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Grid-connected lithium-ion battery energy storage system: A bibliometric analysis for emerging future directions

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ABSTRACT

The lithium-ion battery energy storage systems (ESS) have fuelled a lot of research and development due to numerous important advancements in the integration and development over the last decade. The main purpose of the presented bibliometric analysis is to provide the current research trends and impacts along with the comprehensive review in the field of the grid-connected lithium-ion battery (LIB) ESS within the year 2010–2021. The research has been performed using refined keyword searches on grid-connected LIB ESS in the Scopus database and the data of the top 100 highly cited articles were extracted. The research trend has shown that the grid-connected LIB ESS literature has increased substantially between 2016 and 2021, compared to the period 2010–2015. The bibliometric analysis consists of detailed keyword co-occurrence network analysis, co-authorship map, distribution of articles over countries, journals, research types, and subject categories. The evaluation of highly cited articles identifies numerous aspects, including methodologies and systems, issues, and challenges, to determine existing constraints and research gaps. The process of deciding, developing, and evaluating the highly cited articles, is expected to contribute to a methodical foundation for potential progress of grid-connected LIB ESS, as well as identify emerging pathways for future researchers. This study may act as a guideline providing future directions towards improving energy efficiency, environmental sustainability, reliability, and flexibility of the LIB ESS integrated power system.

1. Introduction

Energy consumption is increasing all over the world because of urbanization and population growth. To compete with the rapidly increasing energy consumptions and to reduce the negative environmental impact due to the present fossil fuel burning-based energy production, the energy industry is nowadays vastly dependent on battery energy storage systems (BESS) (Al-Shetwi et al., 2020). Different combinations of renewable energy sources (RESs) and energy storage devices are integrated which can either be used as a standalone system often called off-grid (Chowdhury et al., 2020) or grid-connected system (Dehghani-Sanij et al., 2019). Due to the variability and less predictability, grid integration of the renewable sources may pose a threat such as high-RES penetration, voltage, and frequency regulation towards grid's stability and reliability. This can happen particularly where RESs are widely used (Stroe et al., 2017). To mitigate these problems, a BESS is considered as the potential solution because of its efficiency, fast response time, long lifetime, and less impact on the environmental (Hannan et al., 2021; Zamee and Won, 2020).

Energy storage (ES) at the grid level is critical for balancing power output and consumption (Chen et al., 2020). Electricity consumption fluctuates on a daily, seasonal, and even ad hoc basis. Furthermore, there is a significant peak-to-valley fluctuation between day and night. The electricity fluctuation may have a greater effect if the PV penetration to the grid is high. It may cause excess energy generated during the day and being unable to fulfill the demand at night may cause the grid unreliability. As a result, peak shaving and load leveling are required to store generated power and provide unoccupied power during peak

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loads. Because of the advantageous properties in terms of energy efficiencies, energy and power density, and lifespan, Li-ion Battery (LIB) is considered one of the most potential BESS technologies (How et al., 2020; Peters et al., 2017). The first application of LIB was documented in 1991 by Sony, a multinational conglomerate company and 20 years later the production has reached two billion cells per year for various applications (Gallo et al., 2016). Various researchers have developed different sizing and control algorithms (Mesbahi et al., 2017; Rurgladdapan et al., 2012), life prediction modeling (Smith et al., 2017), state of charge estimation (How et al., 2020) of LIB ESS. The application of the LIB ESS is also varied such as; Electric vehicle (EV) application (Hannan et al., 2020), Hybrid Renewable Energy Storage (HRES) System (Marchi et al., 2016), Microgrid (MG) application (Peters et al., 2017), and frequency regulation and peak shaving (Chen et al., 2020).

Evaluation of the scholarly impact of published articles with higher citation in a particular field is becoming increasingly important. (Reza et al., 2021). The frequency of citations obtained is widely used as a metric for assessing the effect of individual works on a field of study. It can be concluded that the increasing amount of citation indicates a substantial degree of significance. As a result, recognizing the highly cited articles might assist in identifying "exceptional" contributions in a subject and highlighting topics for further research (Wali et al., 2021). Bibliometric analysis of the most referenced publications in various disciplines has been presented in numerous studies during the previous decade. The bibliometric study defines as the branch of study concerned with the statistical assessment of all forms of information using computational and scientific methodologies (Reza et al., 2021). Moreover, bibliometric analysis has shown to be a viable approach for a critical and systematic analysis of the existing literature in different fields of research (Cabeza et al., 2020). Bibliometric analysis of the highly cited publications in various disciplines has been published in numerous studies during the previous decade such as; thermal management in electric batteries (Cabeza et al., 2020), Thermal energy storage systems (TESS) (Calderón et al., 2020), the smart control application of TESS (Tarragona et al., 2020), economies and sustainability assessment in wastewater treatment (Furness et al., 2021), ESS integration in grid decarbonization (Reza et al., 2021), BESS integration with RE sources (Wali et al., 2021), economical aspect of solid waste management (Tsai et al., 2020), TESS application in the built environment (Borri et al., 2021), current advancements in the field of liquid air energy storage (LAES) (Borri et al., 2020), and thermochemical conversion of plastics (Khatun et al., 2021).

In this regard, the study is conducted on the assessment of the currently published research articles in the field of grid-connected LIB ESS. However, no such bibliometric analysis was found to be conducted in the field of grid-connected LIB ESS. Therefore, the main goal of this research is to utilize bibliometric research to assess and distinguish the various methods developed for determining issues and challenges, hence identifying the extremely impactful research in the field of grid-connected LIB ESS. The key contributions of the research are: providing detailed information and analysis of the highly cited articles on grid-connected LIB ESS, highlighting the existing research gaps, issues, and challenges to develop an efficient LIB ESS with a real-time applications. Also, few potential recommendations are provided for future research based on the discussion and evaluation of the current research trends.

2. Method of study

A bibliometric approach is employed to evaluate this research, which is considered a globally recognized scientific approach. A bibliometric analysis is defined as the statistical method which is applied to analyze the scholarly literature focused on metrics including citations (Cabeza et al., 2020). This research aims to extract the key features of the articles with the maximum number of citations and to deliver insight into the evaluation of grid-connected LIB energy storage systems. To obtain the research goal, initially, a dataset of the top hundred highly cited articles has been formatted (as shown in Table 1) through an extensive search from the Scopus database. After that, data such as highly cited articles for the last 5 years, subject and study type, articles published in journals or conferences and their impact factors, and most prolific authors were extracted to develop the analysis and find out the research gap in the research field. The overall system process is shown in Fig. 1.

2.1. Surveying methodology

To study more about the current state of research in the grid-connected LIB ESS, an extended search on the Scopus database was performed on the 2nd week of April 2021 to obtain the articles based on the citation. Different search filters were applied to the database to obtain the selected 100 article dataset. Firstly, the keywords such as, "Energy storage system", "Li-ion", and "grid-connected" are applied as the initial searching filter. Secondly, the articles are sorted out according to the "times cited highest to lowest". To extract the recent research trend, the last 12 years (2010–2021) is considered as the "year limitation" filter. After that, the "language" filter is applied, and "English" is chosen as the article language. The ratio of self-citations within the database of extensively cited articles was categorized and was calculated using the Scopus database's "exclude self-citations" filter. Finally, the "subject filter" was applied to the database to find the final sets of articles. Numerous articles were found, but relevant articles were identified by evaluating the manuscript's title, abstracts, emphasis, and citations. The different stages of the selection process are shown in Fig. 2.

2.2. Article selection criteria

To obtain the final set of highly cited articles, various inclusion and exclusion criteria are applied. The criteria of inclusion and exclusion of the overall article selection process are discussed below.

- The articles that have been written only in "English" are taken into consideration.
- In this study, only articles published between 2010 and 2021 are considered.
- All the relevant articles on grid-connected, LIB, and energy storage systems are considered in the analysis. The exclusion criteria comprehended research on chemical and biochemical materials, biochemistry, nanoscience, nanomaterials, molecular analysis. and catholyte analysis.
- The articles with an average citation per year (ACY) of more than 9 were only considered for the analysis.

2.3. Selection process

- In the first stage, the initial selection process was conducted by searching in the Scopus database with the keywords, "Energy storage system", "Li-ion", and "grid-connected", 1623 (n = 1623) articles were found.
- In the second stage, the "year limitation" filter was applied and the articles that are published within the year 2010–2021 are considered for further analysis. A total of 1622 (n = 1622) articles were selected from the database.
- In the third stage, the "language filter" is applied where the articles written only in the "English" language are considered and a total of 1550 (n = 1550) articles were chosen.
- In the fourth stage, the criteria from inclusion and exclusion are applied and a total of 1333 (n = 1333) articles were selected.
- Finally, according to the "times cited highest to lowest" and "ACY" a total of n = 100 top-cited articles in the field of grid-connected LIB ESS are extracted from the Scopus database.

Table 1
100 highly cited articles in the field of Grid-connected LIB Energy Storage System.

