be utilized as a reference point for future smart grid research. Atia *et al.* [62] present a novel model for the optimization of a hybrid renewable energy system with a BESS in residential MGs based on mixed-integer linear programming. Demand response of available controllable appliances is coherently considered in the proposed optimization problem with reduced calculation complexities. Aghamohammadi *et al.* [69] propose a technique for calculating the ideal size of a battery energy storage system (BESS) for MG primary frequency management. A dc/ac converter control strategy for the BESS is designed by taking into account overloaded features and constraints of the battery's state of charge (SOC). To test the performance of the proposed control strategy, simulation analyses are carried out utilizing the PSCAD-EMTDC software.

C. BATTERY STORAGE OPTIMAL DESIGN AND SIZING

Bahmani-Firouzi *et al.* [52] propose a cost-based formula for determining the ideal size of battery energy storage (BES) in MG's operation management. Improved bat algorithm is a novel evolutionary approach for producing corrective measures and performing least-cost dispatching. One grid-connected low voltage MG evaluates the approach's performance, and the ideal size of the BES is calculated professionally. Reddy *et al.* [87] consider the influence of uncertainty in the wind, solar PV, and load demand estimates in developing a novel technique for the optimum scheduling issue. To verify the efficiency of the suggested optimum scheduling technique, simulation results for IEEE 30 and 300 bus test systems using the Genetic Algorithm (GA) and Two-Point Estimation Method (2PEM) were achieved. To test the efficiency of the proposed technique, results for sample systems with GA and two-point estimate based on optimal power flow and GA and Monte Carlo Simulation (MCS) were obtained. Sachs *et al.* [96] propose a two-layer model prediction technique for an enhanced control strategy for optimal microgrid operation. Simulation experiments are conducted using real-world data to demonstrate the suggested strategy's performance and economic benefits. The results reveal that the control technique is successful in terms of computational feasibility, accuracy, enhanced resilience, and cost reduction.

D. DYNAMIC PRICING AND ELECTRICITY MARKET

Beck *et al.* [111] propose a PV-battery system using a mixed-integer linear optimization model that minimizes the overall discounted operating and investment expenses. A resolution

TABLE 6. Top 10 most frequent utilized controllers in the selected topmost cited 110 articles.

Ref.	Type of Controllers	Objective	Advantages	Disadvantages
[96] [129]	Model Predictive Control	To predicting the future behavior of the system over the finite time window.	• Cost-efficient. • Robustness and shifting in performing conditions. • Improved energy saving. • Multiple variables control. • Decrease in offset error. • Enhanced transient response. • Peak load shifting capability. • Reduction in fluctuations. • Required less computational time.	• Higher installation cost. • Complex algorithm.
[75] [135]	Frequency Controller	To control the AC motor torque and speed by changing motor input voltage and frequency.	• Cost-effective. • Improved power factor. • Lower harmonics. • Reversal of motor. • Smooth starting. • Smooth acceleration and deceleration time.	• Some harmonics distortion. • Electromagnetic interference. • Inrush current. • Limited motor lead length. • High voltage spikes.
[136]	Proportional-integral controller	Widely used in industrial control systems and a variety of other applications requiring continuously modulated control.	• Easy to implement. • Uses low resources. • Robust to tuning mismatches. • By simple trial and error, easy to tune. • Better response to unmeasured disturbances.	• Difficult to tackle multiple constraints and perform optimization. • Difficult to tackle multiple variables with strong interaction. • Lower efficiency to tackle non-linearities. • Lower efficiency in processes with long dead time.
[85]	Fuzzy logic controller	Widely used in machine control.	• High precision. • Rapid operation. • Similar to human reasoning. • Simple mathematics for nonlinear, integrated, and complex systems. • Efficient for HVAC systems.	• Limited number of usages of input variables. • To enhance the accuracy, needs more fuzzy grades, hence increase exponentially the rule. • Lack of real-time response. • Longer running time and lower speed of the system. •
[43]	Supervisor Control Algorithms	A high level of overall monitoring of individual process controllers.	• Guarantee of stability, and optimality. • High reliability. • Reasonable implementation cost. • Fast data transmission between all layers low computation burden.	• Inefficiency and no applicability in large-scale systems. • Needs fast two-way high-bandwidth communication.
[46] [58]	Autonomous Control Method	To cope with increasing complexity in production and logistics.	• Real-time operation. • Asynchronous data and control. • Robustness. • Scalability.	• Expensive. • Safety and security concerns.
[55] [109]	Hierarchical Control	To handle complex problems by decomposing them into smaller subproblems.	• Variability of the load. • Requires a low communication bandwidth.	• Central controller failure results in the microgrid losing synchronization and optimal operation.
[59]	Hydraulic Controller	To restrict the continuation flow.	• Improved system response. • Reduced umbilical. • Small number of hydraulic hoses.	• Higher the surface component numbers. • Increase the subsea component numbers. • There is no electrical signal. • Slower operation. • Valve opening and closing sequences are fixed.
[141]	Dual Loop Controller	To achieve improved performance and accuracy of the load's motion and position.	• Dual loop control structure is more promising. • Limit the output current. • Allows damping resonances of the output LC filter.	• Higher cost. • Complex design. • Needed more maintenance. • Feedbacks lead to an oscillatory response. • Lower overall gain. • Less stable.
[66] [71]	Conventional Droop Control Scheme	To share the load power among sources.	• Does not need internal communication between different converters connected in parallel. • Good response speed. • Stability.	• Frequency and amplitude deviations. • Slow transient response. • Limited power flow control capabilities. • Difficulties in the coordination of distributed controllers.

