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Optimal Algorithms for Energy Storage Systems in Microgrid Applications: An Analytical Evaluation Towards Future Directions

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ABSTRACT The optimal algorithm of Energy Storage System (ESS) has gained remarkable attention in developing a microgrid (MG) system to reduce the intensity of carbon emission in the electricity sector and alleviate the environmental impact by 2050. This article provides a historical background and a comprehensive analysis of the optimal algorithm of ESS in MG applications. A brief search has been directed through the Scopus database with some predefined conditions on the last week of January 2021 over 11 years to select the top-cited articles. This bibliometric study is evaluated in this field over the last decades based on the year of publication, interrelation of co-occurrence keywords, articles type, country of origin, journal, and publisher that published the 120 top-cited articles. A sum of 4995 articles was revealed within the year 2010 to 2020 in the field of the optimal algorithm of ESS in MG applications, and the top-most 120 papers were received in total 23003 citations (mean-119.69; median-157.5). Articles having the highest citation revealed in 30 different journals, 27 different regions and 6 different publishers. This bibliometric approach of ESS in MG applications offers the trends of research, gaps of this field, and knowledge essential for further development and advancement in this area. It is predicted that extracting, evaluating, and investigating the top-most cited articles will support further research in the optimal algorithm of ESS in MG applications.

INDEX TERMS Energy storage system (ESS), optimal algorithm, microgrid (MG), bibliometric analysis.

I. INTRODUCTION

Nowadays, traditional energy sources have lost their position in the competitive energy market due to their higher production cost, global warming, pollution, and the depletion nature of climate. Therefore, Renewable Energy Sources (RESs) such as solar and wind energy (economic and eco-friendly) are the best solution that has been used worldwide to serve the demand of electricity and minimize greenhouse gas emissions [1]. MGs that combine loads and several Distributed Energy Resources (DERs) operate both islanded and grid-tied mode, taking maximum advantage of the RESs. Besides their numerous benefits, RES has some uncertain and accidental manner that are non-dispatchable. To reduce the variability and higher intermittency of RESs, MG plays a vital role by employing Energy Storage System (ESS) and conventional power to form a hybrid MG [2]–[4]. For this, we intended to analyze the current scientific articles to evaluate the research trends and to visualize the interrelation between the development and revealed articles in the field of ESS in MG application.

Several strategies have been used to perform a review, for instance, primary path analysis, traditional review, and bibliometric analysis. Bibliometric analysis is one of the best

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TABLE 1. Several bibliometric review articles discussion highlighting the research gaps.

Year	Ref.	Focused topics	Research gaps
2012	[16]	Bibliometric and citation analyses were presented for ant colony optimization between 1996 and 2010.	The highly cited papers, subject area, citation analysis was presented. However, co-occurrence keywords and prominence of the manuscript is not explained towards future direction.
2018	[17]	Hundred most-cited articles on general thoracic surgery are analyzed.	Surveying method, highest cited articles and potential study area were discussed. However, the keyword analysis, issues, challenges, and future direction were not discussed.
2019	[7]	A bibliomeric analysis on thermal energy storage is explained from SCOPUS database.	The selected topmost cited papers were presented. However, keyword analysis of the articles are not highlighted properly to find the potential future research.
2020	[18]	A comprehensive bibliometric analysis on thermal management of electric batteries is presented where the Scopus database was used for data extraction.	A detailed keyword analysis, research trends, and highly cited articles were introduced. However, the future directions on the existing research are not recommended.
2021	[6]	Bibliometric evaluation and future research direction in integrated energy storage to gain decarbonization of grid are discussed from the selected manuscripts on Scopus database.	Entailed issues and challenges, keyword analysis, author's prominence and journal impact were discussed. However, research potentials and further research recommendation are not correctly mentioned.
2021	[13]	An advanced bibliometric analysis on sustainability and challenges in biodiesel production from waste cooking oil is presented from the selected manuscript on Scopus database.	The selected most cited article is not explained research trends, literature gap, future direction, and recommendations.

platforms to understand how articles pertaining to a specific area change over time and helps us investigate the hot articles to assist decision-makers. The frequency of publication by country, author, year, overall citations, and study type are the parameters to be examined. Citation analysis within certain fields and journals is one of the primary tools in bibliometric has turned out to be a popular way to rate the impact of the journal, particular literature, journals editors, or authors [5]. The attribute of intimate papers mostly depends on the citations of the journal rather than the journal impact factor. Despite the frequently used method, certain limitations ought to be taken while analyzing citations in a field. For instance, the tendency of individual citation practice can bias the citation rate or articles revealed earlier took colossal time to gather citations.

The approaches of bibliometric practice have been used to report the most cited papers in different fields like grid decarbonization with the support of energy storage integration [6], thermal energy storage system [7], liquid air energy storage [8], retirement planning and financial literacy [9], battery storage system (BSS) integrated renewable energy [10], imaging literature [11], orthopedic surgery [12], and biodiesel production from waste cooling oil [13]. A review article on grid-connected RESs has been conducted by Al-Shetwi *et al.* in 2020, where RES integration requirements and control methods are presented [14]. However, coordination and comprehensive management of RES integration are still undefined and require further research. Faisal *et al.* (2020) developed an article on battery energy storage systems in MG applications where the fuzzy logic controller is utilized to control the charging and discharging of the battery, and an optimal partial swarm optimization (PSO) is introduced for scheduling the ESS [2]. In 2020, Hannan *et al.* reviewed an article on MG to discuss an optimal algorithm and method for energy storage systems sizing towards achieving MG decarbonization [15]. Table 1 presents an overview of various bibliometric literature review articles by several researchers to find the focused area and existing research gaps.

Although the literature as mentioned earlier can give valuable information and insights on the future research direction in the field of an optimal algorithm for ESS in MG applications, to our knowledge, this study has been the first to use bibliometric analysis to present a detailed overview in this topic. Therefore, this article aims to comprehensively review the literature of optimal algorithms for ESS in MG applications based on bibliometric analysis. In this study, a total of 120 highest cited articles from 2010 to 2020 were extracted from the database of Scopus. We investigate the scientific literature based on citation bibliometric evaluation, bibliometric evaluation of co-occurrence keyword analysis, and bibliometric evaluation based on the last 5 years citation, study type, journal, subject area, and most profile author's affiliation. The final objective of this article is mentioned below:

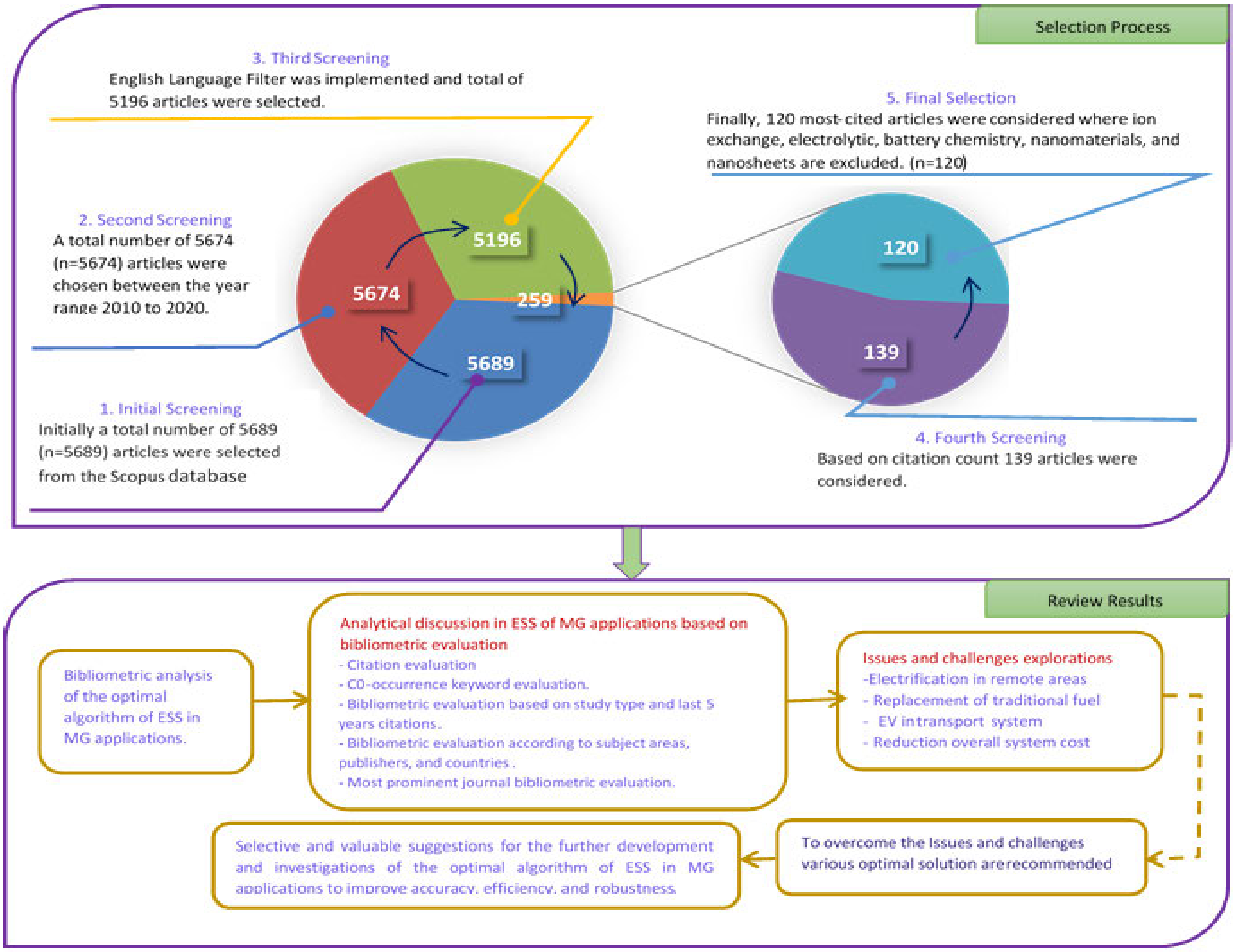

FIGURE 1. Schematic diagram of the process of selection 120 top-cited articles.

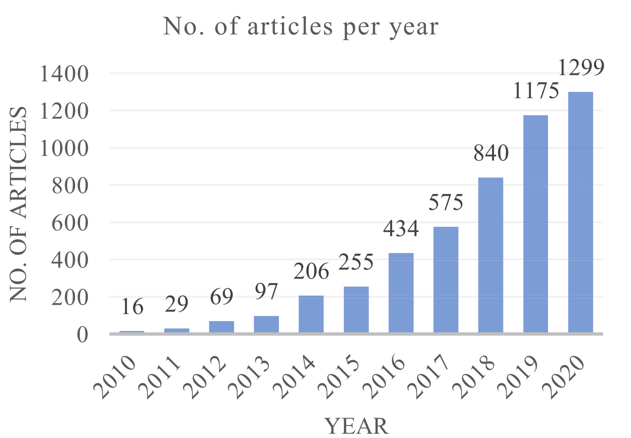

FIGURE 2. Research trends in the field of ESS in MG applications from the year 2010 to 2020.