Rank	Ref	Keywords	Abbreviated Journal Name	Type	Publisher	ACY	Country	Number of Citation	Last 5 years citation	FWCI	PP
1	Luo et al. (2015)	BESS. PS. economic performance	APENERGY	Journal	Elsevier	272.83	China	1637	1486	87.65	99.903
2	Díaz-González et al. (2012)	BESS, Wind power plant	RSER	Journal	Elsevier	98.33	Spain	885	551	7.56	99.903
3	Zakeri and Syri (2015)	BES, Cost of ES, RE, integration,	RSER	Journal	Elsevier	124.5	Denmark	747	659	88.84	99.903
4	Lund et al. (2015)	ES, smart grid, Ancillary service, DSM, Electricity market	RSER	Journal	Elsevier	104.67	Finland	628	571	7.28	99.903
5	Chen et al. (2012)	BESS, RE, optimal sizing, microgrid	TSG	Journal	IEEE	63.78	Norway	574	365	35.03	98.506
6	Kousksou et al. (2014)	ES, RE, progress	SOLMAT	Journal	Elsevier	64	France	448	349	7.5	99.903
7	Luthander et al. (2015)	ES, DSM, Load shifting, PV, self-consumption	APENERGY	Journal	Elsevier	73.5	Sweden	441	404	8.89	98.288
8	Gür (2018)	ES. grid reliability, grid security, MG	ENENVSC	Journal	RSC	125.67	United States	377	377	9.95	99.887
9	Hannan et al. (2017)	ES, EV, Hybridization, PE	RSER	Journal	Elsevier	80.75	Malaysia	323	323	6.03	98.086
10	Hoppmann et al. (2014)	Battery storage, Distributed EG, Solar, PV	RSER	Journal	Elsevier	42.86	Switzerland	300	263	2.7	98.288
11	Li and Wen (2014)	BESS, DR, Building energy modeling. Building optimal control	RSER	Journal	Elsevier	35.29	China	247	196	2.56	99.525
12	Amirante et al. (2017)	ES, PS, RE, Technical and economic performance	ENCONMAN	Journal	Elsevier	54.5	Italy	218	218	5.85	99.903
13	Kisacikoglu et al. (2010)	Battery, Charger, PHEV, Reactive power, V2G	APEC	Conf. Proc.	IEEE	19.82	United States	218	66	36.91	99.907
14	Tant et al. (2013)	BESS, PV, VR, multi-objective optimization, peak shaving	TSTE	Journal	IEEE	27.13	Belgium	217	124	6.4	99.770
15	Hu et al. (2016)	ES, EV, Lithium-ion Battery, Machine Learning	TIE	Journal	IEEE	40.8	China	204	194	14.79	99.798
16	Das et al. (2017)	Controller, Dynamics, Integration, Reliability, Renewable, Suitability	RSER	Journal	Elsevier	49	India	196	196	3.69	97.913
17	Battke et al. (2013)	ES, LCOE, Monte Carlo simulation, Techno-economic modeling, Uncertainty	RSER	Journal	Elsevier	24.5	Switzerland	196	135	1.88	98.288
18	Lan et al. (2015)	BESS, PV generation, Irradiation, Ship PS	APENERGY	Journal	Elsevier	32.33	Singapore	194	186	7.15	99.862
19	Hesse et al. (2017)	Battery aging, BES, Grid connection, Lithium ion, optimization	ENERGIES	Journal	MDPI	47.5	Germany	190	190	4.41	99.863
20	(R. Wang et al., 2016)	Charging/ discharging efficiency, cooperative control, distributed BESS, MG	TSG	Journal	IEEE	30.33	China	182	154	21.07	99.886
21	Lai and McCulloch (2017)	Electrical energy storage, LCOE, PV	APENERGY	Journal	Elsevier	44.75	United Kingdom	179	179	14.01	99.862
22	Nottrott et al. (2013)	Economics, BESS, Forecasting, Optimal scheduling, PV generation	RENENE	Journal	Elsevier	21.25	United States	170	120	3.44	98.288
23	Shivashankar et al. (2016)	Cloud movement, ES, Intermittent PV,	RSER	Journal	Elsevier	31.8	India	159	153	2.39	89.022

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Table 1 (*continued*)

Rank	Ref	Keywords	Abbreviated Journal Name	Type	Publisher	ACY	Country	Number of Citation	Last 5 years citation	FWCI	PP
		Power fluctuation, Smoothing									
24	Aghamohammadi and Abdolahinia (2014)	BESS, MG, Overloading characteristic, Primary frequency control	IJEPES	Journal	Elsevier	22.43	Iran	157	111	7.94	98.872
25	Sarkar and Bhattacharyya (2012)	ES, Flow battery, Peak shaving, Vanadium redox flow battery	IJENRES	Journal	Wiley-Blackwell	24.67	Brazil	148	124	2.4	99.859
26	Traube et al. (2013)	EV, ES, Grid, integration, PV	TPEL	Journal	IEEE	18.75	United States	147	86	8.42	99.907
27	Hemmati and Saboori (2016)	EV, BESS, Hybrid BESS, RE	RSER	Journal	Elsevier	28.6	Iran	143	143	2.19	99.209
28	Tan et al. (2013)	DG, EM, MG, MPC	TPWRD	Journal	IEEE	17.88	Singapore	143	83	8.43	9.886
29	Moshövel et al. (2015)	Battery management strategy, Battery modeling, home storage system	APENERGY	Journal	Elsevier	23.667	Germany	142	124	8.38	98.288
30	Garcia-Torres and Bordons (2015)	EM, ES, Hydrogen	TIE	Journal	IEEE	23.33	Spain	140	124	6.21	94.936
31	Eghtedarpour and Farjah (2014)	BESS, Grid-connected, MG control, SoC	IET-RPG	Journal	IET	18	Iran	126	91	3.84	99.592
32	Stroe et al. (2017)	ES, Frequency regulation, Lifetime, Lithium-ion battery	TIA	Journal	IEEE	31	Finland	124	124	11.54	98.872
33	Sani Hassan et al. (2017)	BES, Feed in tariff, Optimization, PV-battery systems	APENERGY	Journal	Elsevier	30.25	United Kingdom	121	121	9.79	98.288
34	Chatzivasileiadi et al. (2013)	Batteries, Compressed air, BESS, RE, Flywheels, Pumped hydro	RSER	Journal	Elsevier	14.75	United Kingdom	118	78	1.23	99.903
35	Zhang et al. (2018)	Battery, BESS, Power condition system, Wide bandgap semiconductor	RSER	Journal	Elsevier	39	China	117	117	2.67	95.014
36	Arcos-Aviles et al. (2018)	MG, BESS, RE, Fuzzy control, EM	TSG	Journal	IEEE	38.67	Ecuador	116	116	16.29	99.886
37	Fares and Webber (2017)	ES, PV, grid, BES, RE, emission	NENERGY	Journal	Springer Nature	29	United States	116	116	8.26	99.770
38	Mulder et al. (2013)	BESS, PV, Batteries, Cash flow analysis, Economical analysis	APENERGY	Journal	Elsevier	14.13	Belgium	113	54	8.01	98.288
39	Vieira et al. (2017)	ES, PN, BMS, Residential buildings, Zero-energy buildings	RENENE	Journal	Elsevier	28	Portugal	112	112	5.36	98.288
40	Greenwood et al. (2017)	ES, PS, Frequency response, Hardware-in-the-loop	APENERGY	Journal	Elsevier	27.75	United Kingdom	111	111	9.61	39.966
41	Faisal et al. (2018)	BESS, EM, MG, Distributed energy resources	ACCESS	Journal	IEEE	36.67	Bangladesh	110	110	5.44	98.506
42	Jayasekara et al. (2016)	BESS, Charge/discharge management, optimal sizing, optimization	TSTE	Journal	IEEE	21.8	Australia	109	106	4.56	99.770
43	Miao et al. (2015)	BESS, wind power, wind speed, Coordinated control	TIA	Journal	IEEE	17.83	China	107	99	5.88	98.872
44	Ross et al. (2011)	BESS, charging/discharging, knowledge-based expert system (KBES)	IET-RPG	Journal	IET	10.5	Canada	105	37	3.31	98.506
45	Beck et al. (2016)	PV, battery. Household load profile, home battery storage, Optimal sizing	APENERGY	Journal	Elsevier	20.4	Germany	102	100	6.43	98.288
46	Parra et al. (2015)		APENERGY	Journal	Elsevier	16.83	Switzerland	101	80	6.48	98.288

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Table 1 (*continued*)

Rank	Ref	Keywords	Abbreviated Journal Name	Type	Publisher	ACY	Country	Number of Citation	Last 5 years citation	FWCI	PP
		Community ES, Lead-acid battery, LIB, Optimization, PV energy time-shift									
47	Quoilin et al. (2016)	Battery, Electricity, PV, Retail, Self-consumption	APENERGY	Journal	Elsevier	20	Belgium	100	100	6.03	98.288
48	Chong et al. (2016)	HRES, RE, Intelligent control	RSER	Journal	Elsevier	19.8	Malaysia	99	98	1.38	99.209
49	Reihani et al. (2016)	BESS, grid, optimization, VR, Peak shaving, Power smoothing	IJEPES	Journal	Elsevier	19.6	United States	98	88	7.69	98.506
50	Jaguemont et al. (2018)	Automotive application, Battery system, Cooling system. Phase-change material	APPLTHERMALENG	Journal	Elsevier	32.33	Belgium	97	97	3.79	99.863
51	Byrne et al. (2017)	BESS, ESS, EMS, BMS, MILP, optimization, optimal control	ACCESS	Journal	IEEE	24.25	United States	97	97	10.78	58.148
52	Das et al. (2018)	BESS allocation, BESS sizing, BESS operation, Energy security, power quality	RSER	Journal	Elsevier	32	Australia	96	96	2.15	99.770
53	Galeotti et al. (2015)	Batteries, Lithium polymer, SoC, SoH	ENERGY	Journal	Elsevier	16	Italy	96	90	4.47	99.986
54	Mulder et al. (2010)	BESS, Batteries, Lead-acid battery, Lithium-ion battery, Smart grid, PV	SOLENER	Journal	Elsevier	8.55	Belgium	94	43	2.51	98.288
55	Charging et al. (2018)	EV, Charging station, distribution system, electricity price, time of utilization (TOU)	TII	Journal	IEEE	30.66667	United States	92	92	11.15	99.907
56	Krieger et al. (2013)	Capacity fade, Lead-acid, Lithium-ion, Off-grid RE, Variable charge. Wind	ENERGY	Journal	Elsevier	11.5	United States	92	92	4.83	99.863
57	Zheng et al. (2015)	ES, DR, smart grid, peak shaving	APENERGY	Journal	Elsevier	15	China	90	84	5.03	99.955
58	Dufo-López and Bernal-Agustín (2015)	Batteries, Grid-connected electricity storage, Net present cost, Time-of-use tariff	ENCONMAN	Journal	Elsevier	15	Spain	90	77	5.62	98.288
59	Rubino et al. (2017)	BESS, PEV, PEV charging, Power converters, Smart grid	APENERGY	Journal	Elsevier	22.25	Italy	89	89	7.56	99.907
60	Bordin et al. (2017)	Battery degradation, Linear programming, Off-grid, Optimization	RENENE	Journal	Elsevier	22	Norway	88	88	4.04	77.423
61	Naumann et al. (2015)	BESS, BESS, LCOE, Li-ion, PV, self-consumption, techno-economic model	EGYPRO	Journal	Elsevier	14.67	Germany	88	88	13.17	98.288
62	Uddin et al. (2017)	Battery degradation, Li-ion battery, PV	APENERGY	Journal	Elsevier	21.75	United Kingdom	87	87	7.11	99.863
63	Balcombe et al. (2015)	ES, ES cost, Grid balancing, Microgeneration, PV, Stirling engine	APENERGY	Journal	Elsevier	14	United Kingdom	84	68	5.14	98.288
64	Goli and Shireen (2014)	ES, ES unit, EMS, PV, PHEV	RENENE	Journal	Elsevier	11.86	United States	83	62	2.05	99.907
65	Hajizadeh and Golkar (2010)	ES, control, fuel cell, PQ, voltage sag, hybrid system	IJEPES	Journal	Elsevier	7.545455	Denmark	83	24	6.50	3.802
66			IJEPES	Journal	Elsevier	16	Belgium	80	76	5.77	99.859