TABLE 7. Top 10 most frequent utilized optimization techniques in the selected topmost cited 110 articles.

Ref.	Type of Optimization techniques	Objective	Advantages	Disadvantages
[51]	Mixed Integer Linear Programming	To capture the discrete nature of some decisions.	• Require less computational time. • Algorithms can be terminated upon finding at least one integral solution.	• If they fail to discover a solution, it's impossible to tell whether it's because there is not one or because the algorithm just could not find one. • It is normally hard to measure how near these approaches' solutions.
[100]	Particle Swarm Optimization	To solve efficiently numerous problems which arise in real life.	• Simple design. • Implementation is easy. • Robustness to control factors. • Computational efficiency is higher.	• Low-quality solution. • Needs memory to update velocity. • Early convergence.
[107] [132]	Stochastic Optimization	Using both definitions of stochastic optimization to address stochastic issues.	• Rapid convergence towards a local minimum. • Higher probability for avoiding local minima.	• Accuracy is not very good. • Without computer assistance, they are slow.
[51] [134]	Robust Optimization	To incorporate uncertainty into mathematical programming models.	• Easy implementation. • Computational cost. • Alternatives to solve the problem.	• Robust optimal solutions are highly conservative.
[94] [108]	Meta-heuristic optimization	To locate, produce, or choose a heuristic that can deliver a satisfactory solution.	• Hybridization: they can be linked with more conventional optimization methods. • They have a wide range of applications: they may be used to solve any problem that can be expressed as a function optimization problem.	• High computational requirements.
[41] [87]	Monte Carlo method	To utilize chance to solve issues that are in essence deterministic.	• Ability to factor in a range of values for various inputs. • Can handle uncertainty more efficiently. • Given the correct boundaries. • Simple and intuitive. • Easy to understand.	• Complex computational model. • If the parameters and constraints are poor in the input model, then the outcomes will be poor as well.
[61] [124]	Genetic Algorithm	To use biologically inspired operators like mutation, crossover, and selection to develop high-quality solutions to optimization and search issues.	• Can tackle difficulties whose constraints and objective functions are discontinuous or nonlinear. • Operations are simple. • Ability to deal with a wide range of objectives and constraints. • Easy to implement.	• Time consuming. • Struggling to handle large number of variables. • No predefined termination conditions. • Premature convergence is uncommon, resulting in the loss of population diversity. • Does not have a standard method for defining a good fitness function. • There's no certainty the global maxima will be discovered.
[52]	Bat algorithm	A powerful method for solving optimization problems.	• Simple and flexible. • Easy to implement. • There are no fixed used parameters. • Ability to switch from the exploration stage automatically and quickly to the exploitation stage. • Capacity to automatically zoom into areas with good solutions. • Uses frequency tuning to increase the population diversity.	• BA cannot efficiently handle discrete optimization problems.
[115]	Q-learning method	To learn the value of an action in a particular state.	• Low complexity. • Achieve long-term results. • The model has the ability to remediate mistakes made during the training phase. • It has the ability to design the ideal model to tackle a specific problem.	• For basic tasks, RL is not the best option. • Too much RL might result in an overabundance of states, lowering the quality of the output.
[128]	Hybrid Harmony Search Algorithm	To increase the convergence speed.	• Clarity of execution. • Its record of success. • Its ability to tackle several complex problems.	• Computational Complexity.
[150]	Stochastic Bi-Level Model Algorithm	To express the uncertainty in the values of the problem parameters as a probability distribution on some or all of the model's variables.	• Reduce the planners' cost. • Appropriate for large-scale problems. • Construct a suitable bidding strategy.	• The model has capacity limitations.

of 60 minutes is shown to be sufficient for effective sizing of PV power and storage capacity. A finer temporal precision of at least 300 s is required for the size of the battery inverter power of the storage system. Tushar *et al.* [122] a new electric vehicle (EV) categorization method for a photovoltaic (PV)-powered EV charging station (CS) that decreases the influence of electricity supply intermittency and the CS's cost of energy trading. It is demonstrated that by concentrating more on green EVs, the unpredictability in PV generation may be efficiently compensated and the overall cost of energy trading to the CS. Real solar and price data are employed for the system's performance analysis. As the percentage of green cars grows, the overall cost to the CS decreases significantly, and the contributions of green EVs in the winter are bigger than those in the summer. Zhang *et al.* [128] propose an optimal day-ahead scheduling model for solar cells, wind turbine units, diesel generators, and battery storage systems in a microgrid system.