- To guide future researchers concerning the literature gaps, advanced technologies, and unresolved studies in the field of ESS in MG applications are highlighted.
- We sought to provide a clear insight into the development, history, and improvement of ESS in MG applications.
- To provide a detailed analysis of the most prominent journal, authors, articles, and co-occurrence keywords.
- In addition, based on the previous studies, the issues, challenges, and further research direction are discussed.

The article is further structured as follows: the detailed surveying methodology for analyzing the topmost cited articles extracted from Scopus is introduced in Section 2. In Section 3, a comprehensive analysis of citation, co-occurrence keywords, publisher, major authors affiliation, journal, and publisher. Section 4 covers issues and challenges with recommendations regarding the optimal allocation of ESS in MG application. Finally, the concluding remarks are highlighted in Section 5.

II. STATE OF ART

Many studies have been done on the optimal algorithm for energy storage management, sizing, allocation, placement, control, and economic analysis in MG applications.

MG concept allows to integrate various DGs, loads, and ESSs which turn MG systems into high cost technology thus optimally manage MG is very crucial to ensure the secure, reliable, and economic operation. Xu and Li [19] developed a consensus algorithm for optimally manage the resources in a MG where a multiagent system is proposed to implement the strategy by exchanging information via local network. The optimal demand and power generation is achieved through a consensus-based optimization by balancing the supply-demand in the upper control stage. Whereas, tracing the power output reference is done in the lower control level by controlling the associated components. Brahaman *et al.* [20] developed an optimal thermal and electrical energy management model for a residential energy hub to incorporate PV panels, combined cooling, heating and power system (CCHP) unit, thermal energy storage (TES), and plug in hybrid electric vehicle (PHEV) while fulfilling the thermal and electrical demand. DR programs is employed in which load is shifted into the low price time slot or curtailed in order to customer satisfaction, and two types of ESS (PHEV and TES) is scheduled according to Time of Use (TOU) price tarrifs. An optimization algorithm is proposed with the objective of energy cost reduction while considering the customers contributions to NO_x, SO_x, and CO_2 emissions. In addition, V2G technology enables PHEVs more profitable by developing new battery technology in near future.

Olivares *et al.* [21] has presented a brief review of the available energy management system frameworks in MG applications, determining the major benefits of each approach/method, and has developed a centralized EMS architecture for stand-alone mode of operation. Future studies can be concentrate on the testing and development of the proposed architecture. Hossain *et al.* [22] proposed a modified partial swarm optimization (PSO) algorithm for real-time energy management to determine battery controls optimally where the cost function reduced the operational cost by 12% than the original cost function. In future consideration, experimental set up will be performed to see the proposed cost function effectiveness while considering the battery degradation cost. Murty and Kumar [23] developed an article where mixed integer linear programming is used to formulate the multi-objective solution for optimal MG energy management where the objective functions such as; cost of emission, total operation cost, and cost of power loss minimizes. In [24], a multiagent-based hierarchical energy management strategy was proposed for multi-MGs to reduce the overall operation cost considering the demand response and adjustable power.

Optimal sizing, allocation, and economic evaluation are very crucial to enhance the reliability and performance of MG operation. Fossati *et al.* [25] proposed a genetic algorithm based method for optimal sizing of ESS in MGs to minimized the operation cost. Results showed that by installing an optimal ESS operational cost reduced by 3.2% in the first scenario, in contrast the reduction was 14.1% in scenario two. In [26], a multi-objective self-adaptive evaluation algorithm was proposed for the optimal sizing of hybrid MG system (i.e. PV, wind, and diesel) to meet the all load demand with high reliability and minimizing the energy cost. Brekken *et al.* [27] presented an optimal control and sizing of zinc-bromine battery energy storage system to increase the power outputs of wind plant and cost of integration was decreased. The further discussion on the economic analysis of the ESS can be included. Zhao *et al.* [28] proposed an optimal unit sizing method considering component life-cycle and practical system for stand-alone MG. Sizing optimization problem was solved by genetic algorithm (GA) based method. The proposed methodology improve the operational life of batteries and RES generation uses by increasing production of RES unit and service of the battery system.

In [29], a novel approach has been presented based on real-coded genetic algorithm techniques to maximize the total net present value (NPV) during the lifetime period of system operation and to achieve the optimal types, arrangement, and size of the ESS in MG. More than one NPVs can be employed for further research to improve the system accuracy. Wen *et al.* [30] proposed a hybrid a hybrid multi-objective partial swarm optimization (HMOPSO) approaches to enhance the voltage profile of the system and reduce the system cost by economic allocation of storages units while considering the wind power uncertainties. However, constrain related to battery state of charge (SOC), battery life degradation, and aging were not considered in the system development. In [31], a mathematical methodological approach was presented to evaluate the effect of varying saturation of RE resources on several factors such as; system reliability, battery bank size, excess energy, SOC, net present cost, payback time, and levelized cost of energy (COE). Pumped hydro along with battery storage can be considered in the future studies to strengthen the reliability of the system and reduce the system net present cost.

Hubert and Grijalva [32] presented an optimization algorithms and energy scheduling model for residential consumers where electricity generation, storage, and consumption were optimally scheduled in a dynamic pricing environment. Kar *et al.* [33] review an article on distributed approaches based on consensus + innovations and energy management for three common function: economic dispatch, state estimation, and optimal power flow. Wen *et al.* [30] proposed a hybrid multi-objective partial swarm optimization (HMOPSO) approach to improve the voltage profile of the system and power system cost minimization by searching sizing and sitting of energy units considering wind uncertainty. In [34], a coordinated control strategy both localized and distributed control of ESS were proposed for voltage regulations where consensus algorithm were used for distributed control and SoC control strategy for localized control.

III. SURVEY METHODS

The key objective is to provide a comprehensive finding of the recent research works in the field of an optimal algorithm for ESS in MG application and present an insight into the development of this respective field. To find out the present trend in this vast scientific research area, a brief search has been conducted in the Scopus database on the last week of January under the year range of 2010 to 2020. "Optimal Algorithm", "Energy Storage Systems", "Microgrid Application", and their integrations are the keywords that were used to search the publications in the Scopus database. Additional filters have been implemented through a vast analysis to select the papers for the bibliometric analysis. One of the filters was "English Language", which was chosen due to resource limitations. Some sorting criteria were applied to all the manuscripts to rearrange in a definite way, among which "Times cited highest to lowest." And "exclude self-citations" filter is two of them. By doing it, numerous articles were retrieved, among which only the relevant articles were selected based on the title, focus, contribution, abstracts, and citations. The process of selection is illustrated by a schematic diagram as presented in Fig. 1.

A. INCLUDING AND EXCLUDING CRITERIA

While sorting out the most cited articles in the ESS in MG application, particular criteria have been implemented to discover the valuable study materials. The inclusion and exclusion criteria while searching the Scopus database are described below:

- All articles regarding Optimal Algorithm, Energy Storage system, MG application, and integration are incorporated. The exclusion criteria included studies on the internet of things, battery chemistry, electrochemical, and desalination.
- The articles which have been published from 2010 to 2020 were selected for the assessment.
- Articles published only in the English language are chosen for the study.

B. SELECTION PROCESS

The process of selecting the most cited 120 articles chosen from the database Scopus in the optimal algorithm of ESS in MG application are listed below:

- After the initial search in the database scopus. Overall, 56589 (N = 5689) articles were identified.
- The second assessment and screening were performed between 2010 and 2020, and a sum of 5674 (n = 5674) manuscripts were considered.
- The third selection was conducted where articles revealed only in the English language are permitted for the selection of 5196 articles.
- During the citation count in the fourth screening, 5057 articles were excluded from 5196, and a full of 139 (n = 139) manuscripts were identified.
- The final evaluation and screening were performed based on the keyword, abstract, and title. Finally, 120 (n = 120) highly cited manuscripts were considered after employing the subject area exclusion criterion where the subject area. For instance, nanosheets, ion exchange, electrolyte, battery chemistry was excluded.

C. TREND OF RESEARCH

The integration of renewable-based ESS in MG has gained popularity among researchers due to their environmental benefits, and various research is leading towards effective integration technologies and applications as well as the optimal location and sizing of ESS [35]–[38]. Afterwards, emphasis was given towards stand-alone applications, optimal algorithm, sizing, a techno-economic assessment of ESS in MG. In Fig. 2, an analysis from the Scopus database regarding the annual number of articles in the field of an optimal algorithm in ESS in MG application has been presented. From the figure, it can be observed that from 2014 there has been a tremendous increase in the number of highly cited articles which indicates the research interest growth of this specific field. Articles publication frequency from 2018 to 2020 is 3314, whereas combining all the published articles from 2010 to 2017 gives the same number as 3314. This determines that 50% of papers are conducted in the last three years between 2018 and 2020, which is equal to the number of published articles (50%) in the first 8 Years (2010-2017).

D. DATA EXTRACTION

Scopus database was utilized to analyze the articles obtained in the year range of 2010 to 2020. The data was presented on the following constraints: 1) list of top-cited articles; 2) study characteristics; 3) top articles based on last five years citation; 4) field of study; 5) publisher of the 120 top-most cited articles; 6) most prominent journal and their impact factor; 8) country; 9) most prominent authors. Finally, after analyzing the top-most cited articles data, an analysis has been provided to present a clear insight into the Optimal Algorithm for the ESS in MG application.

E. CHARACTERISTICS OF THE STUDY AND RESULTS

Initially, a total number of 5674 articles associated with this subject were discovered from the database Scopus. From the analysis, it has been observed that the citation range of these selected 120 articles is between 36 and 719, attaining the total 23003 number of citations. Additionally, in the last 5 years, the total number of citations is 10648 whereas, 16 articles were attained more than 300 citations. The article having the most citation named "A Survey on smart grid potential applications and communication requirements" is published in "IEEE Transactions on Industrial Informatics", having an Impact Factor (IF) of 8.480 (2019-2020) with 719 citations. The top-most 120 papers were considered and presented in Table 2, containing the name of authors, DOI, keywords, country, journal name, publishing year, publisher name, last 5-year citations, and total citations.

IV. ANALYTICAL DISCUSSION

To dimension the influence of Optimal Algorithm for Energy Storage Systems in MG Application, a comprehensive study of the available publications must be carried out based on the most influential research and the present research tendency

TABLE 2. Top 120 highly cited papers in the field of EES in MG application.