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Table 1 (*continued*)

Rank	Ref	Keywords	Abbreviated Journal Name	Type	Publisher	ACY	Country	Number of Citation	Last 5 years citation	FWCI	PP
	Lucas and Chondrogiannis (2016)	Flow batteries, FR, smart grid, grid storage system									
67	Morstyn et al. (2016)	Batteries, DC MG, Hybrid ES	TPWRS	Journal	IEEE	15.6	United Kingdom	78	77	5.97	99.592
68	Soong and Lehn (2014)	BESS, DC-AC power conversion, power conversion, power electronics	TPWRD	Journal	IEEE	10.86	Canada	76	56	4.47	99.481
69	Xu et al. (2017)	ES, ancillary services, Arbitrage, battery aging mechanism, economic dispatch	TPWRS	Journal	IEEE	25	United States	75	75	8.40	99.907
70	Nadeem et al. (2019)	EV, optimization, RE, BESS	ACCESS	Journal	IEEE	37	India	74	74	6.67	99.903
71	Luthander et al. (2016)	BESS, Curtailment, Peak power shaving, self-consumption	ENERGY	Journal	Elsevier	14.6	Sweden	73	73	4.83	98.288
72	Graditi et al. (2016)	BESS, Flexible electricity price, Load shifting, Technical-economical evaluation	RSER	Journal	Elsevier	14.6	Italy	73	59	1.44	77.423
73	Aktas et al. (2017)	Hybrid ESS, Bi-directional converter, battery, ultracapacitor	EPSR	Journal	Elsevier	17.5	Turkey	70	70	6.09	66.355
74	(Y. Wang et al., 2016)	bidirectional DC-DC converter, coupled inductor, high conversion ratio, capacitor	TPEL	Journal	IEEE	14	China	70	69	5.48	98.174
75	Dufo-López (2015)	Batteries, Control, Electricity storage, Optimization, Real-time pricing tariff	APENERGY	Journal	Elsevier	11.67	Spain	70	49	4.92	98.288
76	Zheng et al. (2014)	Modeling application, Modeling approach, Vanadium flow battery	APENERGY	Journal	Elsevier	9.714	China	68	56	1.47	99.859
77	Sichilalu et al. (2016)	Dispatch strategy, PV, wind, Fuel cell, Heat pump water heater, Optimal control	SOLENER	Journal	Elsevier	13.4	South Africa	67	66	2.86	99.862
78	Marcos et al. (2014)	Control strategies, Energy storage sizing, Grid-connected, PV, smoothing	ENERGIES	Journal	MDPI	9.57	Spain	67	62	2.64	89.022
79	Nyholm et al. (2016)	Batteries, Households, Self-consumption, Self-sufficiency, Solar PV	APENERGY	Journal	Elsevier	13.2	Sweden	66	66	4.25	98.288
80	Parra and Patel (2016)	Break-even analysis, Lead-acid battery, Li-ion batteries, PV, LCOE	APENERGY	Journal	Elsevier	13.2	Switzerland	66	63	4.65	98.288
81	Das et al. (2019)	LOLP, off-rid HRES, optimization, NPC	ENCONMAN	Journal	Elsevier	29.5	India	59	59	9.83	99.862
82	Ashique et al. (2017)	BMS, CMS, DC fast charging, EV charging, PV-grid charging	RSER	Journal	Elsevier	14	Bangladesh	56	56	1.08	99.907
83	Habib et al. (2018)	BESS, hybrid ESS, MG, Cyber-attacks, protection scheme	TIA	Journal	IEEE	17.67	United States	53	53	25.85	98.030
84	Hu et al. (2018)	BESS, RE, MG, Model predictive control (MPC), Power converters	APENERGY	Journal	Elsevier	17.33	Australia	52	52	5.58	99.886

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Table 1 (*continued*)

Rank	Ref	Keywords	Abbreviated Journal Name	Type	Publisher	ACY	Country	Number of Citation	Last 5 years citation	FWCI	PP
85	Ge et al. (2018)	BESS, PV, SoC balancing, cascaded multilevel inverter (CMI)	TIE	Journal	IEEE	17	United States	51	51	6.41	97.010
86	Yang et al. (2018)	BESS, EMS, grid integration, PV plant	TIE	Journal	IEEE	16	China	48	48	6.02	98.506
87	Khalid et al. (2018)	BESS, DP, wind	APENERGY	Journal	Elsevier	14	Saudi Arabia	42	42	4.5	98.506
88	Liu et al. (2019)	BESS, Building power supply, PV	ENCONMAN	Journal	Elsevier	22	China	44	44	2.26	99.862
89	Zia et al. (2019)	Battery degradation, DC MG, DR, EMS, Li-ion battery, Optimization, PV	APENERGY	Journal	Elsevier	21	Pakistan	42	42	7.40	99.863
90	Baumann et al. (2019)	BESS, RE, MADM, MCDA, sustainability	RSER	Journal	Elsevier	20.5	Germany	41	41	1.55	99.903
91	Mazzoni et al. (2019)	BESS, optimal ED, Poly generation	APENERGY	Journal	Elsevier	18.5	Singapore	37	37	5.99	99.903
92	Razmi et al. (2019)	High temperature thermal ES, CAES, desalination, Thermodynamics	RSER	Journal	Elsevier	18.5	Canada	37	37	6.00	99.903
93	Eldeeb et al. (2019)	Hybrid ESS, multi-objective optimization, Battery cycle (BC) life	TIA	Journal	IEEE	18	United States	36	36	6.85	99.209
94	Koskela et al. (2019)	ES, PV, Cost optimization, Energy community model, self-consumption	APENERGY	Journal	Elsevier	17	Finland	34	34	5.82	98.288
95	Hernández et al. (2019)	Batteries, Degradation, Lifetime. PV, Power management strategy	ENERGY	Journal	Elsevier	16	Spain	32	32	5.94	99.209
96	Chapaloglou et al. (2019)	BESS, RE, EMS, Island power systems, Load forecast, Peak shaving	APENERGY	Journal	Elsevier	16	Norway	32	32	5.64	99.683
97	Krishan and Suhag (2019)	ESS, BESS, RE, flywheel, fuel cell, distributed generation	IJENRES	Journal	Wiley-Blackwell	15.5	India	31	31	4.5	99.903
98	Figgener et al. (2020)	ESS, BESS, Home storage systems, Industrial storage systems, market	EST	Journal	Elsevier	20	Germany	20	20	9.49	98.288
99	Rathor and Saxena (2020)	BESS, RE, EMS, distributed energy resources (DER)	IJENRES	Journal	Wiley-Blackwell	18	India	18	18	2.98	99.907
100	Pellow et al. (2020)	BESS, Li-ion batteries, electronic waste, End-of-life management, Recycling	SUSMAT	Journal	Elsevier	16	United States	16	16	2.36	99.843

FWCI: Field-Weighted Citation Impact, PP: Prominence percentile, ES: Energy storage, BESS: Battery energy storage system, EG: Energy generation, PS: Power system, RE: Renewable energy, DSM: Demand-side management, MG: Microgrid, PV: Photovoltaic, RSC: Royal Society of Chemistry, DR: Demand response, VR: Voltage regulation, LCOE: Levelized costs of electricity, MDPI: Multidisciplinary Digital Publishing Institute, DG: Distributed Generation, MPC: Model predictive control, EM: Energy management, SoC: State of charge, SoH: State of health, BMS: Battery management system, EMS: Energy management system, MILP: Mixed-integer linear programming, PEV: Plug-in electric vehicles, PHEV: Plug-in hybrid electric vehicle, PQ: power quality, FR: Frequency modeling, DCC: Distributed cooperative control, LOLP: Loss of load probability, CAES: Compressed air energy storage.