To demonstrate the usefulness and validity of the proposed model and methodology, numerical results for multiple test microgrids using the IEEE 9-bus, IEEE 39-bus, and IEEE 57-bus systems to represent their transmission networks are used. The suggested technique is validated using normal operating mode and various typical failure modes, and simulations indicate that the HSDE algorithm is competitive.

E. EV, PHEV, AND OPTIMAL CHARGING

Xu *et al.* [31] present an optimization methodology for energy management and component size in a single smart house with home batteries, PEV, and PV arrays. The home with BESS does not acquire electric energy from the grid during the peak periods of the electric price based on the created CP control legislation in the home to vehicle (H2V) and vehicle to home (V2H) modes. Wu *et al.* [57] provide a stochastic dynamic programming framework for the best energy management of a smart house with PEV energy storage. Finally, the authors investigate the performance of the three operating modes for typical weekdays using time-varying electricity prices and time-varying household power usage. Caramanis *et al.* [127] a decentralized, massively parallel architecture that allows for tractable transmission and distribution locational marginal price (T&DLMP) discovery. Moreover, efficient scheduling of centralized generation, decentralized conventional and flexible loads, and distributed energy resources (DERs). T&DLMPs may discover using the suggested iterative distributed architecture, which captures the entire complication of each participating DER's intertemporal preferences and physical system dynamics.

F. PV AND WIND POWER GENERATION

Brekken *et al.* [47] explain how to size and regulate a zinc-bromine flow battery-based energy storage device. The findings indicate that the power flow control approach substantially influences the right size of the system's rated power and energy. In particular, artificial neural network control methodologies resulted in much less expensive energy storage devices than simpler controllers. The findings reveal that by improving the control and coordination of energy storage systems, wind plant production predictability may be raised. At the same time, the cost of integration associated with reserve requirements is reduced. Khatib *et al.* [88] present an overview of key information that should be considered while developing and installing standalone PV systems. Guo *et al.* [129] a two-stage strategy for the cost-effective operation of an electric vehicle (EV) parking deck with on-site renewable energy generation similar to a microgrid. Case studies show that the proposed framework outperforms the competition by providing an effective day-ahead marginal power pricing for tomorrow's operation and improving the profitability of the microgrid-like EV parking deck during real-time operation.

G. BATTERY ENERGY MANAGEMENT

Gee *et al.* [67] offer a battery/supercapacitor hybrid energy storage system for enhancing battery lifespan in a small-scale remote-area wind-power system. This work presents a technique for evaluating and implementing supercapacitor energy storage devices and control algorithms in the application area under consideration. To illustrate system practicality, the components of a prototype test system are detailed, and experimental results are provided. Yu *et al.* [75] developed a MATLAB/Simulink, where photovoltaic (PV), fuel cell, and battery are chosen as the usual DRERs and DESDs, respectively. Finally, many typical case studies are conducted, with simulation results confirming the suggested distributed power management. Byrne *et al.* [106] present a history of grid-scale energy storage, an overview of EMS topologies, and a synopsis of the most popular storage applications. These lay the groundwork for a study of EMS optimization techniques and design.

H. STANDALONE HYBRID RENEWABLE ENERGY SYSTEM

Suberu *et al.* [50] analyze the current state of three major types of energy storage technology (pumped hydroelectricity storage, batteries, and fuel cells) that can be used to integrate and regulate intermittency in renewable energy (RE). Finally, the article stated that energy storage systems (ESSs) are chosen based on their performance characteristics and the fuel source they employ and that no one ESS can satisfy all of the criteria for being labeled a supreme ESS. Sechilariu *et al.* [55] offer a building integrated photovoltaic (BIPV) system for metropolitan settings, particularly for self-feeding of buildings with PV arrays and storage. A DC network distribution is examined to eliminate numerous energy transformations. The experimental results support the concept of a future smart grid communication option between BIPV and the utility grid. According to Garcia *et al.* [78], ANFIS-based EMS of a grid-connected hybrid system is described and evaluated. It shows wind turbine (WT) and photovoltaic (PV) solar panels as major energy sources, as well as hydrogen (fuel cell -FC-, hydrogen tank, and electrolyzer) and battery-based ESS. Dynamic simulations

TABLE 8. Article distribution based on the specific subject of interest.