Rank	Ref.	Author Name and publishing year	Article DOI	Keywords	Abbreviated Name	Publisher	Country	Number of Citation	Last 5 Years Citation	Average Citation Per Year (ACY)
1	[39]	Gungor et al. (2013)	https://doi.org/10.1109/TII.2012.2218253	AMI, Smart Grid, DR, Communications.	TII	IEEE	Turkey	719	431	102.7
2	[40]	Zakeri et al. (2015)	https://doi.org/10.1016/j.rser.2014.10.011	BES, Cost of ES, Electricity Market, ES, RE integration, Techno-economic analysis, Smart grid	RSER	Elsevier	Denmark	717	629	143.4
3	[41]	Tie et al. (2013)	https://doi.org/10.1016/j.rser.2012.11.077	EV, EM, Hybrid EV. Supervisory Control, Optimization, Drive cycle	RSER	Elsevier	Malaysia	665	466	95
4	[42]	Lund et al. (2015)	https://doi.org/10.1016/j.rser.2015.01.057	Energy flexibility, DSM, ES, Ancillary service, Electricity market, Smart grid	RSER	Elsevier	Finland	598	541	119.6
5	[43]	Justo et al. (2013)	https://doi.org/10.1016/j.rser.2013.03.067	AC MG, DC MG, MG control, MG protection, RES	RSER	Elsevier	Tanzania	581	418	83
6	[44]	Nehrir et al. (2011)	https://doi.org/10.1109/TSTE.2011.2157540	EM, ES, RE	TSTE	IEEE	United States	521	310	57.9
7	[45]	Palma-Behnke et al. (2013)	https://doi.org/10.1109/TSG.2012.2231440	Demand-side management, EM, MG, PV, Wind	TSG	IEEE	Chile	464	322	66.3
8	[46]	Su et al. (2014)	https://doi.org/10.1109/TSG.2013.2280645	plug-in electric vehicle (PEV), MG, RE, smart grid	TSG	IEEE	United States	403	334	67.2
9	[27]	Brekken et al. (2011)	https://doi.org/10.1109/TSTE.2010.2066294	ES, wind, Control systems, power system security	TSTE	IEEE	United States	377	168	41.9
10	[47]	Chauhan et al. (2014)	https://doi.org/10.1016/j.rser.2014.05.079	RE, Integration, demand	RSER	Elsevier	India	367	292	61.2
11	[48]	Li et al. (2016)	https://doi.org/10.1109/TSTE.2015.2467383	Combined heat and power dispatch, ES, Wind	TSTE	IEEE	China	337	330	84.2
12	[49]	Ma et al. (2014)	https://doi.org/10.1016/j.apenergy.2014.01.090	COE, NPC, Solar-wind-battery system	APENERGY	Elsevier	China	324	236	54
13	[50]	Li et al. (2010)	https://doi.org/10.1109/TIE.2009.2037103	ES, Hardware-in-the-loop (HIL), Wind, simulation	TIE	IEEE	Canada	319	113	31.9
14	[51]	Zhou et al. (2016)	https://doi.org/10.1016/j.rser.2016.03.047	Home EMS, RE	RSER	Elsevier	China	317	311	79.2
15	[52]	Fathima et al. (2015)	https://doi.org/10.1016/j.rser.2015.01.059	Solar, Wind, optimization, ESS	RSER	Elsevier	India	314	271	62.8
16	[53]	Akinyele et al. (2014)	https://doi.org/10.1016/j.seta.2014.07.004	Integration, Underwater-CAES, RE	SETA	Elsevier	Nigeria	313	261	52.2
17	[54]	Nunna et al. (2013)	https://doi.org/10.1109/TIE.2012.2193857	energy markets. MG, Auction algorithms	TIE	IEEE	Kazakhstan	295	191	42.1
18	[55]	Zhao et al. (2013)	https://doi.org/10.1109/TSTE.2013.2248400	Lead-acid batteries, optimization, MG	TSTE	IEEE	China	290	219	41.4
19	[29]	Chen et al. (2011)	https://doi.org/10.1109/TPEL.2011.2116808	ESS, DG, genetic algorithm (GA), optimization	TPEL	IEEE	China	282	152	31.3
20	[56]	Lund et al. (2017)	https://doi.org/10.1016/j.energy.2017.05.123	Smart grid, ES, RES	Energy	Elsevier	Denmark	281	281	93.7
21	[20]	Brahman et al. (2015)	https://doi.org/10.1016/j.enbuild.2014.12.039	DR, Thermal ES, PHEV	ENBUILD	Elsevier	United States	256	224	51.2
22	[57]	Mohammadi et al. (2014)	https://doi.org/10.1016/j.ijepes.2013.08.004	MG, uncertainty, ES	IJEPES	Elsevier	Iran	247	186	41.2
23	[58]	Levron et al. (2013)	https://doi.org/10.1109/TPWRS.2013.2245925	MG, DG, OPF, smart grid, ESS	TPWRS	IEEE	Israel	246	158	35.1
24	[59]	González-Gil et al. (2014)	https://doi.org/10.1016/j.enconman.2014.01.060	EM, rail, Energy efficiency methodology	ENCONMAN	Elsevier	Spain	244	188	40.7
25	[60]	Li et al. (2014)	https://doi.org/10.1016/j.rser.2014.05.056	Building energy modeling, DR, ESS	RSER	Elsevier	China	233	182	38.9
26	[28]	Zhao et al. (2014)	https://doi.org/10.1016/j.apenergy.2013.09.015	MG, sizing, RES, optimization, ES	APENERGY	Elsevier	China	231	168	38.5
27	[61]	Olatomiwa et al. (2016)	https://doi.org/10.1016/j.rser.2016.05.040	EM, Grid-connected, RE	RSER	Elsevier	Nigeria	224	221	56
28	[62]	Choi et al. (2012)	https://doi.org/10.1109/TSG.2011.2164816	Optimization,Battery, EM, supercapacitor	TSG	IEEE	South Korea	222	135	27.7
29	[63]	Amirante et al. (2017)	https://doi.org/10.1016/j.enconman.2016.11.046	ES, RES, Economic analysis	ENCONMAN	Elsevier	Italy	210	210	70
30	[64]	Bouzid et al. (2015)	https://doi.org/10.1016/j.rser.2015.01.016	DPGS, Grid-feeding, forming, Grid-supporting.	RSER	Elsevier	France	210	181	42
31	[65]	Sechilariu et al. (2013)	https://doi.org/10.1109/TIE.2012.2222852	ES, smart grid, Battery, EM, PV	TIE	IEEE	France	210	109	30
32	[66]	Jin et al. (2014)	https://doi.org/10.1109/TIE.2013.2286563	DC MG, BES, PV, voltage regulation	TIE	IEEE	Singapore	208	151	34.7
33	[67]	Hernandez et al. (2014)	https://doi.org/10.1109/SURV.2014.032014.00094	MG, smart grid, demand forecasting	IEEE Commun. Surv. Tutor	IEEE	Spain	208	169	34.7
34	[68]	Ma et al. (2015)	https://doi.org/10.1016/j.apenergy.2014.06.005	Pumped storage, PV, Techno-economic, optimal	APENERGY	Elsevier	China	202	163	40.4
35	[69]	Ma et al. (2014)	https://doi.org/10.1016/j.renene.2014.03.028	PV, wind, simulation, modelling	RENENE	Elsevier	China	199	145	33.2
36	[70]	Wang et al. (2014)	https://doi.org/10.1109/TSG.2013.2284664	EES, EM	TSG	IEEE	United States	190	141	31.7
37	[71]	Calvillo et al. (2016)	https://doi.org/10.1016/j.rser.2015.10.133	ES, RE, smart grid, transport system	RSER	Elsevier	Spain	189	170	47.2
38	[72]	Carpinelli et al. (2013)	https://doi.org/10.1109/TSG.2012.2231100	ES, GA, smart grid	TSG	IEEE	Italy	189	130	27
39	[73]	Lan et al. (2015)	https://doi.org/10.1016/j.apenergy.2015.08.031	ESS, Irradiation, PV	APENERGY	Elsevier	Singapore	188	180	37.6
40	[74]	Datta et al. (2011)	https://doi.org/10.1109/TEC.2010.2089688	ESS, frequency control, fuzzy logic	TEC	IEEE	Australia	181	93	20.1
41	[75]	Niknam et al. (2012)	https://doi.org/10.1016/j.energy.2012.03.064	ES, MG, Self-adaptive GSA	Energy	Elsevier	Iran	177	95	22.1
42	[76]	Conti et al. (2012)	https://doi.org/10.1109/TPWRD.2012.2194514	Dispatching, optimal control, power distribution	TPWRD	IEEE	Italy	176	92	22
43	[77]	Hesse et al. (2017)	https://doi.org/10.3390/en10122107	BESS, grid connected, optimization, Techno-economic analysis	Energies	MDPI	Germany	175	175	58.3
44	[78]	Xu et al. (2015)	https://doi.org/10.1109/TSG.2014.2354033	Charging/discharging, ESS, MG	TSG	IEEE	China	171	143	34.2
45	[79]	Xiong et al. (2018)	https://doi.org/10.1016/j.apenergy.2017.11.072	Power transition, power management, energy loss	APENERGY	Elsevier	China	170	170	85
46	[80]	Borhanazad et al. (2014)	https://doi.org/10.1016/j.renene.2014.05.006	PV, RE, wind, Multi objective, PSO	RENENE	Elsevier	Malaysia	170	153	28.3
47	[81]	Arefifar et al. (2012)	https://doi.org/10.1109/TSG.2012.2198246	Energy loss, ESS, MG, MG design	TSG	IEEE	United States	170	115	21.2
48	[25]	Fossati et al. (2015)	https://doi.org/10.1016/j.renene.2014.12.039	EES, sizing, Fuzzy logic, GA, MG	RENENE	Elsevier	Spain	169	143	33.8
49	[19]	Xu et al. (2015)	https://doi.org/10.1109/TIE.2014.2356171	RE, Consensus algorithm, landed microgrid	TIE	IEEE	China	169	150	33.8
50	[82]	Wang et al. (2015)	https://doi.org/10.1016/j.apenergy.2015.01.004	DR, optimization, EM, hybrid RES	APENERGY	Elsevier	Singapore	167	131	33.4
51	[83]	Bidram et al. (2014)	https://doi.org/10.1109/MCS.2014.2350571	Optimization, ESS, MG, controller	Contrl. Syst.	IEEE	United States	167	141	27.8
52	[84]	Wang et al. (2012)	https://doi.org/10.1109/TSG.2012.2217764	EM, intelligent coltrol, PV, smart grid	TSG	IEEE	China	167	94	20.9
53	[85]	Baghaee et al. (2016)	https://doi.org/10.1016/j.energy.2016.09.007	Fuel cell, multi-objective, PSO, PV, wind, sizing	Energy	Elsevier	Iran	166	166	41.5
54	[86]	Soliman et al. (2014)	https://doi.org/10.1109/TSG.2014.2302245	DSM, distributed algorithm, game theory	TSG	IEEE	Canada	163	128	27.2
55	[87]	Yang et al. (2018)	https://doi.org/10.1016/j.rser.2018.03.047	BESS, sizing, MG, RES	RSER	Elsevier	Australia	161	161	80.5
56	[88]	Gee et al. (2013)	https://doi.org/10.1109/TEC.2012.2228195	Battery, ES, wind	TEC	IEEE	UK	161	99	23
57	[30]	Wen et al. (2015)	https://doi.org/10.1109/TPWRS.2014.2337936	ESS, multi-objective PSO, RES	TPWRS	IEEE	China	160	130	32
58	[89]	Mendes et al. (2011)	https://doi.org/10.1016/j.rser.2011.07.067	Optimization, ES, MG, sustainability	RSER	Elsevier	Finland	160	99	17.8
59	[90]	Nguyen et al. (2014)	https://doi.org/10.1109/TSG.2013.2274521	EV, EMS, cost minimization	TSG	IEEE	Canada	159	122	26.5
60	[91]	Hug et al. (2015)	https://doi.org/10.1109/TSG.2015.2409053	distributed optimization, economic dispatch	TSG	IEEE	Switzerland	158	147	31.6
61	[92]	Wang et al. (2014)	https://doi.org/10.1109/TSTE.2014.2305433	Power smoothing, ES, power control, PV	TSTE	IEEE	Australia	157	116	26.2
62	[93]	Bhandari et al. (2015)	https://doi.org/10.1007/s40684-015-0013-z	Hybrid RES, PV, wind, optimization	IJPEM-GT	Springer Nature	South Korea	156	129	31.2
63	[94]	Meng et al. (2016)	https://doi.org/10.1016/j.rser.2016.03.003	EMS, control, MG	RSER	Elsevier	Denmark	155	148	38.7
64	[95]	Korkas et al. (2016)	https://doi.org/10.1016/j.apenergy.2015.10.140	DR, MG, optimization	APENERGY	Elsevier	Greece	155	141	38.7
65	[96]	Geertsma et al. (2017)	https://doi.org/10.1016/j.apenergy.2017.02.060	ES, control system, marine system, ship design	APENERGY	Elsevier	Netherlands	154	154	51.3
66	[97]	Yoldaş etal. (2017)	https://doi.org/10.1016/j.rser.2017.01.064	EV, MG, smart grid, distributed generation	RSER	Elsevier	Turkey	154	154	51.3
67	[98]	Bogdanov et al. (2016)	https://doi.org/10.1016/j.enconman.2016.01.019	100% RE, grid, integration, ES, optimization	ENCONMAN	Elsevier	Finland	154	145	38.5
68	[99]	Amrollahi et al. (2017)	https://doi.org/10.1016/j.apenergy.2017.05.116	RE, DR, MG, optimization, MILP	APENERGY	Elsevier	Iran	151	151	50.3
69	[100]	Mouli et al. (2016)	https://doi.org/10.1016/j.apenergy.2016.01.110	Battery, EV, ES, PV	APENERGY	Elsevier	Netherlands	151	169	37.7
70	[101]	Shivashankar et al. (2016)	https://doi.org/10.1016/j.rser.2016.01.059	ES, PV, Power fluctuation, smoothing	RSER	Elsevier	Malaysia	150	144	37.5
71	[56]	Lund et al. (2016)	https://doi.org/10.5278/ijsepm.2016.11.2	ES, RE, transportation, heating	IJSEPM	Aalborg U Press	Denmark	150	149	37.5
72	[102]	Mousavi et al. (2017)	https://doi.org/10.1016/j.rser.2016.09.060	ES, Flywheel, RE	RSER	Elsevier	Iran	149	149	49.7
73	[103]	Salimi et al. (2015)	https://doi.org/10.1049/iet-gtd.2014.0607	DSM, distributed algorithm, game theory	IET-GTD	IET	Iran	149	138	29.8
74	[103]	Mahmoud et al. (2014)	https://doi.org/10.1016/j.jfranklin.2014.01.016	REM, EMS, Distributed generation, PV	JFRANKLIN	Elsevier	Saudi Arabia	149		24.8
75	[104]	Zidar et al. (2016)	https://doi.org/10.1049/iet-gtd.2015.0447	EM, intelligent coltrol, PV, smart grid	IET-GTD	IET	Croatia	148	139	37
76	[105]	Singh et al. (2016)	https://doi.org/10.1016/j.enconman.2016.09.046	BESS, PV, wind, optimization	ENCONMAN	Elsevier	India	147	147	36.7
77	[34]	Wang et al. (2016)	https://doi.org/10.1109/TPWRD.2015.2462723	Coordinated control, distributed ESS, voltage regulation	TPWRD	IEEE	Singapore	147	146	36.7
78	[106]	Motevasel et al. (2014)	https://doi.org/10.1016/j.enconman.2014.03.022	EMS, MG, wind, optimization	ENCONMAN	Elsevier	Iran	145	103	24.2
79	[107]	Shadmand et al. (2014)	https://doi.org/10.1109/TSG.2014.2315043	GA, MG, PV, wind, smart grid	TSG	IEEE	United States	142	113	23.7
80	[108]	Zhang et al. (2014)	https://doi.org/10.1109/TVT.2013.2295591	RE, EV, Scheduling	TVT	IEEE	China	142	111	23.7