2.4. Research trend

The rapid increase of RES such as PV and wind etc. use leads to the research related to the effective and stable integration of RES with the power grid. Lithium-ion batteries can be used in the electrical grid for several reasons, including smoothing out oscillations in RE outputs. According to the Scopus database, the first work on the grid-connected LIB ESS was listed in 2006 (Taylor and Duvall, 2006). Following that, several researchers devise various techniques for integrating the RE and LIB ESS into the grid-connected system. To extract the highly cited articles, the initial selection process was performed and a total of 1333 articles were found related to the grid-connected LIB ESS. In Fig. 3, the number of articles published each year is presented. It can be observed that the number of publications is increasing every year. 2020 has the

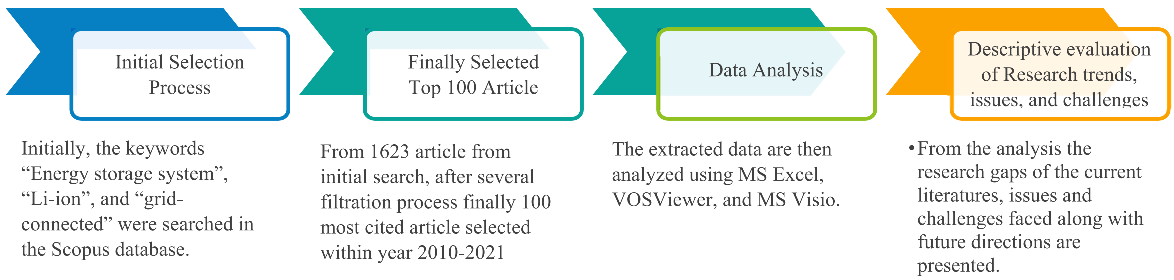

Fig. 1. The overall process of the methodology.

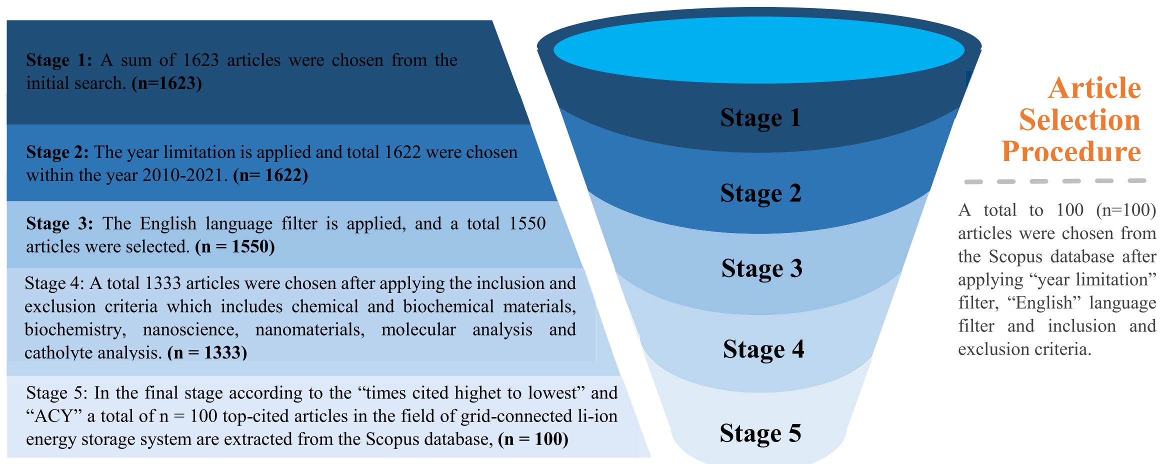

Fig. 2. The entire article selection procedure.

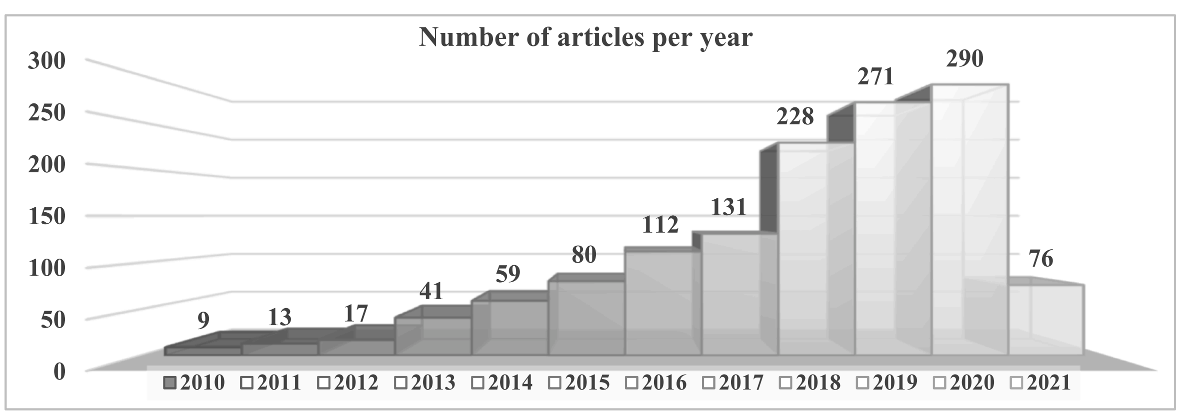

Fig. 3. The number of articles published each year.

maximum number of publications (290) followed by the year 2019 (271). Among the articles, 64.89% of articles were published within the year 2018–2021 whereas 10.42% of articles were published in five years.

2.5. Data extraction

The Scopus database was utilized for analysis purposes, and the data extraction was performed independently. The following data were extracted from the selected articles: 1) The top 100 highly cited articles' titles; 2) the highest number of citations in last five years; 3) study type; 4) classification according to the subject; 5) the publisher title; 6) the sum of publications published in each article types (journal/conference proceedings); 7) journal IF; 8) classification according to the originated countries; 9) the most prodigious authors and co-authorship map. After the article extraction process, an evaluation is performed in providing insights into the field of grid-connected LIB ESS.

2.6. Study characteristics and findings

A total of 1623 articles were found from the initial screening process from the Scopus database. After several screen processes, finally, the top 100 highly cited articles were extracted with the citation range of 16–1637. The total citation of the selected 100 articles is 15355 whereas the total number of citations in the last five years is 13158. It is observed that recent year's innovative articles received more citations compared long year's total citation. Overall, evaluation of the increased number of cited articles in grid-connected ESS refers to the high research interest among the researchers in the corresponding field of research.

3. Results and discussion

It is critical to identify and comprehend the recent research trends as well as the most notable research in a certain field to recognize and expand that field. The purpose of this research is to determine the significance of current research trends as well as to identify the significant publications in the field of grid-connected LIB ESS.

3.1. Selected highly cited articles

In Table 1, the list of 100 highly cited articles in the field of grid-connected LIB ESS is presented along with keywords, article type, publisher year, publisher, country, Field-Weighted Citation Impact (FWCI), Prominence percentile (PP), and last five years of citations which are extracted. An analysis is provided based on the retrieved data enabling future researchers to have a clearer insight. Table 1 shows that the citation rate is increasing over the years. The article published much earlier has a tendency to have high citation probability than newly published articles.

The most cited article in the field of grid-connected LIB energy storage systems is "Overview of current development in electrical energy storage technologies and the application potential in power system operation" by Luo et al. which was published in "Applied Energy" journal form "Elsevier" publisher in the year 2015 with the citation of 1637. The article has presented a brief overview of the recent electrical energy storage technologies and their application in the power generation and distribution system. A detailed description of the three types of ES technologies such as mechanical, electrical, and electrochemical BESS are provided along with a comparative study of the different types of technologies concerning energy density, power density, specific energy, specific power, power rating, rated energy capacity, suitable storage duration, discharge time at power rating, power capital cost, energy capital cost, operating and maintenance (O&M) cost and level of maturity. The article summarized that Pumped Hydroelectric Storage (PHS) is mostly applied for large-scale BESS worldwide due to the low power/energy densities characteristics. Moreover, the appropriate EES system application for the period is dependent on two key factors such as; energy capacity and self-discharge. The second most cited article is "A review of energy storage technologies for wind power applications" by Díaz-González et al. published in the journal of "Renewable and Sustainable Energy Reviews" in 2012 with a citation of 885. A detailed description and comparative analysis of different energy storage technologies along with their application in the wind power application are provided in the article. The BESS application in minimizing the wind power generation issues such as; fluctuation suppression, Low voltage ride through (LVRT), supporting voltage control, oscillation damping, Spinning reserve, load flowing, peak shaving, transmission curtailment, time-shifting, unit commitment, and seasonal storage. The third most cited article is "Electrical energy storage systems: A comparative life cycle cost analysis" by Zakeri and Syri published also in "Renewable and Sustainable Energy Reviews" in the year 2015 with a citation of 747. Techno-economic analysis of different electrical BESS is presented in the article. The article provides a detailed discussion on imperatives of electricity storage, characteristics of BESS technologies, and cost analysis of BESS along with different types of battery storage technologies.

3.2. Distribution of articles across the year

The research trend is a permanent influence of a corresponding field for hypothetical future research development. The distribution of articles in grid-connected LIB ESS across the year shows the research trends of the corresponding field. Fig. 4 illustrates the distribution of various articles from the selected highly cited article dataset from 2010 to 2021. It can be observed that 49% of the article in the selected database are published within the year 2015–2017. The highest number of articles (17) are published in the year 2015 followed by 2016 and 2017 with 16 articles each. Only 23 articles were published within the year 2010–2014. The number of selected publications in recent years for example 2020 and 2021 could be higher than the previous years. However, as the ACY is considered as 9, therefore, not many articles are included in recent years. Overall, the publication trend shows that the research trend is increasing day by day and the researchers are trying to develop the grid-connected LIB ESS with increasing research interest and efforts.