Field of interest	Article Rank based on Table 2	Publication Frequency	Citation Range
Micro grid integration and development	6, 9, 21, 26, 31, 40, 46, 60, 61, 77, 87, 88, 103, 110	14	81- 437
Battery storage integration and technology	14, 18, 22, 29, 32, 33, 39, 52, 62, 64, 73, 83, 100, 107	14	84- 226
Battery storage optimal design and sizing	5, 12, 16, 44, 48, 57, 58, 68, 95, 106	10	84- 479
Dynamic pricing and electricity market	3, 41, 55, 69, 72, 84, 90, 96, 104	9	85- 698
EV, PHEV and optimal charging	17, 47, 50, 70, 81, 82, 89, 94, 102	9	86- 202
PV and wind power generation	7, 13, 23, 49, 63, 91, 108	7	83- 389
Battery energy management	2, 27, 35, 42, 67, 71, 80	7	101- 726
Standalone hybrid renewable energy system	10, 15, 38, 51, 66, 85, 98	7	88- 262
Intelligent load management	4, 20, 36, 37, 43, 86, 105	7	84- 482
Demand side Management	8, 25, 59, 65, 74, 76	6	105- 299
Power conversion and power quality	28, 30, 54, 92, 99, 101	6	86- 172
Techno-economic Assessment	1, 19, 24, 45	4	82- 807
Life cycle analysis	53, 56, 75, 109	4	83-680
Vehicle to Grid (V2G) application	34, 78, 79	3	103- 155
Building energy management	11, 93, 97	3	89- 249

show that the ANFIS-based EMS performs well for the hybrid system under investigation and that it outperforms the traditional EMS.

I. INTELLIGENT LOAD MANAGEMENT

Sun *et al.* [45] propose a distributed control technique for a modular photovoltaic (PV) generating system with battery energy storage elements based on enhanced dc bus signaling. The suggested control techniques guarantee seamless switching of a battery converter between charging and discharging and a grid-connected converter between rectification and inversion. Experiments validate the proposed control techniques' practical viability and efficacy. She *et al.* [60] a novel MG architecture that combines solid-state transformers with zonal dc microgrids Both ac and dc networks may access the distribution system by using the solid-state transformer's dc and ac linkages, allowing for coordinated power management and excellent power supply dependability. The simulation results are displayed to demonstrate the proposal's viability.

J. DEMAND-SIDE MANAGEMENT

Brahman *et al.* [48] present a domestic energy hub concept, which accepts electricity, natural gas, and solar radiation at its input port and uses them to meet the output port's electrical, heating, and cooling demands. In addition, a multi-objective optimization is carried out to account for the contribution of consumers to CO2, NOx, and SOx emissions. The findings show how incorporating a DR program, smart PHEV management, and TES into the proposed energy hub model reduces energy costs. Wang *et al.* [65] propose a process for developing a hybrid renewable energy system (HRES) from the conceptual design stage to optimal functioning, which includes solar, wind, and a diesel engine as a backup resource, as well as battery storage. The approach is presented using a single-family residential house as an example.

K. POWER CONVERSION AND POWER QUALITY

Wang *et al.* [68] present a power smoothing approach for a grid-connected 1-MW solar photovoltaic (PV) power plant. To smooth the PV plant's variable output power, a hybrid energy storage system (HESS) consists of a vanadium redox battery and a supercapacitor bank. Extensive simulation findings back up the effectiveness of the suggested power control approach. Ding *et al.* [93] offer a unique multiport isolated bidirectional dc-dc converter for hybrid battery and supercapacitor applications that achieves zero voltage switching for all switches over the entire load range. The simulation and experimental findings verify the effectiveness of the control approach, the validity of the soft-switching analysis, and the parameter design methodologies. Petrollese *et al.* [137] provide a unique control technique for the best management of microgrids with high renewable energy penetration and various energy storage technologies. The results demonstrate a significant improvement in performance in terms of lower microgrid running costs and increased use of the hydrogen storage system to maintain a spinning reserve in batteries.

L. TECHNO-ECONOMIC ASSESSMENT

Hassan *et al.* [84] developed an optimization model to tackle the mixed-integer linear programming (MILP) problem and evaluate the benefits of alternative electricity tariffs and battery storage to maximize feed-in tariff (FiT) income streams for current PV producing systems. The findings reveal the value of battery storage for current and new PV systems that are eligible for FiT subsidies and operate under time-varying power pricing. Akram *et al.* [95] propose the grid-connected configuration of a microgrid, where two constraint-based iterative search methods are given for optimal scaling of the wind turbine (WT), solar photovoltaic (PV), and battery energy storage system (BESS). By exploring every feasible solution in the given search space, the suggested approach tries to prevent over- and under-sizing. Furthermore, it takes into account the PV, WT, and BESS usage factors, making it more realistic. Simulation results demonstrate the efficacy of the suggested technique. The idea of extending the lifespan of PEV batteries by using them in a secondary, stationary application was investigated by Beer *et al.* [114]. The findings

TABLE 9. Summary of controllers and optimization schemes in top 110 articles based on subject areas.