TABLE 2. *(Continued.)* Top 120 highly cited papers in the field of EES in MG application.

81	[109]	Palizban et al. (2016)	https://doi.org/10.1016/j.est.2016.02.001	ESS, RES, modern grid	EST	Elsevier	Finland	139	138	34.7
82	[33]	Kar et al. (2014)	https://doi.org/10.1109/JSTSP.2014.2364545	consensus+ innovations, distributed algorithms, Distributed energy management, economic dispatch	JSTSP	IEEE	United States	139	106	23.2
83	[110]	Hung et al. (2014)	https://doi.org/10.1016/j.apenergy.2013.08.069	BESS, PV, OPF, Voltage stability	APENERGY	Elsevier	Australia	139	109	23.2
84	[111]	Krishna et al. (2015)	https://doi.org/10.1016/j.rser.2015.07.187	REM, EMS, Distributed generation, PV	RSER	Elsevier	India	138	122	27.6
85	[112]	Hemmati et al. (2016)	https://doi.org/10.1016/j.rser.2016.06.029	Hybrid ESS, RE, EV, ESS	RSER	Elsevier	Iran	137	137	34.2
86	[113]	Silvente et al. (2015)	https://doi.org/10.1016/j.apenergy.2015.05.090	MG, Scheduling, DSM, Energy planning	APENERGY	Elsevier	UK	137	122	27.4
87	[114]	Bhandari et al. (2014)	https://doi.org/10.1007/s40684-014-0021-4	RE, PV, wind, hydro, Hybrid, modelling	IJPEM-GT	Springer Nature	South Korea	137	110	22.8
88	[115]	Theo et al. (2017)	https://doi.org/10.1016/j.rser.2016.09.063	RES, DG, Energy planning, modelling, optimal	RSER	Elsevier	Malaysia	136	136	45.3
89	[24]	Bui et al. (2018)	https://doi.org/10.1109/TSG.2016.2585671	MG, MILP, DR, EMS	TSG	IEEE	South Korea	135	135	67.5
90	[32]	Hubert et al. (2012)	https://doi.org/10.1109/TSG.2012.2220385	Home EMS, smart grid, DR, optimization	TSG	IEEE	United States	135	71	16.9
91	[21]	Olivares et al. (2011)	https://doi.org/10.1109/PES.2011.6039527	DG, EMS, MG, optimization	PES	IEEE	Chile	135	66	15
92	[26]	Ramli et al. (2018)	https://doi.org/10.1016/j.renene.2018.01.058	RE, PV, wind, Differential evolution algorithm	RENENE	Elsevier	Saudi Arabia	134	134	67
93	[116]	Colak et al. (2016)	https://doi.org/10.1016/j.rser.2015.10.036	ESS, RE, Critical challenges, Smart grid	RSER	Elsevier	Turkey	134	124	33.5
94	[117]	Lu et al. (2015)	https://doi.org/10.1016/j.apenergy.2015.06.007	ES, DR, scheduling, Zero energy building	APENERGY	Elsevier	China	134	110	26.8
95	[118]	Talari et l. (2015)	https://doi.org/10.1049/iet-gtd.2014.0040		IET-GTD	IET	Germany	134	126	26.8
96	[119]	Unamuno et al. (2015)	https://doi.org/10.1016/j.rser.2015.07.194	RES, MG, smart grid, Distributed power generation	RSER	Elsevier	Spain	133	125	26.6
97	[120]	Mohammadi et al. (2017)	https://doi.org/10.1016/j.rser.2017.07.030	Conceptual model, Energy hub,MES	RSER	Elsevier	Iran	132	132	44
98	[121]	Gabrielli et al. (2018)	https://doi.org/10.1016/j.apenergy.2017.07.142	ES, MG, MILS, Power-to-gas, scheduling	APENERGY	Elsevier	Switzerland	131	131	65.5
99	[122]	Wang et al. (2014)	https://doi.org/10.1109/TSTE.2013.2293772	DR, MG, renewable integration, load control	TSTE	IEEE	China	130	93	21.7
100	[123]	Abedi et al. (2012)	https://doi.org/10.1016/j.rser.2011.11.030	Hybrid energy systems, Optimum power management strategy, fuzzy optimization	RSER	Elsevier	United States	126	79	15.7
101	[124]	Li et al. (2019)	https://doi.org/10.1109/TIE.2018.2840498	MG, scheduling, discretized step transformation	TIE	IEEE	China	103	103	103
102	[125]	Adefarati et al. (2019)	https://doi.org/10.1016/j.apenergy.2018.12.050	Economic, Emission, Environment, MG, Reliability	APENERGY	Elsevier	Nigeria	89	89	89
103	[126]	Parra et al. (2019)	https://doi.org/10.1016/j.rser.2018.11.010	Smart grid, RE, power-to-gas, ES	RSER	Elsevier	Switzerland	77	77	77
104	[127]	Hajiaghasi et al. (2019)	https://doi.org/10.1016/j.est.2018.12.017	Hybrid ES, MG, RE, sizing	EST	Elsevier	Iran	75	75	75
105	[128]	Huang et al. (2019)	https://doi.org/10.1109/TSG.2017.2767860	ES, RE, planning, Topological layering	TSG	IEEE	China	73	73	73
106	[129]	Wong et al. (2019)	https://doi.org/10.1016/j.est.2018.12.015	Distribution network, ESS	EST	Elsevier	Malaysia	71	71	71
107	[130]	Nadeem et al. (2019)	https://doi.org/10.1109/ACCESS.2018.2888497	EV, ER, optimization, planning	IEEE Access	IEEE	India	69	69	69
108	[131]	Wu et al. (2019)	https://doi.org/10.3390/en12040642	Capacity configuration, Hybrid ES, Micropower grid, PSO, Power fluctuation	Energies	MDPI	China	56	56	56
109	[31]	Ma et al. (2019)	https://doi.org/10.1016/j.enconman.2018.12.059	Solar-wind-battery system, COE, RE	ENCONMAN	Elsevier	China	56	56	56
110	[132]	Dolatabadi et al. (2019)	https://doi.org/10.1109/TSTE.2017.2788086	stochastic optimization, Wind, Energy hub, uncertainty information gap decision theory (IGDT)	TSTE	IEEE	Canada	55	55	55
111	[133]	Das et al. (2019)	https://doi.org/10.1016/j.enconman.2019.01.107	Loss of load probability, Off-grid hybrid RES, Net present cost (NPC)	ENCONMAN	Elsevier	India	53	53	53
112	[134]	Yan et al. (2019)	https://doi.org/10.1109/TSG.2017.2788440	BESS, Plug-in electric vehicle, optimal control	TSG	IEEE	United States	53	53	53
113	[135]	Huang et al. (2019)	https://doi.org/10.1186/s41601-019-0126-4	ES, MG, RE, Energy hub, Clustering analysis	PCMPS	Springer Nature	China	52	52	52
114	[22]	Hossain et al. (2019)	https://doi.org/10.1016/j.renene.2019.01.005	RES, MG, PSO, Optimum battery control	RENENE	Elsevier	Australia	51	51	51
115	[136]	Lian et al. (2019)	https://doi.org/10.1016/j.enconman.2019.112027	RES, Hybrid RES, sizing	ENCONMAN	Elsevier	China	48	48	48
116	[137]	Jabarullah et al. (2019)	https://doi.org/10.1016/j.scs.2019.101475	ES, Energy hub, DR, PHEV	SCS	Elsevier	Malaysia	48	48	48
117	[138]	Arani et al. (2019)	https://doi.org/10.1016/j.ijepes.2018.12.040	Aggregated ESS, Distributed ESS, Droop control method, State of Charge (SoC)	IJEPES	Elsevier	Iran	48	48	48
118	[139]	Javed et al. (2019)	https://doi.org/10.1016/j.energy.2019.03.131	Techno-economic assessment, GA, COE	Energy	Elsevier	China	42	42	42
119	[23]	Murty et al. (2020)	https://doi.org/10.1186/s41601-019-0147-z	RES. MG. EM. DR	PCMPS	Springer Nature	India	41	41	41
120	[140]	Xu et al. (2020)	https://doi.org/10.1016/j.renene.2019.09.099	Curtailment rate, Levelized COE, PSO, PV-wind-HSPSI hybrid energy system	RENENE	Elsevier	China	36	36	36