3.3. Keyword Co-occurrence network (KCN) and Co-citation network analysis

The keyword co-occurrence network (KCN) analysis shows the interconnection between different keywords, the weight, and the occurrence of the keyword and provides an insight into the overall field of research in the corresponding field. This KCN analysis reflects accumulated domain knowledge and aids in the extraction of essential information aspects and concepts based on the forms and strength of linkages between terms appearing in the study (Radhakrishnan et al., 2017). Contrastingly, co-citation analysis is a highly effective and efficient method for mapping information. Co-citation network analysis is a technique that divides the research journals into isolated groups of articles that address specific issues (Surwase et al., 2011). When two articles appear are cited by a third article, they are considered as co-cited. The bond of the paired articles increased along with the number of citations collectively. Once multiple researchers cite the same paired articles, clusters of research begin forming. The articles that are co-cited in the same cluster commonly share an identical concept.

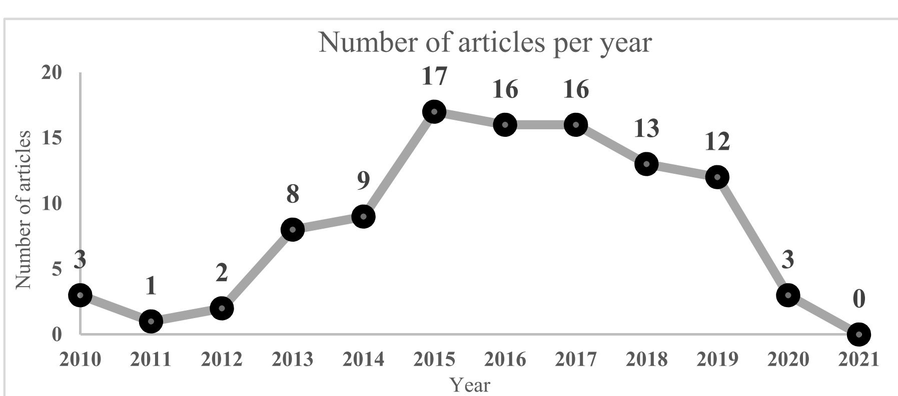

Fig. 4. Number of articles per year in the field of grid-connected LIB ESS.

In Fig. 5 (a), the KCN analysis, and in Fig. 5 (b), the co-citation analysis of the selected most cited manuscripts obtained from the Scopus database is presented. VOSviewer software is used where a database is required as an input parameter for the keyword analysis which is formed through manual selection of the selected manuscript. From Fig. 5 the size and the label define the keyword weight whereas the line defines the relationship between the labels. Moreover, depending on the field of information, various colors are used to identify various cluster types.

From the VOSViewer dataset, 107 keywords are found with 2 or more interconnection which is classified into 4 categories which are denoted as four colors, such as red, green, blue, and yellow. Among the color-based clusters, the red cluster consists of 37 keywords, green and blue both consist of 26 keywords whereas the yellow cluster consists of 18 keywords. “Energy storage” has the peak occurrence followed by “electric batteries” and “cost”. A strong relationship between the keywords energy storage, renewable energy resources, smart grid, data storage equipment, and energy management system can be found in the red clusters. Electric batteries, lithium-ion batteries, optimization, photovoltaic generation are in the yellow clusters which are also connected with the red and green clusters through electric batteries. In the green cluster, cost, electric energy storage, compressed air, solar cells, and wind power are consisting of. The photovoltaic system, photovoltaic cells, self-consumption, energy market, economics, and cost analysis are in the blue clusters which relate to the green cluster with “cost”.

In Fig. 5 (b), from the selected 100 highly cited article databases, nine different sets of clusters were formed which are differentiated in Fig. 5 (b) with separate color codes. In the blue cluster, a strong link between Hesse H.C. and Stroe D.I. is found where both mainly focused on the grid-connected Li-ion ESS field. The most prominent pair of authors in the yellow cluster are Zkeri B. and Xu Y. where the main research focus is including the life cycle cost analysis and control strategies of the PV-battery-based MG. In the red cluster, a strong relationship and similar types of research were found between Battke B., graditi G., lai C.S., and Habib H.F within the year 2013–2019. Battke B. mainly focuses on battery sizing and optimization models, lifecycle cost analysis, and applications. For Green cluster, ESS application on distribution networks and MG and smart grid application are the key research areas of Das C.K, Jayasekara N., Chen S.X., and aktas A. and solid bondage was found between them. Techno-economic analysis and economic benefits are considered as the vital research area in the purple cluster as a strong bond was shown between Hopmann J., Parra D., Das M., and Nottrott A. within the year 2013–2019. Co-citation analysis generates clusters that illuminate institutional tendencies in interdisciplinary research. The clusters of the co-citation network analysis provide vital information regarding the research type, research specialty, and research timeline which can lead to a better understanding of the research trends.

In Fig. 6, the evaluation of the top 15 keywords over the year 2010–2020 is presented using MS Excel and MS Visio. The impact of each keyword is presented as the size of the rectangle and the size of the connected line denotes the number of keywords that belong to each category. Initially, the keywords are divided into four categories such as; energy storage system, electric batteries, cost analysis, and PV system. In the second stage, the most common 15 keywords are selected from the four categories. In the third stage, the selected 15 keywords are then sorted in terms of years within the year 2010–2020. According to the analysis, the most common keyword is, “Energy storage” followed by “batteries” and “cost”. It can be observed that the used keyword “energy storage” is mostly used within the year 2015–2019. According to Fig. 6, the most used keywords in the last 5 years (2016–2020) are; Energy storage (28), Cost (19), Optimization (16), Batteries (11), and Renewable energy resources (10). Thus, it can be concluded from Fig. 6 as follows:

- The KCN-based analysis is used to rapidly investigate extensive literature.
- In recent years, a substantial increase in Energy management, cost, and economic analysis-related research is observed.
- Nowadays, the researchers are more focused on developing the optimization methods of the energy storage and renewable energy sources and cost analysis along with the new and cost-effective BESS technologies.
- Moreover, through statistical measurements, the presented KCN-based study will describe relationships between keywords, factors, and development methodologies in the field of grid-connected LIB ESS.

3.4. Bibliometric analysis of research types

The top ten most cited publications in the last five years in the field of grid-connected LIB energy storage systems are listed in Table 2. It can be observed that the ranking of the articles with the highest citation in the

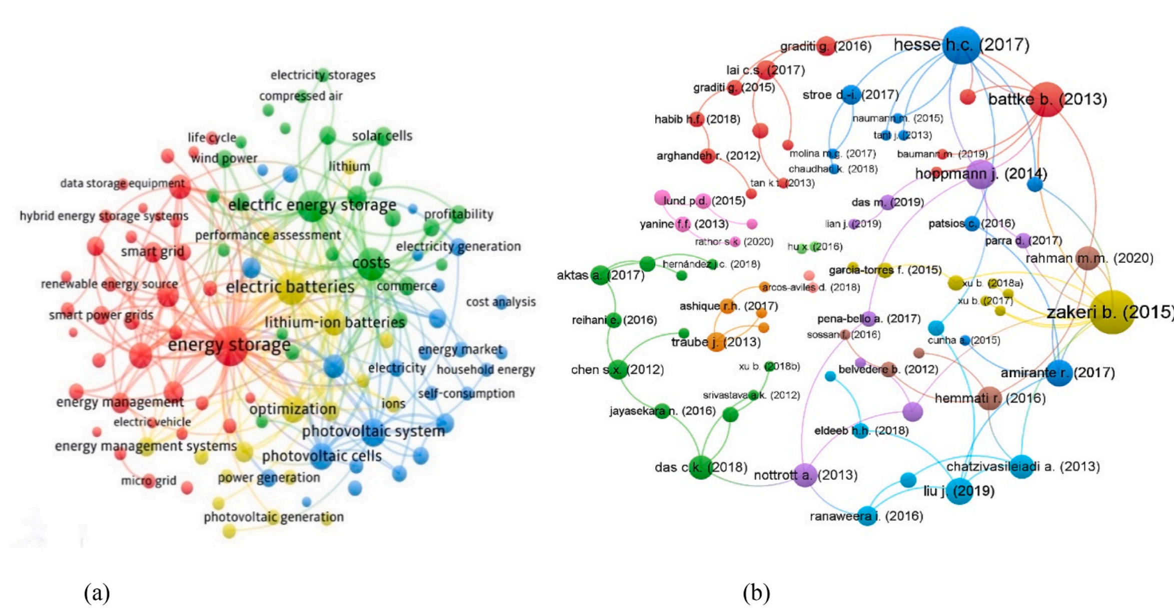

Fig. 5. The analysis of the selected most cited articles (a) Co-occurrence keyword analysis; (b) Co-citation network analysis.

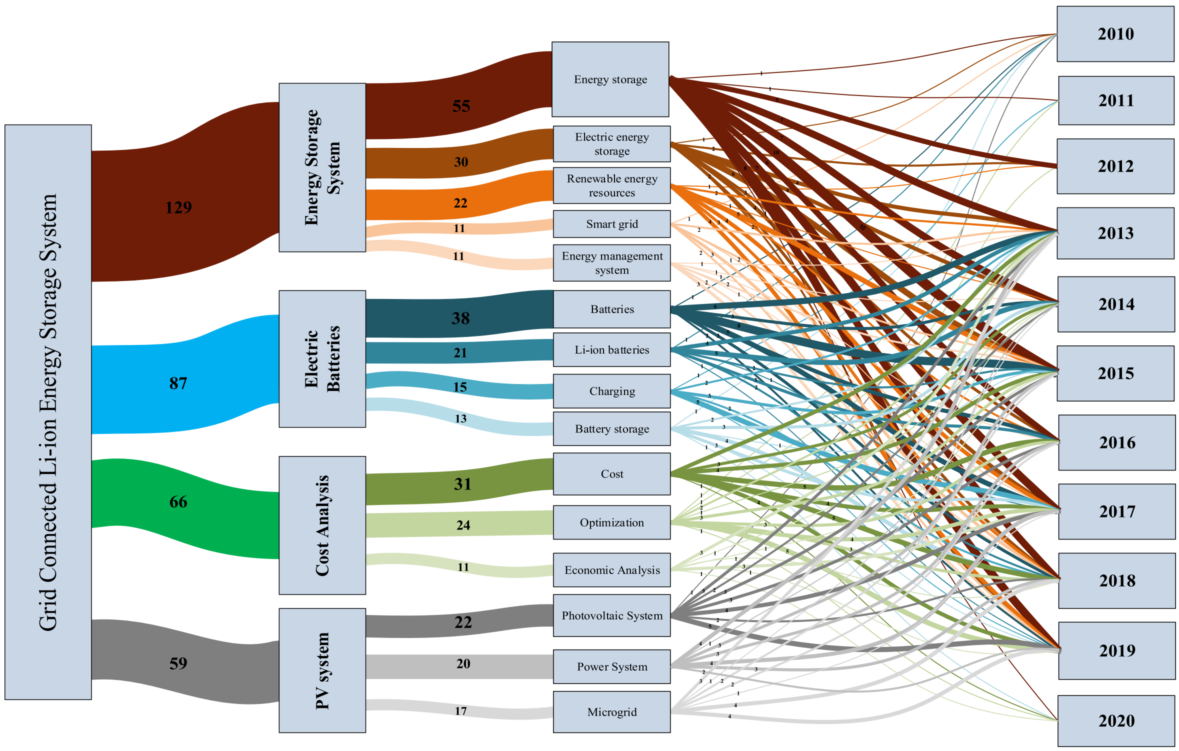

Fig. 6. Sankey diagram of the evaluation of the keywords in the grid-connected LIB ESS.