Subject area	Refs.	Controllers	optimizations	Objective	Key findings	Research gaps
Microgrid integration and development	[49]	microgrid central controller	-	Designing of energy management strategy.	Delivers fast convergence.	Real-time system was not executed.
	[61]	-	Genetic Algorithm	To simulate the charging process.	The proposed model can be utilized in reliability improvement.	Issues such as peak-load shifting were not analyzed.
Battery storage integration and technology	[58]	Stochastic Optimal Control	-	Energy management and control system.	Flexibility and allows different power electronics interfaces and combinations.	-
	[62]	Linear programming	-	To determine the influence of load flexibility on component sizing.	Increased demand flexibility for smart grid adoption.	Battery storage is not considered for studying the economic feasibility.
Battery storage optimal design and sizing	[52]	-	Bat Algorithm	Determination of the optimal size of the energy storage system.	High DG stability with low operational cost.	The unbalanced microgrid system with RES can be developed.
	[96]	Model predictive control	-	Minimization of cost and maximization of renewable fraction.	Recursive weight update results in increased adaptivity and lowers prediction errors.	A suitable validation scheme was not conducted.
Dynamic pricing and electricity market	[111]	-	Mixed-Integer Linear Optimization	To minimize the total discounted electricity costs.	The outcomes would lead to the development of optimal sizing for future designs.	Validation results with other schemes are missing.
	[128]	-	Hybrid harmony search and differential evolution	To minimize the generation and operational cost.	The reliability of the proposed technique is achieved under normal and fault operation situations.	Adaptive parameters and improved mutation can be employed for better outcomes.
EV, PHEV, and optimal charging	[57]	Stochastic optimal control	-	To minimize the consumed electricity cost.	High savings and load shifting's from the grid.	Multi-objective optimization can be conducted.
Techno-economic and life cycle cost analysis	[84]	-	mixed integer linear programming	Maximization of Feed-in tariff and minimizing electricity import.	The feasibility of battery system in PV would be feasible when battery unit cost drops to £138/kWh.	Impact of optimized onsite battery-based distributed system on local distribution system was not conducted.
	[95]		Source sizing and battery sizing	Optimal source sizing and battery sizing.	Avoid under the sizing and oversizing.	The novelty in the methodology was not depicted significantly.
PV and wind power generation	[47]	Artificial neural network	-	To evaluate the most cost-effective battery system and the impact of an energy storage power flow control method on system sizing and needs.	The revenue estimation is not affected by the inclusion of the battery system.	The performance metrics with regards to other controllers was not significant.
	[129]	model predictive control	-	To determine electricity sales cost.	Improvement in total revenue based on real-time operation.	-
Battery energy management	[67]	Supervisory control	-	Improvement towards battery lifetime.	The battery life can be increased by transferring transient power variations to the supercapacitor.	Multi-objective optimization may be formulated for delivering better outcomes.
	[75]	Distributed control algorithms	-	Optimal utilization of output power.	Low harmonics during switching operations.	The validation of the proposed control algorithm is not conducted.
Standalone hybrid renewable energy system	[55]	Hierarchical control	-	Towards minimizing multiple energy conversions.	Stability is maintained, and constraints load.	Prediction uncertainties based on power sources could be studied.
Intelligent load management	[45]	Distributed control	-	Development of control strategy for PV and battery system.	Stable operation in island mode, high power balancing is achieved.	Residential PV system model can be set up for future work.
	[60]	Variable control techniques for different components	-	To integrate solid-state transformer (SST) with the distribution system.	The integration was achieved successfully.	Further investigation to integrate high power SST with distribution network is required.
Demand-side Management	[48]	-	Multi-objective optimization	To minimize energy cost and emission.	Low exchange of power among the network components due to high emission rate.	-
Power conversion and power quality	[93]	Hydraulic controller	-	To achieve zero voltage switching for all switches based on hybrid battery and super-capacitor model.	Low ripples due to interleaving control.	Battery SOC was not considered.
	[137]	Model Predictive Controller	-	Energy management.	Better integration between storage systems with low operational cost.	Further study towards improved generation scheduling should be conducted.
Vehicle to Grid (V2G) application	[117]	-	Symbiotic Organisms Search	Energy management.	Smart charging management results in minimizing the cost.	The validation with other metaheuristic algorithms could be performed.
Building energy management	[131]	Model predictive control	-	To optimize the operation of the microgrid system.	Future outcomes based on forecasts and newly updated information were available.	Optimization of large microgrid systems by employing improved MPC can be conducted.

suggest that repurposing discarded PEV batteries can generate substantial financial value for stationary applications.