on that specific field. Thus, to develop this detailed literature study of the systems with ESS and MG Application, bibliometric analysis appeared as a valuable tool to analyze a significant amount of scientific data, dividing the evaluation into different scientific areas, countries in which the documents were published and give a clear view on the most influential research ideas in ESS and MG integration.

A. LIST OF 120 MOST-CITED ARTICLES WITH CITATION EVALUATION

In Table 2, the selected top cited 120 articles in the ESS and MG application field have been placed from the database Scopus. From Table 2 and the extraction of data, anyone can receive a broad insight into the most cited papers published by various researchers, publishers, publishing years, and the origin of the country as well as the varieties of research topics. It can be investigated that articles published earlier have had more citations than the recently published articles. To realize the recent technological improvement, as well as development in the optimal algorithm of the energy storage system of MG some hot papers are considered which are published between 2010 to 2020 with average citations per year (ACY) 30 and all these papers, are being presented in Table 2.

The article with the highest citation by Gungor *et al.* was revealed in 2013; however, articles having the second-highest citation by Zakeri *et al.* were published in 2015. From the last four years (2017-2020), highly cited papers are being published in 2017 by Lund, *et al.*, having a citation of 281. Among the latest articles of 2020, the article published by Murty *et al.* (2020) has attained 41 citations. This analysis provides a clear view of older and recent trends of research work in the field of ESS in MG applications.

The most cited paper in the optimal algorithm for ESS in MG Application is ''A Survey on smart grid potential applications and communication requirements'' by Gungor *et al.* (2013), which has been published in ''IEEE Transactions on Industrial Informatics'' with a total of 719 citations [23]. The review article is based on the issues related to the smart grid architecture from the viewpoint of potential applications and the communications requirements needed for ensuring performance, flexible operation, reliability, and economics. The second most cited paper is titled ''Electrical energy storage systems: A comparative life cycle cost analysis'' by Zakeri *et al.* (2015) which focuses on economic aspects of different storage systems for three main applications: bulk energy storage, T& D support services, and frequency regulation [27]. The examined fields were pumped hydro power storage, compressed air energy storage (CAES), flywheel,

TABLE 3. Top ten most used keywords in different articles from 2010 to 2020.

Position	Keywords	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Frequency
1	Energy Storage	[13]	[6,9,19, 40]	[28,48]	[23,31, 38,56]	[25,32, 61,83]	[2,4,15,21,39, 44,57]	[11,14,37,69, 70,71, 1,85],	[29,43, 65,72]	[55]	[103,104,105,108, 113,116,106,117]		43
2	Renewable Energy Resources				[5]	[8,10,12,26, 46,80, 87]	[2,50, 57,62, 84,96]	[14,27, 67,71, 81,85]	[20,29, 72]	[55,92]	[103,104, 105,107, 109,111, 114, 115]	[119]	34
3	Microgrid	[91]	[19,58]	[41]	[5,7, 17,18,23]	[8,22, 26,32 33,79,99]	[15,44, 49,86, 96]	[63,64]	[66]	[89,98]	[101,102, 104,113]	[119]	31
4	Optimization		[19,58, 91]	[28,90]	[3,18]	[26,79]	[15,34, 50,60, 62,94]	[67,76]	[43,68]	[92]	[107,108, 110, 111]		24
5	Energy Management	[91]	[6]	[28,52, 90]	[3,7, 31]	[24,36, 59,78, 82]	[48,50, 84]	[14,27, 63]		[89]	[114]	[119]	22
6	Wind	[13]	[9]		[7,56]	[12,35,46,78, 79,87]	[15,62]	[11,53, 76]		[92]	[109,110, 118]	[120]	20
7	Photo Voltaic			[52]	[7,31]	[32,61, 79,83, 85,87]	[34,39, 62,84]	[53,69, 70]			[112]		17
8	Smart Grid			[52,90]	[1,23,31,38]	[8,33, 79]	[2,4, 96]	[37,93]	[20,66]		[103]		17
9	Demand Response			[90]	[1]	[25,99]	[21,50, 94]	[64]	[68]	[89]	[113,116]	[119]	13
10	Distributed Generation		[19,91]		[5,23]		[84]		[66,88]				7

electrochemical batteries (e.g., lead-acid, NaS, Li-ion, and Ni-Cd), flow batteries (e.g., vanadium-redox), super conducting magnetic energy storage, super capacitors, and hydrogen energy storage (power to gas technologies). The paper was published in Elsevier with a citation of 717. The article in the third position, according to citations, is a review article on electric vehicle energy management and energy sources published in "Renewable and Sustainable Energy Reviews" in 2013 [28]

Fig. 3 illustrates the distribution of the top-most cited 120 articles in the field of ESS and MG application between 2010 and 2020. It can be observed that from 2010 to 2014, there was an upward trend in the number of highly cited article publications, and it reaches a peak in 2014 with 25 articles. Then, from 2014 to 2018, the number of highly cited articles dropped sharply, and it was 5 in 2018. Again, 2019 saw a dramatic rise in the number of top-most cited articles with 18 articles, and in 2020 it falls to 2. So, it can be observed that with the increase of article age, the rate of citations in a particular article also tends to increase. However, while constructing the top cited list, we only considered the article which had the ACY more than 15 to realize the recent technological improvement, as well as development in the optimal algorithm of the ESS n MG applications. Therefore, since articles published earlier have had more citations than the recently published articles but in terms of ACY the recent article had the more average citations rate as most of the limitations and gaps of the previous papers have been addressed in the recent articles.

B. BIBLIOMETRIC EVALUATION OF CO-OCCURRENCE KEYWORD

Fig. 4 and Table 3 determine the bibliographic representation of the most frequently used keywords from the top-most mentioned 120 articles elected from the largest database Scopus. A software VOSviewer has been utilized to form the figure where all the keywords are connected through a network. The circle and its label show the influence of the keywords, and the connective line within the keywords determines the connection.

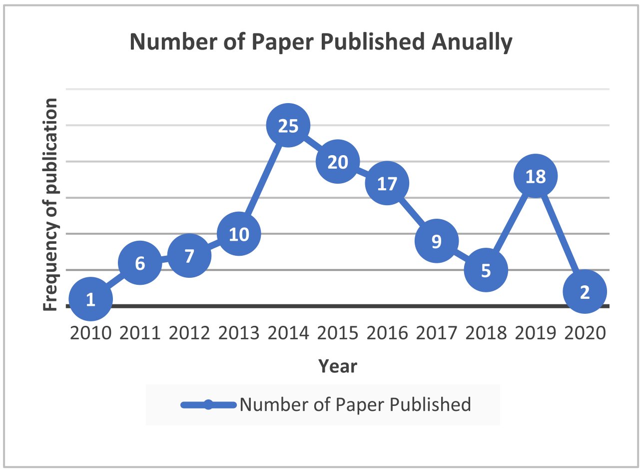

FIGURE 3. Top 120 most-cited articles distribution (2010-2020).

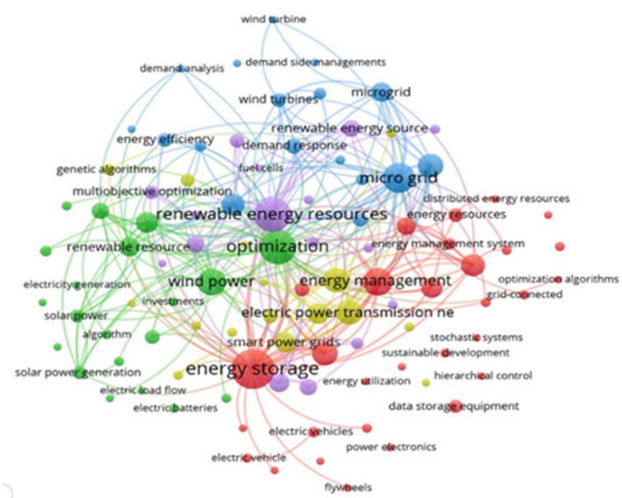

FIGURE 4. Most frequently used keywords network in ESS of MG applications from the database Scopus.

According to the knowledge of the study, various colors are utilized to present several cluster groups. It can be seen that the green cluster combines renewable resources, wind power,

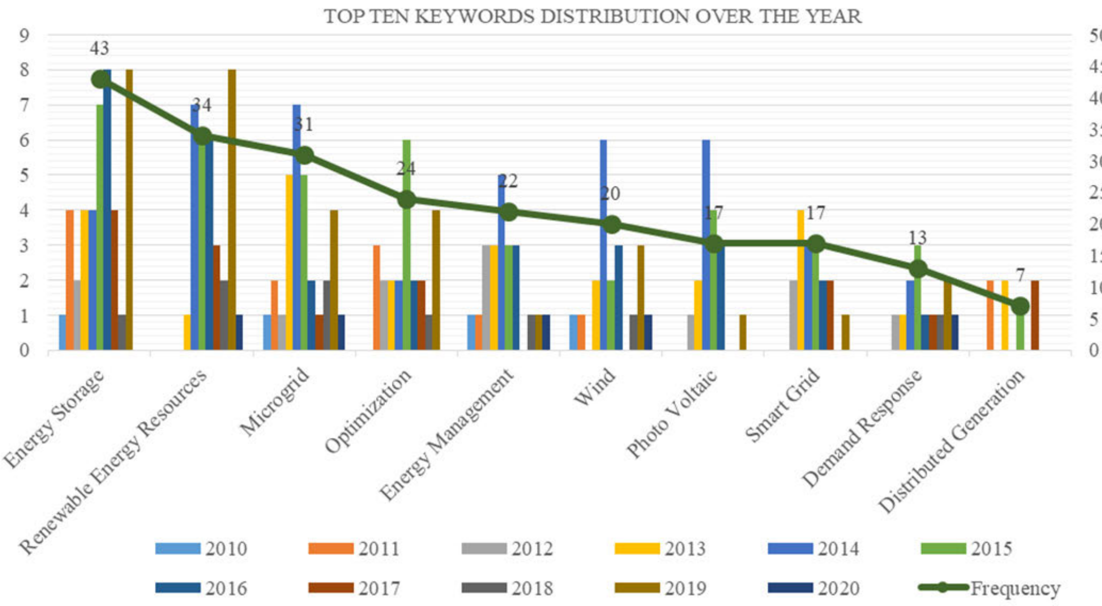

FIGURE 5. Top 10 keywords distribution over the year 2010 to 2020.

solar power, and optimization defines powerful bonding among them in publications. The energy storage, energy utilization, energy management, electric vehicles, power electronics are directly related to each other and are in the red cluster. The blue cluster represents MG, demand response, energy efficiency, demand-side management, which leads to economic analysis. However, the electric power transmission, smart power grids, and genetic algorithms are presented in the yellow cluster, which greatly impacts the transmission system. Finally, renewable energy resources, fuel cells, and multi-objective optimization are in the purple cluster which aids energy systems more economical and eco-friendlier.