Table 2
The list of top ten highly cited articles in the last five years.

Rank	Ref.	Keywords	Overall citation ranking	Past 5 years citation	ACY
1	Luo et al. (2015)	ESS. PS. economic performance	1	1486	272.83
2	Zakeri and Syri (2015)	BES, Cost of ES, RE, integration,	3	659	124.5
3	Lund et al. (2015)	ES, smart grid, Ancillary service, DSM, Electricity market	4	571	104.67
4	Díaz-González et al. (2012)	BESS, Wind power plant	2	551	98.33
5	Luthander et al. (2015)	ES, DSM, Load shifting, PV, self-consumption	7	404	73.5
6	Gür (2018)	ES. grid reliability, grid security, MG	8	377	125.67
7	Chen et al. (2012)	BESS, RE, optimal sizing, microgrid	5	365	63.87
8	Kousksou et al. (2014)	ES, RE, progress	6	349	64
9	Hannan et al. (2017)	ES, EV, Hybridization, PE	9	323	80.75
10	Hoppmann et al. (2014)	Battery, Distributed EG, Solar, PV	10	263	42.86

last 5 years varies from the overall highly cited articles listed in Table 1. The power system economic performance analysis by Luo et al. in (Luo et al., 2015), has the maximum citation and is ranked as no 1 in both Tables 1 and 2. Energy storage cost analysis is presented by Zakeri et al. in (Zakeri and Syri, 2015) is placed as rank 2 with a 659 citation last year. Average citation per year (ACY) is the ratio of the total citation and the year gap between the recent year and the article published year. The citation of an article is largely dependent on ACY as older publications tend to have a greater citation rate than the newest articles (Gür, 2018). by Gür is published in 2018 and has an ACY value of 125.67 which is only surpassed by Luo et al. (2015) with an ACY value of 272.83. Among the list, nine of the articles are review articles. A novel MILP based cost-benefit-based optimal BESS sizing is described by Chen et al. (2012) is the only experimental analysis-based article on the list.

The selected publications are classified into seven different types of research categories are shown in Table 3. The record 38% of articles are belonging to the Modeling, simulation, and performance analysis category followed by the Review category with 26% publication. Experimental setup, development, and analysis type consist of 13% article whereas observational and intervention consist of 10% and 7% each.

3.5. Distribution of selected article over journals, publisher, and country of origin

The distribution of selected article over journals, publisher and country of origin are another key part of the bibliometric analysis of the field of grid-connected LIB ESS as it provides the future researchers necessary directions. All these information on high impact journals, publishers, and countries of the corresponding field of research may help to collaborate with the future researchers and scientific community for further improvement. The distribution of the selected highly cited

Table 3
Categorization of the selected articles according to the type of research.

Types of study	Publication frequency	Year range	Citation range
Modeling, simulation, and performance assessment	38	2011–2019	32–574
Review (Systematic and Nonsystematic)	26	2010–2020	20–885
Experimental setup, development, and analysis	13	2013–2019	32–143
Observational	10	2010–2020	20–2018
Intervention	7	2013–2020	16–118
State of the Art Technical overview	6	2015–2020	18–1637

articles over different journals and the impact factors of the corresponding journals are presented in Fig. 7. Among the selected database, only one article was presented in IEEE Applied Power Electronics Conference and Exposition, 2010 (Kisacikoglu et al., 2010), while 99 were published in various peer-reviewed journals. The selected articles were distributed among 27 different journals with the impact factor (IF) ranging from 1.2 to 46.5. It can be observed that the highest 25% of articles are published in the "Applied Energy" journal followed by "Renewable and Sustainable Energy Reviews" with 17% articles. Among the 27 different journals, there are nine journals from different "IEEE" journals. Among the IEEE journals, "IEEE Transactions on Industrial Electronics", "IEEE Transactions on Industry Applications" and "IEEE Transactions on Power Systems" each have published 4% of articles. From Fig. 7, it can be said that journals of higher impact factors tend to have lesser publication. "Nature Energy" journal has the highest IF (46.5) followed by "Energy and Environmental Science" with If 30.3 have only 1% article from the selected list of datasets.

The selected articles were published by seven publishers which are presented in Fig. 8. It can be noticed that 91% of articles belonged to either Elsevier or IEEE. The record 67% of articles are published by Elsevier followed by IEEE with 24% publication. Aside from these, Wiley-Blackwell has a 3% publication whereas both MDPI and IET have 2% of publication each from the selected set of articles.

According to the first author's affiliation, the selected articles have originated from 28 different countries which are shown in Fig. 9. The United States has the maximum number of publications (15%) followed by China (11%). Moreover, Germany has contributed 7% of the publication whereas Belgium, India, Spain, and United Kingdom have contributed 6% of the total publication from the selected database. The remaining countries have contributed below 5% of the selected highly cited articles.

3.6. The highly prolific author in the field of grid-connected BESS

The eight most prolific authors have been identified from the database of selected articles. It can be observed that a total of 20 authors are having 2 or more articles. The details of the authors publishing 2 or more articles where at least one article was published as a first author including the current institution, country, number of articles and citations, and *h*-index have been extracted and presented in Table 4. Daan six from STIWA Automation GmbH has a record of 3 articles. According to the number of citations and *h*-index, Xianfeng Li from China ranked top followed by M A Hannan and Rodolfo Dufo-López. In Fig. 10, the co-authorship network is presented where the network of authors from the selected articles collaborated in the grid-connected LIB ESS research are shown. The size of each node refers to the number of publications of individual authors whereas the width of the connected lines between two authors refers to the number of collaborated articles.

Various authors have highlighted different approaches to the field of grid-connected LIB ESS. For example, Daan six from Switzerland mainly focused on demand response (DR), demand management (DM), energy trading, and decarbonizations. Daan Six (Tant et al., 2013), and (Mulder et al., 2010) describe the integration of BESS with PV in residential distribution grids. M A Hannan focused on developing technologies related to the battery management system (BMS), Fuzzy Logic Controller (FLC), Battery state of charge (SOC), and electric vehicle (EV). An overview of the application of ESS in EV (Hannan et al., 2017) and microgrid (Faisal et al., 2018) is presented by Hannan et al. Nevertheless, Rodolfo Dufo-López in (Dufo-López and Bernal-Agustín, 2015) presented a techno-economic analysis of a grid-connected BSS concerning a time-of-use (TOU) electricity tariff. Identifying the highly prolific authors can help future researchers to obtain new ideas and extensive literature from the corresponding experts and develop a relationship to generate new research ideas for the development of grid-connected LIB ESS.

3.7. Article distribution over various subject categories

To obtain a better understanding of the current interests of the researchers in the field of grid-connected LIB ESS, the selected articles are categorized into different subject categories are shown in Table 5. The highest 25% publication is listed in the field of "BESS development and application" over the year 2015–2019. A total of 22% of publications is in the field of "BESS development and application" over the year