M. LIFE CYCLE ANALYSIS

Zakeri *et al.* [41] closely evaluate the literature on the study of utility-scale power storage systems' life cycle costs, giving an updated database for the cost factors (replacement expenses, O&M expenses, and the primary costs). In addition, the life cycle costs and levelized cost of electricity delivered by electrical energy storage are investigated, with the Monte Carlo approach used to account for uncertainties. The findings show how different storage systems compare in terms of cost for three major applications: bulk energy storage, T&D support services, and frequency regulation. Mendes *et al.* [59] provide a critical overview of the various bottom-up techniques for optimization planning and analysis of integrated community energy systems (ICES). Due to the robust and flexible three-level optimization technique, hourly time step, and other scale considerations, the survey demonstrates that the distributed energy resources customer adoption model (DER-CAM) can be considered an effective tool for ICES design modeling to the multiple successful implementations with modeling microgrid systems.

N. VEHICLE TO GRID (V2G) APPLICATION

Zhang *et al.* [74] discuss delay-optimal charging scheduling for electric vehicles (EVs) at a charging station with several charge points. The objective is to reduce the average waiting time for electric vehicles while maintaining a long-term cost limitation. The authors propose queue mapping to convert the EV queue to the charging demand queue and show that the reduction of the average lengths of the two queues is equivalent. The authors show which sets of system states are ideal for charging no demand and charging as many demands as feasible. Finally, they conduct a numerical analysis of the suggested policies. Kamankesh *et al.* [117], a new stochastic framework that considers the uncertainties in the modeling of PHEVs and RESs using the well-known Monte Carlo simulation, is used to investigate the optimal energy management of MGs (microgrids), including RESs, PHEVs, and storage devices. Using the suggested approach in case studies is compared to previous algorithms in various settings with and without PHEV charging effects.

O. BUILDING ENERGY MANAGEMENT

Liu *et al.* [51] present an optimum bidding approach for a microgrid with intermittent distributed generation (DG), storage, dispatchable DG, and price-sensitive loads in the day-ahead market. Numerical simulations on a microgrid, including a wind turbine, a solar panel, a fuel cell, a microturbine, a diesel generator, a battery, and a responsive load, demonstrate the benefits of both stochastic and resilient optimizations. Zhang *et al.* [131] provide a coordinated operation framework based on model predictive control (MPC) for a grid-connected home microgrid that takes prediction mistakes into account. In addition, a sensitivity analysis is carried out in order to explore the effects of energy storage units on microgrid operation. The suggested strategy is both cost-effective and versatile, according to simulation findings. Haruni *et al.* [135] present a standalone renewable hybrid power system's unique operation and control technique. A wind turbine, a fuel cell, an electrolyzer, a battery storage unit, and a set of loads make up the proposed hybrid system. The suggested control system is evaluated for various wind and load situations using the MATLAB Simpower package. The findings are presented and debated.

VI. KEY ISSUES AND CHALLENGES

There are a few constraints in this bibliometric survey that should be mentioned. To begin, just the Scopus database is utilized to choose the topmost cited 110 manuscripts. It is very difficult to compile a single complete list of the 110 topmost referenced papers while also taking into account additional datasets such as Google Scholar or Web of Science, which might be recommendations for future research. Secondly, only manuscripts published between 2011 and 2021 are considered for preparing the final topmost cited manuscript list. The publications from the year range are evaluated to understand the recent research trend. Thirdly, the search was confined to English; thus, the manuscripts written in other languages that may have a worldwide influence were possibly omitted. Finally, the articles that met the inclusion requirements were selected for the final analysis. The intercrossing and combination of many disciplines confused the assessment of a given subject. Studies based on battery storage and microgrid technology are incorporated, but anything linked to the nanomaterial and chemistry of the battery is barred from consideration. Regardless of the limitations previously mentioned, citation evaluation is a crucial technique used across many fields, and when used properly, it may be a useful tool to identify which authors, publications, and topics are persuading or influencing study in a subject. Apart from the limitations of the bibliometric study mentioned above, many obstacles in battery storage controllers and optimization integrated microgrid are reported which are discussed below.

A. RENEWABLE ENERGY TECHNOLOGIES

Renewable energy (RE) resources now play a crucial role in integrating the BS and microgrid in order to achieve the Sustainable Development Goals (SDGs) [151]. The integration of RE with the present energy industry is gaining popularity, particularly in Europe and USA. However, natural gas, nuclear power, and coal continue to be the primary sources of electricity around the globe. RE sources integration with microgrid are not usually suggested because of their unreliability and reliance on the environment. Integration of battery storage controllers and optimization schemes with microgrid EMS might be the fossil fuel-based energy generation sector's future alternative. The current challenge facing researchers is battery efficiency and optimal integration. An improved microgrid or isolated grid HRES can be used in developing nations where grid energy is occasionally unavailable.