The top 10 most used keywords from the selected articles have been presented in Table 3 within the year 2010 to 2020. The main reason for this analysis is to conceive the recent research trends in the field of Optimal Algorithm for Energy Storage Systems in MG Application. The most used keyword is "Energy Storage", followed by "Renewable Energy Resources" and "Microgrid". The figures are 43, 34, and 31 respectively. "Energy Management", "Demand response", and "Optimization", which are closely related to each other, have paid more attention in recent years. The detailed representation of the top 10 keywords shown in Table 3 is graphically represented in Fig. 5.

C. BIBLIOMETRIC EVALUATION OF HIGHEST LAST FIVE YEARS CITATION AND STUDY TYPE

Based on the highest citation obtained in the last 5 years top 10 articles with ACY have been presented in Table 4. The first article titled "Electrical energy storage systems: A comparative life cycle cost analysis" by Zakeri *et al.* (2015) has received the last 5-year citations (629), with the highest ACY (143.4), which holds 2nd position in the list of top-cited articles followed by Lund *et al.* (2015) holds the second position with 541 citations in the last five years. However, the article which ranked 1st position in the list of top-cited articles shown in Table 2 holds 4th position in the highest last 5-year citation list with 431 citations. From Table 2 and 4, it can be pointed that nowadays, researchers focused on energy management and cost analysis for the development of ESS in grid applications which have more citations and ACY than the ordinary ESS constructions.

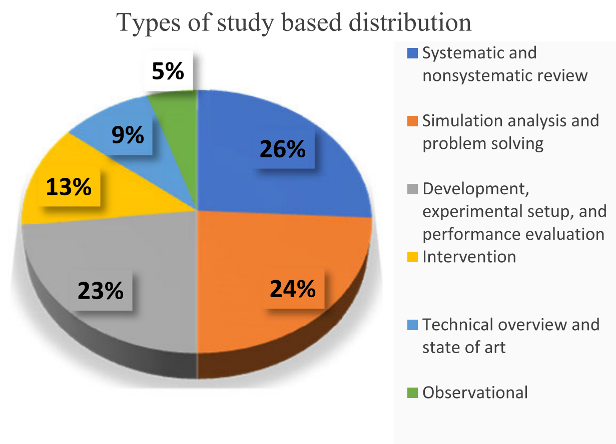

FIGURE 6. Top cited article distribution based on types of study.

Regarding the types of study, the allocation of the chosen top-cited articles is presented in Table 5 and Fig. 6. The systematic and non-systematic review holds the highest percentage of articles (26%) among the selected articles, followed by the Problem formulation and Simulation Analysis (24%)

TABLE 4. Top ten articles based on "most last 5 years Citations."

Rank	Ref.	DOI Number	Keywords	Last 5 years citation	Rank in the top-cited list	ACY
1	[40]	https://doi.org/10.1016/j.rser.2014.10.011	BES, Cost of ES, Electricity Storage, smart grid, Electricity Market, RE integration	629	2	143.4
2	[42]	https://doi.org/10.1016/j.rser.2015.01.057	DSM, ES, Electricity market, Smart grid, Energy system flexibility, Ancillary service	541	4	119.6
3	[41]	https://doi.org/10.1016/j.rser.2012.11.077	EV, EM, Hybrid EV. Supervisory Control, Optimization, Drive cycle	466	3	95
4	[39]	https://doi.org/10.1109/TII.2012.2218253	DR, Smart Grid Communications, Advanced Metering Infrastructure (AMI)	431	1	102.7
5	[43]	https://doi.org/10.1016/j.rser.2013.03.067	AC MG, DC MG, MG control, MG protection, RES	418	5	83
6	[46]	https://doi.org/10.1109/TSG.2013.2280645	MG, plug-in electric vehicle (PEV), RE, smart grid	334	8	67.2
7	[48]	https://doi.org/10.1109/TSTE.2015.2467383	Combined heat and power dispatch (CHPD), ES, Wind	330	11	84.2
8	[45]	https://doi.org/10.1109/TSG.2012.2231440	Demand-side management, EM, MG, PV, Wind	322	7	66.3
9	[51]	https://doi.org/10.1016/j.rser.2016.03.047	Home EMS, RE	311	14	79.2
10	[44]	https://doi.org/10.1109/TSTE.2011.2157540	EM, ES, RE	310	6	57.9

and development, experimental setup, and performance evaluation (23%). From the table, a strong co-relation has been found among the frequency of publication in different studies, citation range, and the range of the year. Simulation analysis and problem-solving are the most influential type of study where 29 articles were published throughout the year from 2010 to 2020 with a range of citations of 55-717.

Thus, it can be observed that review (systematic and nonsystematic), problem-solving, and simulation types of study are the dominant article holders in the top-cited article list.

TABLE 5. Number of articles based on study types.

Study Type	Frequency of publications	Year limit	Citation limit
Systematic and nonsystematic review	31	2011-2019	48-665
Simulation analysis and problem-solving	29	2010-2020	55-717
Development, experimental setup, and performance evaluation	28	2012-2020	53-464
Intervention	15	2011-2019	51-324
Technical overview and state of art	11	2013-2019	53-431
Observational	6	2015-2017	134-210

D. BIBLIOMETRIC EVALUATION OF SUBJECT AREAS AND DISCUSSION ON THE HOT TOPIC

The presentation of the top 120 most cited articles about the different subject areas is illustrated in Table 6. The researcher can be obtained a clearer insight into the focus of the recent study area from Table 6. "Microgrid" contains the highest percentage (19.17%) of articles with a citation range (103-581), followed by 15.83% of articles on "Energy storage system (ESS) development". "Energy management system of ESS integrated microgrid", "Optimal allocation, economic analysis, and sizing of ESS", and "Renewable energy system development" are the subject area contained an almost same percentage of articles; the figures are 10%, 9.17%, and 8.33% respectively. However, only 1.67% of articles were published on the areas such as "Optimal allocation and sizing of MG", "Environmental impact of grids", "Building energy development", and "Distributed generation (DG) system planning, optimization, and control".

It is demonstrated that from the selected articles, a sum of 26.67% of articles was listed on the grid, MG, and smart grid development. A survey on communication requirements and application of smart grid by Gungor *et al.* [35] and a review on

AC-Microgrid compare to DC-Microgrid by Justo *et al.* [30] are the top 2 articles among the top 5 most cited manuscripts with 1300 citations. Several articles have investigated several points of view of the MG, grid, and smart grid development, for instance; scheduling MG [122],to minimize the power losses and operational cost during addressing the intermittent nature of RES [33], the control strategy of MG [56], [75], [115], and multi-objective particle swarm optimization (MOPSO) method for MG [69]. Different approaches and management strategies are introduced to the smooth operation of the grid or MG [42], [46], [64], [77]. New approaches and management such as; rolling horizon strategy [32], game-theoretic approach [60], consensus and innovations approach [83], and metaheuristic optimization approaches [131] are introduced. Several surveys and reviews are also carried out to highlight the critical issues in smart grid technologies [114], future trends and electrical power demand forecasting in MGs and smart grids [57], and the optimization technique in MGs integrated hybrid energy systems [40]

ESS development is one of the common fields of study which include cooperative or coordinated control of distributed ESS in MG [67], [98], alleviate power fluctuation control strategy based on improved partial swarm optimization [129], and economic allocations and real-time simulations [38], [80], [91]. Several energy storage technologies, hybrid ESS as a transportation application, comparative

TABLE 6. Distribution of highly cited articles based on subject areas.

Subject Area	Articles covered based on Table 2	Publication frequency	Range of Citation
Microgrid development	[5,7,8,15,17,22,23,30,32,41,42,46,47,53,60,64,74,78,86, 95,96,99,101]	23	103-581
Energy storage system (ESS) development	[2,11,13,16,29,44,57,58,65,68,71,72,77,81,85,104,107, 108, 117],	19	48-717
Energy management of ESS integrated MG	[14,21,28,37,49,63,82,89,90,91,114,119]	12	41-317
Optimal allocation, economic analysis, and sizing of ESS	[9,19,24,39,48,55,75,106,109,113,120]	11	36-377
Renewable energy system development	[6,10,27,50,62,67,84,100,105,115]	10	48-521
Grid and smart grid development	[1,33,36,52,54,66,93,94,111],	9	53-719
Photovoltaic (PV) integration and development	[31,34,38,40,61,70,79]	7	142-210
Variable renewable electricity development (wind, solar)	[4,12,35,56,87,110,118]	7	42-598
Electric vehicles (EV) development in transportation	[3,45,59,69,80]	5	142-665
BESS integration and development	[18,43,76,83,112]	5	53-290
Smart energy system development	[20,73,97,98]	4	131-281
Optimal allocation and sizing of MG	[26,92]	2	134-231
Environmental Impact of grids	[102,103]	2	77-89
Building energy development	[25,116]	2	48-233
Distributed generation (DG) system planning, optimization, and control	[51,88]	2	136-167

life cycle cost analysis, recent developments, design and control methods, and hybrid ESS in MG application are presented in several review articles [27], [41], [53], [88], [102], [106], [125], [136]. From the selected database, 4.17% of manuscripts were on BESS integration and development include economic and reliable operation of standalone MGs taking into account the lifetime characteristics [43], feasibility study of an islanded MG [97], and voltage stability and energy loss of commercial distribution systems with the integration of PV [104]. A review on lithium-ion battery storage is also discussed to provide an insight into the operation, system design, and the selection of economical battery technologies to find a particular system application [66].

Optimal allocation, economic analysis, and sizing of ESS are some promising areas of study, essential for better execution of an MG at the minimum feasible cost, including 10.83% of manuscripts from the selected papers. From the topmost cited manuscripts, several optimization algorithms are presented to reduce expense [25], [48], [62], [96]. New algorithm and strategies, for example, genetic algorithm [71], real-coded genetic algorithm [2], artificial neural network control strategies [34], and multi-objective particle swarm optimization (MOPSO) and weighted sum approach (WSA) [139] is introduced. Optimal placement, control, demand response, and size determination are also reviewed in several manuscripts [78], [127], [133].