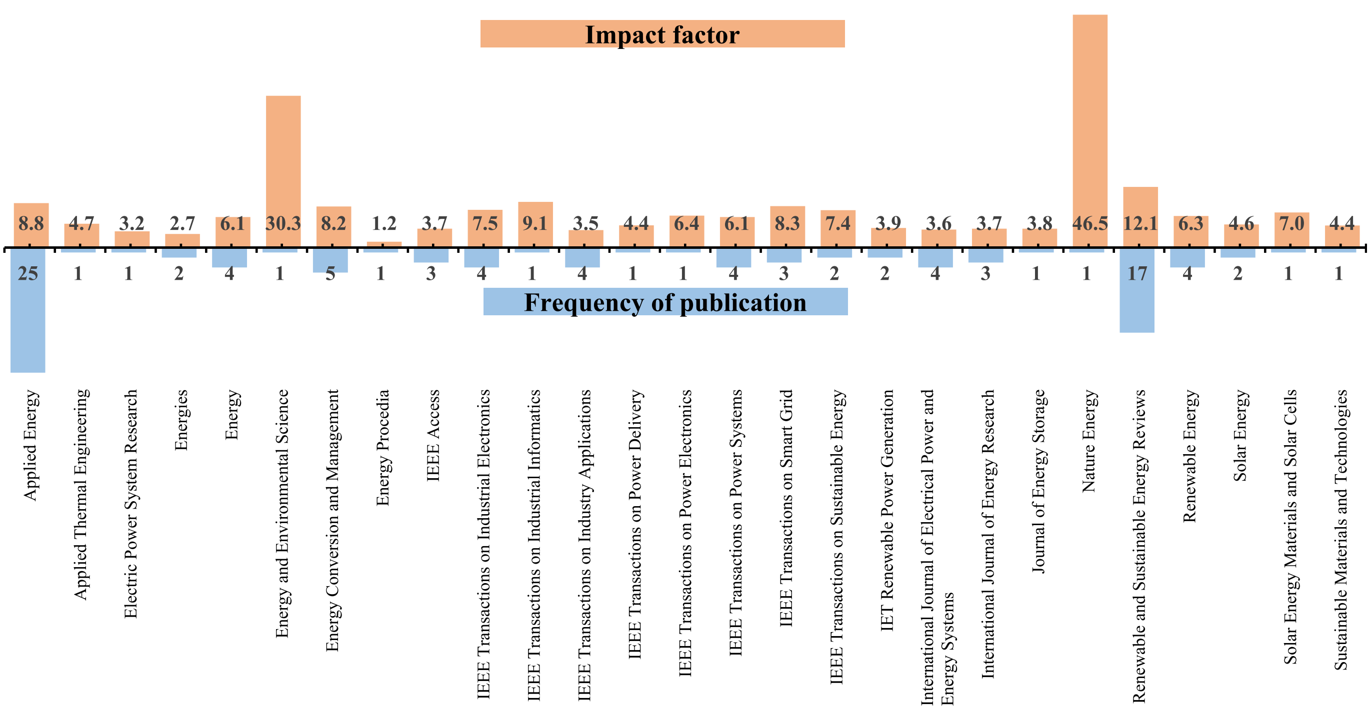

Fig. 7. Distribution of selected highly cited articles over different journals and journal impact factors.

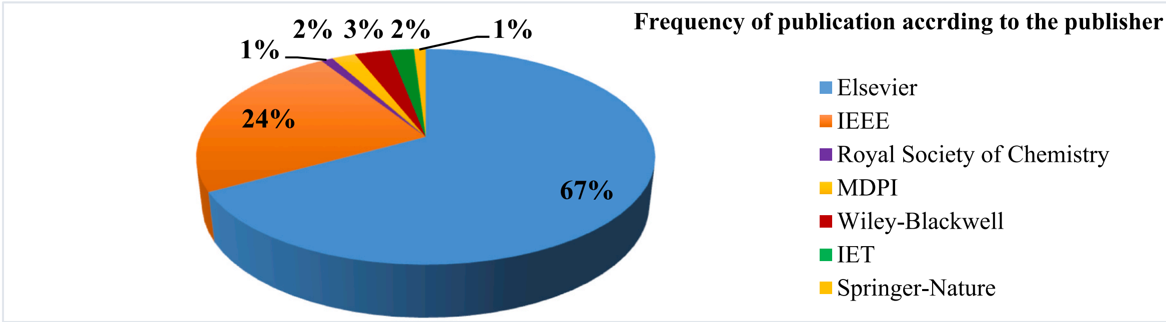

Fig. 8. Frequency of publication according to the publisher.

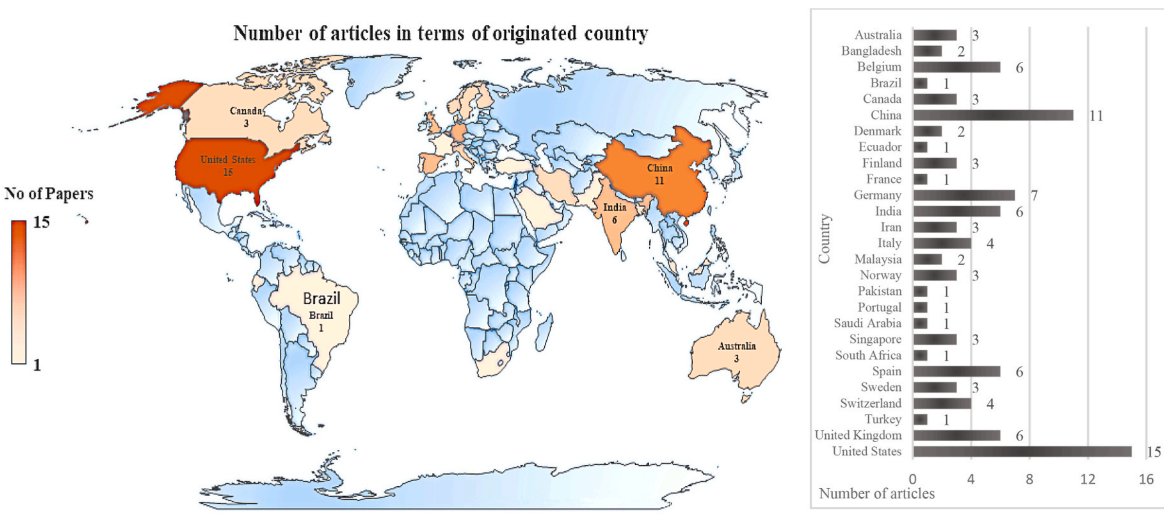

Fig. 9. Number of articles in terms of originated country.

Table 4
The eight highly prolific authors in the field of grid-connected LIB ESS.

Rank	Author Name	Current Institution	Country	No. of article	No. of citation	*h*-index	Position on the authors' list
1	Daan Six	STIWA Automation GmbH	Belgium	3	1158	12	Co-author (n = 3)
2	Rodolfo Dufo-López	Universidad de Zaragoza	Spain	2	4907	33	First author (n = 2)
3	Rasmus Luthander	Uppsala Universitet	Sweden	2	651	7	First author (n = 2)
4	Grietus Mulder	EnergyVille	Belgium	2	1569	21	First author (n = 2)
5	David Parra	Université de Genève	Switzerland	2	1427	23	First author (n = 2)
6	M A Hannan	Universiti Tenaga Nasional	Malaysia	2	6619	38	First author (n = 1), Co-author (n = 1)
7	Javier Marcos	Universidad Pública de Navarra	Spain	2	771	13	First author (n = 1), Co-author (n = 1)
8	Xianfeng Li	Dalian Institute of Chemical Physics Chinese Academy of Sciences	China	2	12,186	60	First author (n = 1), Co-author (n = 1)

2014–2020 whereas 21% of publications belongs to the field of "Cost analysis and Economic assessment" over the year 2015–2020. Only 1% publication is listed in the "Vehicle to Grid (V2G) application" and "Environmental prospective" fields each.

4. Discussion on the developed methodologies

Current, LIBs are highly optimized, lasting months to years, although few are projected to last decades. The LIB is vastly used in portable electronic devices. LIBs come in a variety of shapes and sizes, with the major distinction being the cathode materials. In Table 6, a short comparative study between six types of LIB is presented based on specific power, specific energy, safety, lifespan, cost, and performance. It can be observed that the Lithium Titanate battery has the greatest performance and lifespan, but the cost is high as well compared to other batteries. Lithium Iron Phosphate has high specific power but low specific energy and high cost. Various researchers have developed different battery types to analyze the most perfect way of application.

Analyzing Table 1, Table 3, and Table 5, it can be observed that, most of the article from the selected dataset is modeling, simulation, and application-based rather than review. More than 20 articles were listed in the ESS and BESS development and application and cost and economic assessment area. Recently, researchers are more focused on developing a cost-effective optimal BESS system in the grid of microgrid

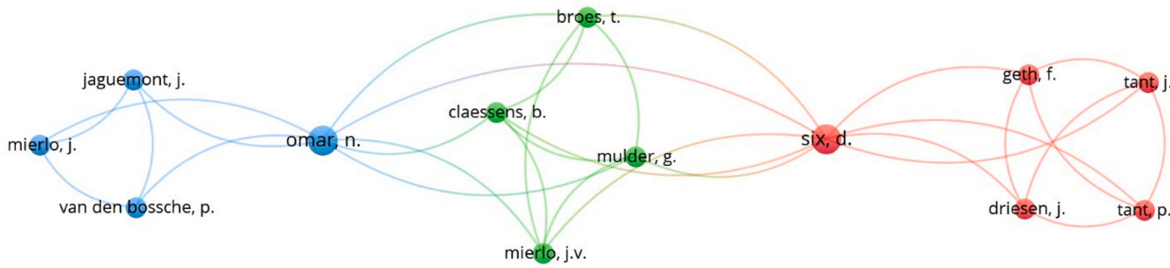

Fig. 10. Co-authorship network of the selected article dataset.

Table 5
Articles are distributed over a variety of subject categories.

Subject Category	Including Articles (Table 1 Article Rank)	Publication Frequency	Range of Citation
ESS development and application	1, 2, 7, 9, 12, 20, 21, 24, 27, 31, 32, 34, 35, 39, 40, 41, 44, 52, 65, 70, 74, 83, 88, 90, 92	25	37–1637
BESS development and application	11, 15, 19, 24, 25, 32, 33, 35, 49, 53, 56, 61, 62, 66, 68, 69, 76, 78, 79, 85, 86, 100	22	16–247
Cost analysis and Economic assessment	3, 11, 17, 21, 22, 38, 47, 55, 57, 58, 61, 62, 63, 69, 72, 75, 80, 81, 87, 91, 98	21	20–747
Grid-connected system and Smart grid development	9, 14, 19, 22, 29, 33, 39, 51, 54, 58, 60, 63, 66, 73, 86, 90, 99, 100	18	16–323
PV application in residential and large-scale grid	8, 11, 22, 23, 26, 29, 37, 39, 46, 60, 62, 64, 71, 79, 88, 95	16	32–377
Controllers and Control strategy development	11, 16, 24, 28, 30, 43, 48, 65, 66, 67, 75, 77, 78, 86	14	48–247
Optimal allocation and sizing of BESS	6, 18, 24, 45, 75, 77, 89, 90, 93, 94, 95	11	32–448
Microgrid development	6, 21, 28, 30, 31, 41, 44, 67, 83, 84, 89	11	42–448
Transportation application (EV)	10, 26, 27, 50, 55, 59, 64, 82, 93	9	36–300
RE application and development	5, 27, 31, 48, 56, 97	6	31–574
Wind power application and development	2, 43, 77, 87	4	42–885
Application in power system	1, 16, 42, 96	4	32–1637
Vehicle to Grid (V2G) application	13	1	218
Environmental prospective	100	1	16

Table 6
Comparison between Lithium-ion batteries.