B. BATTERY STORAGE INTEGRATION ISSUES

Distributed BS gives the microgrid the flexibility and redundancy it needs to respond to changing energy prices while also ensuring the safety, efficiency, battery life, and necessary load/generation profiles [152], [153]. However, increasing the store capacity might make managing the BS more difficult [154]. As a result, the best operation plan for reducing storage cost and size should be established. The storage's selection and optimal charging and discharging are critical components of its optimal size [155]. The main factors for good storage sizes are extended lifetime, efficiency, slow discharging, and fast charging. Despite the fact that numerous researchers have presented alternative solutions, the problem of managing the storage's efficient charging and discharging remains. When in microgrid-connected or islanded mode, voltage regulation, frequency control, and load fluctuation significantly influence storage [156], [157].

C. OPTIMIZATION EXECUTION ISSUES

Optimization methods that create and employ random variables are known as stochastic optimization methods [99], [139], [148], [158], [159]. The main drawback of stochastic techniques is that they are not extremely accurate, though they are typically near enough. For this reason, they are generally not employed when another approach is feasible. Hence, in-depth exploration is necessary to overcome the accuracy issue. Dynamic programming is a computer programming approach as well as a mathematical optimization tool [139]. Dynamic programming has the benefit of being able to find both local and global optimum solutions. Also, practical knowledge may be employed to better dynamic programming efficiency. However, there is no one-size-fits-all paradigm for dynamic programming; hence various conditions may arise during the solution process. As a result, further exploration is required to address the challenges of dynamic optimization.

D. CONTROLLER ISSUES

Model predictive control is widely utilized in microgrid EMS [96], [131] due to its multiple advantages such as optimal control, smoothing power, and robustness against uncertainty; however, it has shortcomings, including sophisticated ICTs, and control features. Another broadly utilized control scheme in microgrid management is multi-agent-based control [142] It offers benefits such as greater flexibility to uncertainty; nonetheless, it has drawbacks of having sophisticated connectivity between the local controller (LC) and agent. Although FL-based control [85], [160] provides enhanced frequency control, power, and voltage regulation for microgrid operation, it has constraints, including time-consuming procedures and high configuration processing units. The conventional droop algorithm has an easy execution process [161], [162]. However, it has limitations, such as the decrease in frequency and voltage control performance due to the reactive power variation. Hence, further investigation is necessary to address the above-mentioned issues.

E. POLICY AND DECARBONIZATION TARGET

The policy seems to play a vital role in achieving various economic and social goals in BS integrated microgrid EMS, such as lowering consumer energy costs and improving system dependability and national security. Clean Development Mechanisms (CDM), Joint Implementation (JI), and Emission trading (ET) are three fundamental components under the "Kyoto Protocol" that the United Nations (UN) has ignored in order to fulfill the reduction of emissions in their objectives cost-effectively [163], [164]. To decarbonize Europe's electricity industry, many measures have been implemented[165]. The industrialized nations have approved the Kyoto Protocol, and worldwide CO_2 emissions have continued to grow as a result of effective energy law implementation. Carbon pricing (emissions trading and carbon taxes) only covered around 15% of worldwide GHG emissions in 2018 [163]. Emission trading system (ETS) earnings were also not reinvested in low-carbon technologies or investigations, resulting in a lack of decarbonization effort. If the right laws are in place, finances for environmentally friendly industrial appliances can become more profitable, and emission decreases can be significantly expedited.

VII. CONCLUSION AND FUTURE PERSPECTIVES

The selection of the controller strategies and optimization schemes plays the most crucial role in the development of the efficient microgrid energy management system. Hence, the topmost cited 110 manuscripts in the area of battery storage controllers and optimization schemes integrated into microgrid EMS have been selected from the Scopus database under some predetermined criteria to perform critical analysis. A variety of analyses have been demonstrated, including article distribution by year, citation in the last five years, categorization by research area, study types, origin country, journal, and publishers. The key findings of this analytical assessment reveal that the majority of the papers (66.63%) involve the development of algorithms and experiments, whereas 20% of the manuscripts are review types. The papers with the most citations were published in 28 different journals and came from 33 different countries. This manuscript also constructively discusses and compares the most widely utilized 24 controller strategies and 21 optimization schemes in the highly cited 110 manuscripts. Among all the controllers, the model predictive controller was used in 9 manuscripts, followed by the frequency controller in 8 papers. In terms of optimization techniques, mixed integer linear programming and particle swarm optimization used in 10 manuscripts each. Moreover, this paper provides the specific advantages and disadvantages of each optimization and controller technique. In addition, this paper aims to deliver the features of the topmost cited manuscripts and offer insight into the evolution of energy storage controllers and optimization schemes in microgrid applications based on the 15 unique research areas. Among all the research fields, most of the articles belong to the microgrid integration and development, with 14 papers. Furthermore, this article focuses on various challenges and potential solutions related to battery storage controller strategies and optimization schemes, including microgrid energy storage integration issues, optimization execution issues, controller issues, and policy and decarbonization targets. Although this paper covers a wide range of state-of-the-art controllers and optimization techniques, further concerns are necessary regarding experimental validation, hardware verification, prototype product design, and real-time application implementations. Based on the critical analysis, the authors provide the following future recommendations:

- The integration of battery storage controllers and optimization schemes and Microgrid EMS is utilized as a more efficient backup power and frequency or voltage regulator [166], indicating that a particular technology is inadequate to allow the future microgrid [167]. Some of the major drawbacks of integrating battery storage controllers and optimization schemes with the microgrid EMS [94] include load quality management, uncertainties of future expansion planning, intermittency of BS and Microgrid support, system capacity constraints, and voltage violations. To address these difficulties, the topmost cited manuscripts provide direction to integrate battery storage controllers and optimization schemes with microgrid EMS properly. As a result, the integration of BS with microgrid has a better chance of meeting future energy crises and ensuring a more efficient supply.
- In EV applications, battery storage controllers and optimization schemes and microgrid EMS integration can help to decrease the heat effect while also guaranteeing system stability and flexibility. Thermal effects resulting from the kinetics and thermodynamics of electrochemical processes might also pose a danger to the BS functionality. To address the problems, a hybrid combination including SC and battery and dynamic regulation and frequency management is appropriate to minimize the effect and ensure dynamic containment [71], [161]. Furthermore, improved battery storage controllers and optimization schemes and real-time and active thermal rating systems can reduce battery aging and power cutting to address these challenges [48], [82]. As stated in [38], [39], [48], [65], a mixture of these, coupled with the DR technique, can ensure a more efficient power supply while constructing an integrated microgrid with BS.
- Selection of an appropriate hyperparameter tuning and framework are two major limitations with battery storage controllers and optimization implementation in the microgrid. Several hyperparameters, such as batch size, iterations, timestep, sampling interval, hidden neurons, hidden layer, bias, weight, learning rate, and so on, have been developed to build sophisticated algorithms. The optimal hyperparameters and grouping functions can minimize computational complexity, reducing the risk of overfitting and underfitting data. Hyperparameters and function selection based on trial and error takes a long time and a lot of human energy. Hence, adjusting the framework and hyperparameters in optimization and control is vital for achieving correct microgrid operation and administration results.
- Although the incorporation of BS optimization in microgrid EMS has proven substantial benefits in generating accurate, resilient, and fruitful outputs, it has a few disadvantages, including computational complexity and a lengthier training period. Furthermore, optimizations may provide unsatisfactory results if the dimension, search capacity, and convergence parameters are not allocated correctly. Hence, the selection of the right optimization algorithm is an important issue to be investigated.
- Microgrid EMS integrated BS technologies will be extremely important to fulfill the next-generation energy requirements and assure a stable and reliable energy supply. Nevertheless, there are important environmental problems that most researchers have ignored. As many studies have proposed, Li-ion batteries may be utilized to minimize carbon emissions and, therefore, environmental impact. Microgrid EMS's optimization and control techniques comprise BS building materials, discharge time, power output, rated power, specific energy, and expenses reported in this bibliometric survey's topmost 110 highly cited manuscripts. Hence, further investigation is required to invent a more efficient integration of microgrid EMS and battery storage controllers and optimization schemes to ensure a more environment-friendly power system.
- It has been noted that the utilization of energy storage with microgrid EMS replaces traditional fuels such as fossil fuel-based resources and serves as a potential alternative for overcoming insufficient system flexibility. Because of their reliance on weather conditions, wind and solar power generation are intermittent and stochastic that must be adjusted according to market conditions [168]. The REMix energy system model can be utilized to analyze capacity growth and power generation to address the challenges. Furthermore, integrating big data, cloud computing, and the internet of things (IOT) may provide more efficient and real-time information exchange to solve the issues mentioned above.

The topmost cited manuscripts have a significant influence on the field of study. In this bibliometric analysis, the topmost cited 110 manuscripts were included after multiple filtering to give future scholars a broad overview of the subject of battery storage controllers and optimization schemes as a type of microgrid EMS integration and current trends and concerns. Understanding the features of highly cited papers has several advantages, including:

- Future researchers can benefit from understanding the features of the topmost cited papers in the area of battery storage controllers and optimization schemes as a kind of microgrid EMS integration.
- The review and analysis of the topmost cited publications give proof of the researchers' study outcomes and assist them in identifying possible research collaborators.
- The bibliometric survey may give researchers a lot of information about the journals that could be interested in publishing manuscripts on the subject of battery storage controllers and optimization schemes and microgrid EMS integration.
- This bibliometric survey may assist the reviewer and journal editors in their assessment of the paper that has been submitted.
- This bibliometric survey may also assist government officials and decision-makers in introducing future energy research directions and developing long-term energy plans aligned with a country's financial and political objectives.

In summary, it is believed that analyzing and identifying the topmost referenced publications over the previous ten years would aid future studies on the area of battery storage controllers, optimization schemes and microgrid EMS integration.

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