Due to the sharp advancement of power electronic technologies, Electric Vehicle (EV) has paid great attention to the researcher as one of the potential GHG solutions. From the selected list, different issues and challenges are presented for the development of EV technologies such as; optimal charging scheduling of EV considering the price of the power grid and uncertain electric vehicle integrated local RES [101], home energy and EV scheduling optimized jointly for the customer preference [82], design EV charging station for workplaces [92], and power management for hybrid ESS integrated plug-in hybrid EV [68]. A review of storage devices, management strategies of low-level energy control, energy sources, control algorithms, and power converters used in electric vehicles technologies is also discussed [28].

Renewable energy resources such as; solar photovoltaic and wind are clean and sustainable energy sources have become one of the major field of study. In [88], battery life time improvement in a small scale wind power system using hybrid energy storage system (battery/supercapacitor) was proposed and hardware implementation and supervising control algorithm was also introduced for long-term benefit. In [49], HOMER software was introduced to perform the techno-economic evaluation of a stand-alone hybrid solar-wind-battery system. Hybrid renewable energy system management strategies, challenges associated to integrated renewable energy system based power generation, hybrid energy systems, operation of hybrid renewable power system, mathematical modeling of hybrid RES, and sizing methodologies of hybrid RES are presented in different review articles [47], [61], [93], [111], [114], [136]. Two-stage mixed-integer linear programming approach for multi-energy system planning [128], stochastic/information gap decision theory (IGBT) approach for short-term scheduling of wind turbine [132], and genetic algorithm for the techno-economic assessment of hybrid solar-wind-battery system [139] were introduced. Therefore, it can be concluded that the above discussion based on the hot topics associated with the optimal ESS algorithms from the top 120 most cited list can offer detailed knowledge for the further researchers which can lead to the advancement and development of the latest technology in this field.

E. EVALUATION OF PUBLISHER, COUNTRY AND JOURNAL IMPACT FACTOR AND REVIEW DURATION

Between the chosen articles, IEEE and Elsevier published 92% of the manuscripts within the defined highest cited articles. Most of the articles were published by Elsevier (56%) whereas 36% were published in IEEE. Among the rest of the 8% articles, 3% were published by the Institution of Engineering and Technology, 3% in Nature, 2% in Multidisciplinary Digital Publishing Institute (MDPI), and 1% in Aalborg University Press. Fig. 7 demonstrates the different publisher's charts where the top-most 120 cited articles were published.

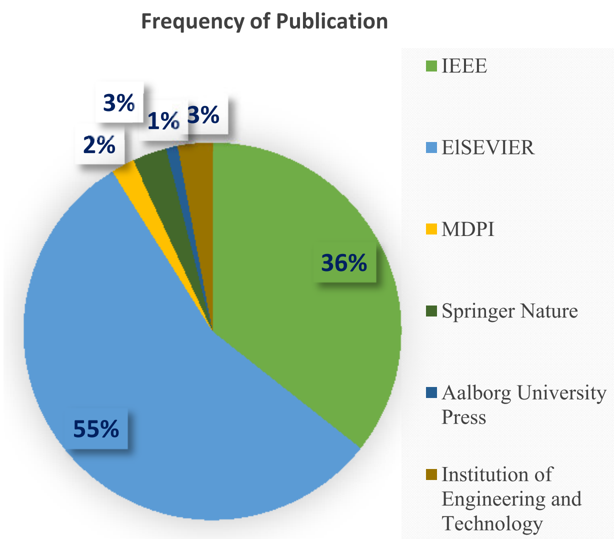

FIGURE 7. Distribution of articles based on the publisher.

Fig. 8 provides the distribution of the highest cited articles chosen from the database Scopus based on a different region. The top-most cited 120 articles are originated from 27 different countries. From the figure, China has published the most significant number of articles with 25 publications. The United States of America (USA) was the second leading country with 12 publications, followed by IRAN with 11publications. India and Malaysia are respectively in 4th e of papers of 7 and 6 among these selected highly cited 120 papers. Thus, it can be concluded that nowadays, researchers tend to develop articles on ESS in MG applications concerning the optimal sizing, placement, cost analysis, and management of energy rather than the chemistry of battery construction as shown in Table 4-6. Moreover, review articles paid more attention to the new enthusiast researchers due to a large amount of information in a specific field.

Fig. 9 illustrates the frequency of articles revealed in 30 different journals, journal impact factors, and the reviewing duration of a journal (weekly based). The 120 manuscripts chosen for the bibliometric analysis were published in 30 different journals with an impact factor ranges from 0.94 to 25.249 (Journal Citation Report JCR-2021) and reviewing duration ranges from 1 week to 33 weeks.

The journal with the highest number of manuscripts cited was "Renewable and Sustainable Energy Reviews", with 25 publications has the impact factor 14.982 takes 12 weeks for reviewing. "IEEE Transactions on Smart Grid" is the second-highest contributor with 16 publications, followed by "Applied Energy" with 15 publications takes time to review 12.9 weeks and 4 weeks respectively. However, "Energy Conversion and Management" and "IEEE Transactions on Sustainable Energy" contain 8 and 7 articles, respectively. Other journals having a number of publications were IEEE Transactions on Industrial Electronics and Renewable Energy (both having 6 publications). The rest of the 22 journals published only 36 articles from the selected 120 top-cited papers. The highest IF 25.249 obtained by IEEE Communication Surveys and Tutorials with the frequency of publication is only 0.83% takes 10 weeks for reviewing. However, the lowest IF 0.94 obtains by IEEE Power and Energy Society General Meeting with the same publication rate takes 12.8 weeks for reviewing. According to the number of publications, the top 5 journals published 60% of articles from the 120 most cited articles with impact factors ranges from 7.917 to 14.982. Fig. 9 shows that the most of the promising journal based on impact factor more than 7 such as; IEEE Power and Energy Society General Meeting, Renewable and Sustainable Energy Reviews, IEEE Transactions on Industrial Informatics, IEEE Control System, IEEE Transactions on Sustainable Energy, IEEE Transaction on Smart Grid, IEEE Transactions on Industrial Electronics, Renewable Energy, and Energy takes more than 10 weeks for reviewing. Whereas, Energy Conversion and Management, Protection and Control of Modern Power Systems, Sustainable Cities and Society, Energy, and Applied Energy are also the top listed journal takes time to review less than 6 weeks. Therefore, the analysis of the journal impact factor and journal reviewing duration will help various enthusiastic researcher to find out the most suitable journal to publish their research article in this specific field of study.

F. BIBLIOMETRIC EVALUATION OF PROMINENT AUTHORS AFFILIATIONS

Among the selected 120 most cited articles in the field of the optimal algorithm of ESS in grid applications, 10 authors were the highest-profile who has published more than two articles with a total of 29 articles shown in Table 7. The authors were from 8 different institutions and 6 countries listed as 1st author 7 times, co-author 20 times, and corresponding author 2 times. In the most profile author list, Tao Ma from the Shanghai Jiao Tong University, China, contributes the highest 5 articles, followed by Josep M. Guerrero from Aalborg University, Denmark with the highest h-index 114 contributes 3 articles. From the table, the highest number of authors (4) were from the USA whereas Hong Kong

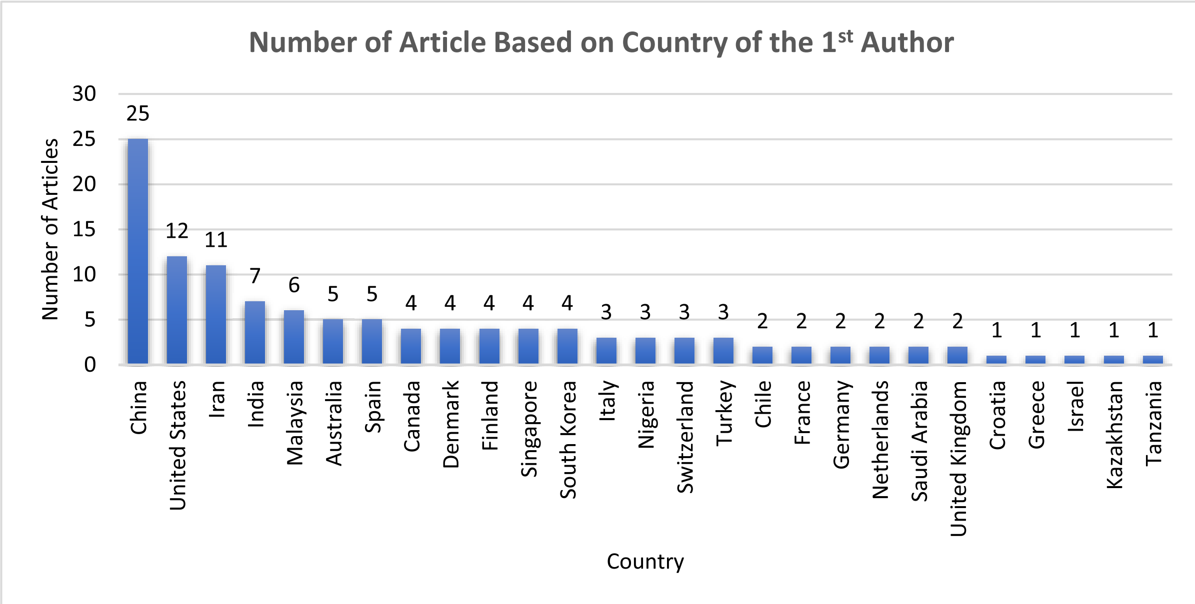

FIGURE 8. Country of the 1st author in which the 120 highly cited articles are published.

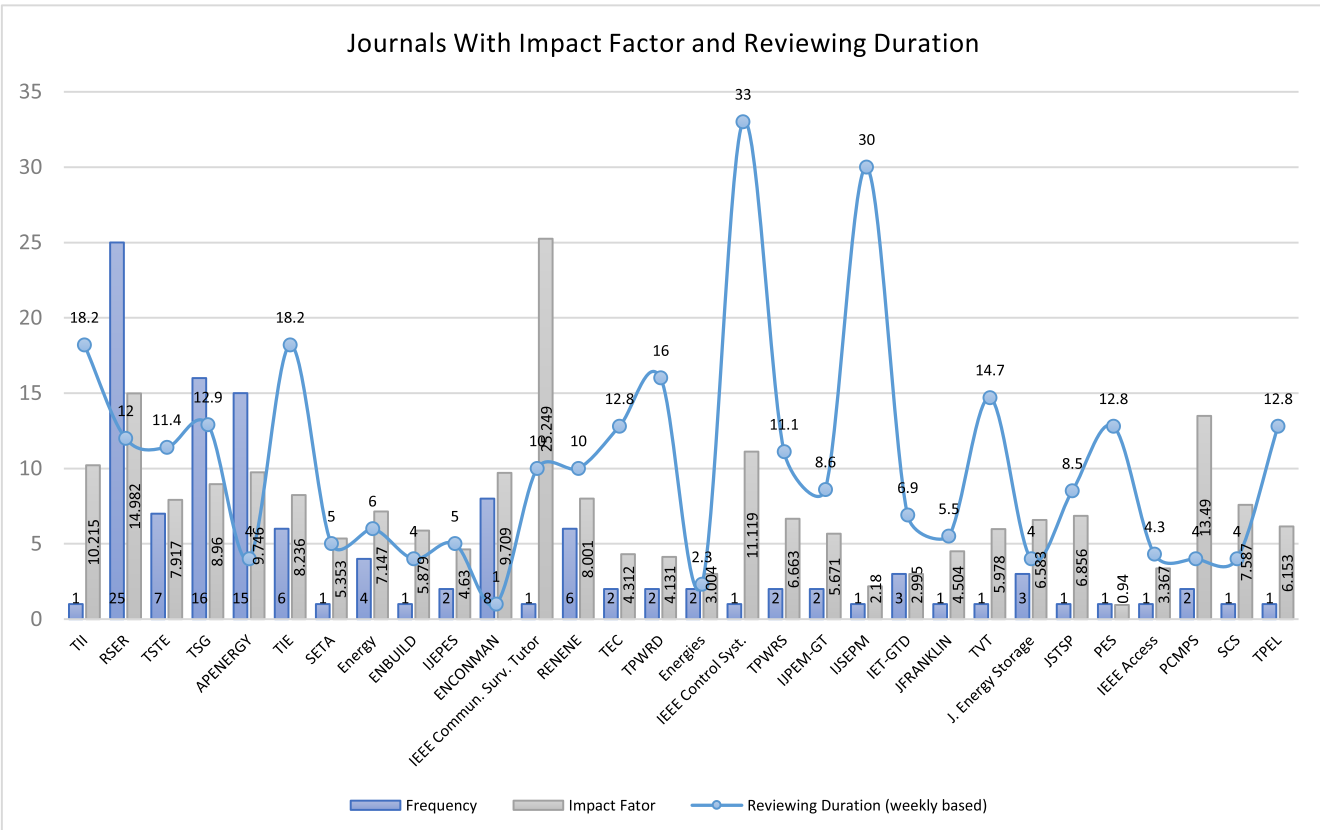

FIGURE 9. Journal in which the top 120 articles are published with impact factor and reviewing duration.

has 2 authors. The Hong Kong Polytechnic University, Hong Kong, and Carnegie Mellon University, USA, both institutions published the highest number of articles (6) in the most prominent author list. Therefore, the most prominent authors in the field of ESS in MG application have h-index ranges from 18 to 114.

The strategies of research among the researcher are different from each other. For example, Tao Ma mainly focuses on

TABLE 7. The 10 most prominent author's affiliation with 2 or more papers.

Rank	Name of the author	Present institution	Country	Frequency of Article	Citation	h-index	Position in the list of authors
1	Tao Ma	School of Mechanical Engineering, Shanghai Jiao Tong University	China	5	15569	61	1st author (n= 4) and Corresponding author (n=1)
2	Josep M. Guerrero	Aalborg University	Denmark	3	68403	114	Co-author in all 3 papers (n=3)
3	Saad Mekhilef	Department of Electrical Engineering, University of Malaya	Malaysia	3	29404	82	Co-author (n=2) and Corresponding author (n=1)
4	Hongxing Yang	The Hong Kong Polytechnic University	Hong Kong	3	19115	64	Co-author in all 3 papers (n=3)
5	Lin Lu	The Hong Kong Polytechnic University	Hong Kong	3	12970	53	Co-author in all 3 papers (n=3)
6	Soummya Kar	The Department of Electrical and Computer Engineering, Carnegie Mellon University	USA	3	9904	45	1st author (n=1) and Co-author (n=2)
7	Gabriela Hug	The Department of Electrical and Computer Engineering, Carnegie Mellon University	USA	3	5690	36	1st author (n=1) and Co-author (n=2)
8	Zhu Han	University of Houston	USA	2	50090	111	Co-author in all 2 papers (n=2)
9	Jianhui Wang	Southern Methodist University	USA	2	29693	87	Co-author in all 2 papers (n=2)
10	Manuela Sechilariu	Alliance Sorbonne University	France	2	2064	18	1st author (n=1) and Co-author (n=1)

a stand-alone hybrid solar-wind- battery system for remote islands [25], [37], [137]. He also developed two articles on standalone photovoltaic generation system based on pumped storage [58], and on the sizing of PV-wind- battery system [59]. Jossep M. Guerrero published 3 articles which are optimal power flow control in MGs integrated energy storage [47], a survey on distributed generation for MG applications [54], and a review on MG energy management and controllers [86]. An analysis of optimization of MG system [69] and two review articles one is on hybrid renewable energy management strategies [51], and another one is on power fluctuations of PV mitigating methods [93] are developed by Saad Mekhilef from the University of Malaya, Malaysia.

After analyzing the 120 most cited papers for the bibliometric study from the selected Scopus database, it can be concluded that "review" type articles have gained tremendous popularity among the researchers as compared to "development, simulation, and problem-solving" type of articles. This is because of the accumulation of a high range of data and the rate of citation. Nowadays, the researcher is showing their eagerness to develop ESS systems in grid application, and renewable energy system more. Cost is one of the key factor that interruption the optimal algorithm of ESS in grid application, however, different optimization techniques to reduce the cost is presented in several manuscripts [2], [27], [50], [62], [111], [119], [123], [132]. Several review articles are presented from the researchers addressing the field of study related to MG development, electric vehicle as transport application, photovoltaic integration and development, and environmental impact on grids.

During this bibliometric study, some limitations should be noted; First of all, for the selection of highly cited 120 articles, only the Scopus database is chosen, which is closely complex while Google Scholar or Web of Science are considered for the suggestions of future research. Secondly, the article within the year range between 2010 and 2020 are selected for constructing the top-most cited list to understand the flows of current research. Thirdly, only the English language is chosen while other languages are excluded, which causes a global impact. Finally, the specific subject area that fulfills the criteria of inclusion is considered. The aggregation and conjunction with in various fields of study confused the adjustment of a specific field. For example, the field of studies such as the ESS technology in Mg applications are included whereas electrochemical, battery chemistry, and internet of things are excluded. Nonetheless, regardless of the limitation, citation analysis is one of the useful valuable methods used in several disciplines to evaluate article academic importance.

V. CHALLENGES AND RECOMMENDATIONS

The optimal algorithm of ESS is highly dependent on the appropriate location and size of the storage for the development of MG. Many issues and challenges with feasible solutions are presented, such as difficulties of supplying electricity in remote areas, dependency on fossil fuel, EV in transportation systems, and overall cost reduction. The presentation of the most relevant difficulties on ESS in MG application is discussed below.

A. ELECTRIFICATION IN REMOTE ISLAND

Battery energy storage systems and MGs with renewable sources play a crucial role in supplying electricity in remote areas and islands [55]. Because of the reliability issues and economic factors, it is difficult to enhance the main power grid to remote areas or far-separated islands, which obstacles those islands' economic development, such as fisheries, tourism, etc. [141]. To solve the above issues, MGs with renewable sources and ESS are widely developed and accepted systems to solve the power supply problems in the far-separated islands [142]. For example, a stand-alone hybrid system with solar-wind battery for a remote island is introduced for the techno-economic feasibility of fulfilling the system to supply the remote island [49], [139]. Solar-wind systems with pumped hydro storage are also introduced to supply an island in Hong Kong [69].

B. REPLACEMENT OF FOSSIL FUELS INTO RENEWABLE SOURCES

This bibliometric study critically presented that renewable energy integrated with ESS in MG application replaces the traditional fossil fuel sources with renewable energy sources such as solar and wind, which are intermittent and variable in nature [143]. The efficient use of renewable energy is crucial to MG's economic, stable, and reliable operation, which is quite challenging. Many steps have been taken to solve this problem to the optimal design, development, and operation of MG systems. For instance, In [46], a stochastic problem for MG energy scheduling is formulated to highlight the operational challenges regarding energy resources and technologies. Despite the intermittent and variable nature of RE, power losses and operational costs are minimized. One of the points focuses is the optimal allocation and sizing of ESS in MG for achieving economic analysis are also presented [25], [26], [29]. The issues and challenges of ESS technologies in MG applications are reviewed in [144].

C. EV IN TRANSPORTATION

ESSs integrated with RE in EV applications play an essential role in reducing the use of conventional oil, GHGs, and CO_2 emission. However, the smooth operation of EV technologies still has many issues and challenges such as; power electronic interface, availability of raw materials, energy managements, safety measurements, and sizing and cost [145]. To solve the above issues, several studies have been presented. Reusing, refurbishing, and recycling of ESS materials are considered for the present and future research prospective and concerning the environmental issues and advancement of tertiary-level applications [146]–[148]. Power electronic interfaces are needed to support the EV technologies from performance reduction, unexpected damages and explosions, power loss, life cycle durations, and size and costs [41], [149]. In order to optimize efficiency and energy economy, modern EV system are developed to highlight the effective and intelligent management of all energy resources [41].

D. OVERALL COST REDUCTION

One of the critical targets of ESS integrated with RE in MG applications is to reduce the overall system cost, that is maintenance, capital, and overall cost. Proper energy management and demand response (DR) is highly focused on minimizing the overall cost. Several algorithms have been considered to solve the mention challenges. In [30], a hybrid multi-objective particle swarm optimization (HMOPSO) is presented to minimize the cost of the power system and improve the voltage profile of the system considering the uncertainties of wind power generations. A combination of ESS and MG associate with the DR model is responsible for the reduction of the overall cost presented in [22], [23], [82], and [135].

VI. CONCLUSION

The purpose of citation evaluation within a certain field and journal is nothing but an ideal way to measure the influence of a journal, author, or article. Considering all the limitations mentioned earlier, the status of a citation could gleam the academic influence of an article. The purpose of this study is to present, analyze, and classify the feature of the 120 top-cited manuscripts revealed in optimal algorithms of ESS in MG applications. In addition, several studies have been presented such as, the bibliometric evaluation of the co-occurrence keywords, most prominent authors, journals, publishers, countries that published the most cited manuscripts, and articles distribution in terms of the type of study and subject area. The final objective of this study is to highlight the latest research trends and offer an insight into the advancement and development in the optimal algorithm of ESS in MG applications. Several benefits have been found by determining the behavior of the top-most cited articles such as:

- The findings from the study of the 120 most prominent articles in optimal algorithms of ESS in MG applications can offer detailed knowledge to future researchers.
- The various enthusiastic researcher can be motivated with the flows of current research set by the feature of the top-most cited manuscripts, which can lead to the advancement and development of the latest technology in this field.
- The bibliometric study and analysis of the top-cited manuscripts can effectively find an effective collaborator and provide a clearer view to the researchers regarding the influential journal to present their research manuscripts.
- The evaluation presented in this study can help the policymakers and government officials develop a long-term policy and further directions for future research pertaining to the economic and financial goals of a country.

However, it is expected that selecting, analyzing, and reviewing those highly cited articles from 2010 to 2020 will support the researchers for further research in the area of optimal algorithms of ESS in MG applications.

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