Lithium-ion battery types	SP	SE	SF	LS	CS	PF
Lithium Cobalt Oxide	L	H	L	L	L	M
Lithium Manganese Oxide	M	M	M	L	L	L
Lithium Nickel Manganese Cobalt Oxide	M	H	M	M	L	M
Lithium Iron Phosphate	H	L	H	H	L	M
Lithium Nickel Cobalt Aluminum Oxide	M	H	L	M	M	M
Lithium Titanate	M	L	H	H	H	H

SP: Specific power; SE: Specific energy; SF: Safety; LS: Lifespan; CS: Cost; PF: Performance; L: Low; M: Moderate; H: High.

(MG) application with the integration of RES. The most cited research article from the selected list of the database is by (Chen et al., 2012). The article presented a cost-benefit analysis on the sizing optimization of ES in both off-grid and grid-connected microgrid applications using mixed linear integer programming (MLIP). The main objective function is minimizing cost whereas the system constraints are charging/discharging and power and energy limitation. Two separate case study was presented. In case 1, the MG is connected to the grid and the analysis shows that a daily investment of $67 per 100 kWh in BESS will benefit the market and the maximum benefit is obtained at the size of BESS is 500 kWh. In the off-grid scenario, the optimal size of BESS is obtained at 1400 kWh after considering all the system constraints.

Different cost analysis with the integration of PV-Battery is presented in (Balcombe et al., 2015; Koskela et al., 2019; Lai and McCulloch, 2017; Naumann et al., 2015; Nottrott et al., 2013). In Table 7, a comparison of different cost optimization methods in PV-battery-based ESS applications is presented. In (Lai and McCulloch, 2017), a new parameter Levelized cost of delivery (LCOD) is proposed to calculate the Levelized

Table 7
A comparative analysis of different cost optimization methods in PV-battery-based ESS.

Year	Reference	Objective function	Key findings
2017	Lai and McCulloch (2017)	LCOE	• A PV-battery-based system is presented with a review of different software approaches for cost analysis. The sensitivity analysis is provided by varying the PV capacity. • A comparative analysis of VRB and LIB is presented
2013	Nottrott et al. (2013)	Cost	• A grid-connected PV + BESS system is designed, and a cost and ES dispatch scheduling are optimized using linear programming (LP).
2017	Naumann et al. (2015)	LCOE and ROI	• An economic model and profitability estimation of BESS integrated with PV-household application is presented. • The technical parameters are end of life (EOL) and aging of battery and the economic parameters are investment cost and electricity price.
2014	Balcombe et al. (2015)	Net present value (NPV)	• The grid-connected Stirling engine combined heat and power (SECHP), PV, and battery-based system for 30 households is modeled and techno-economic analysis is presented. • Although the optimal system has 30% excess energy, the consumer needs 28% demand from the grid, and the installed battery reduces ramping down by 40%.
2019	Koskela et al. (2019)	LCOE	• The goal of the research is to provide insight into the influence of electricity pricing on PV and BESS. • The sizing was done for apartment buildings and detached houses and the optimized PV-LIB system shows an annual profit.

cost of energy (LCOE). The basic LCOE function is:

$$LCOE = \frac{Life\ cycle\ cost\ (\$)}{Lifetime\ energy\ production\ (kWh)} \tag{1}$$

A comparative study between vanadium redox flow battery (VRB) and LIB is presented. In (Nottrott et al., 2013), cost optimization and ES dispatch scheduling of a PV + BESS-based grid-connected system using linear programming are performed. in (Naumann et al., 2015) provided and techno-economic model of BESS with the integration of household PV system where LCOE and return on investment (ROI) are the objective functions. The result shows that, for long-term profitability, the battery should be replaced at 80% SOH. In (Balcombe et al., 2015), cost optimization of a Stirling engine combined heat and power (SECHP), PV and battery-based grid-connected system is model and simulated to analyze the annual economic benefits whereas in (Koskela et al., 2019), the LCOE is considered as the objective function and the PV-LIB-based BESS system is applied as a residential energy storage system.

Cost optimization of grid-connected DC microgrid including PV and Lithium-ion BESS is presented in (Zia et al., 2019). LIB lifecycle degradation model considering temperature, depth of discharge is proposed along with PV cost modeling. The main objective function is minimizing cost whereas the charging/discharging, maximum and minimum power, and capacity are considered as the constraints of the system. Tecno-economic assessment of PV coupled LIB is presented in (Parra and Patel, 2016; Uddin et al., 2017). In (Uddin et al., 2017), a household PV system integrated with LIB is presented where 3Ah 18650-type cells are used for constructing the degradation and aging model of LIB. The result shows 550 days of storage and 3800Ah of cycling the remaining SoC is 50%. Parra et al. in (Parra and Patel, 2016), presented a methodology based on a combination of lead-acid batteries (LAB) and LIB with the integration of PV for a single household in Switzerland and the economic performance is analyzed. The main objective function is considered as LCOE and Levelized value of energy storage (LVOES). The sensitivity analysis is carried out varying the cycle loss, whole sell price, and retail price varying −30% and +30% and the result shows that the internal rate of return (IRR) for LIB in Switzerland and Germany is 0.8% and 4.3% respectively whereas in Geneva (Switzerland) it is −0.2% due to higher retail price.

Another important application of LIB is in the transportation sector especially in Electric vehicle (EV) application (Eldeeb et al., 2019; Goli and Shireen, 2014; Hu et al., 2016; Kisacikoglu et al., 2010; Traube et al., 2013). A comparative study of BESS optimization and charging strategy in EV application is presented in Table 8. In (Kisacikoglu et al., 2010), the potentiality of the vehicle to grid (V2G) reactive power compensation is analyzed. An inverter and DC-DC converter and bi-direction charger is designed to support the grid. In (Hu et al., 2016), sparse Bayesian predictive modeling (SBPM) is used to estimate the SOH and prognosis of lithium nickel-manganese-cobalt oxide (LiNMC) batteries. High penetration of PV may cause power reliability issues. In addition to the PV, high penetration of EV may cause a greater problem in the distribution feeder is analyzed in (Traube et al., 2013). In (Traube et al., 2013), minimizing the PV irradiance intermittency for a small amount of time with the integration of a plug-in hybrid electric vehicle (PHEV) charging station through bidirectional dc-dc chargers which will act as an ES in the overall system. The result concluded that the integration of EV with PV system through a prototype 10-kW 575-to-250-V bidirectional dc-dc charger causes improvement of the grid reliability by reducing the ramping rate of the PV inverter output power. In (Goli and Shireen, 2014), the control strategy of a grid-connected PV-PHEV charging station through a designed DC/DC boost converter, DC/AC bi-directional converter, and DC/DC buck converter is presented consisting of 4 modes of operation. In mode 1. The PHEV is off, in mode 2, the charging station drawing power from both grid and PV, in mode 3, the power is delivered from PV only, and in mode 4, normal operation as the battery is fully charged and the PV will deliver power to the grid. The result shows promising performance for future implications. The sizing hybrid battery/ultracapacitor (UC) system for PEVs is presented using wavelet transformation and a non-dominated sorting genetic algorithm (Eldeeb et al., 2019). The objective function of the multi-objective approach consists of the cost, weight, and volume of HESS. The result shows a 40% saving of price and weight while compared with the existing system.

Table 8
Comparative study of BESS optimization and charging strategy in EV application from the selected database.

Year	Reference	Key findings
2010	Kisacikoglu et al. (2010)	• A DC-DC converter and bi-direction charger are developed to compensate for the reactive power of the grid while integrating with an EV charging station.
2016	Hu et al. (2016)	• Sparse Bayesian predictive modeling (SBPM) is used to estimate the SOH of LiNMC battery at different temperatures is estimated with an average error >1.2%.
2013	Traube et al. (2013)	• A prototype of a 10-kW 575-to-250-V bidirectional dc-dc charger is developed to minimize both PV and EV charging station penetration and to reduce the ramping rate of the grid.
2014	Goli and Shireen (2014)	• A control strategy of a grid-connected PV-PHEV charging is presented. • The system has four modes of operation. In mode 1. The PHEV is off, in mode 2, the charging station drawing power from both grid and PV, in mode 3, the power is delivered from PV only, and in mode 4, PV will be delivering power to the grid.
2019	Eldeeb et al. (2019)	• The multi-objective hybrid BESS/UC sizing is presented. The objective functions are cost, weight, and volume of HESS. • The wavelet transformation and non-dominated sorting genetic algorithm are used for solving the optimization problem.

Numerous control strategy in the grid, smart grid, and MG applications has been introduced by various researcher (Eghtedarpour and Farjah, 2014; R. Wang et al., 2016) In (R. Wang et al., 2016), a control strategy for integrating BESS in MG application by maintaining the supply-demand balance and minimizing the power loss due to the incompetence of charging/discharging. The result was validated through five bus systems applied in two case studies where, in Case 1, the RE integration is constant, and in Case 2 the RE is varied with respect to time. charging/discharging control strategies BESS, integrated with DC MG with non-deterministic RES and dynamic loads are presented in (Eghtedarpour and Farjah, 2014).

The optimization, frequency control, and energy management system (EMS) development of BESS in grid-connected mode is presented in (Arcos-Aviles et al., 2018; Dufo-López, 2015; Dufo-López and Bernal-Agustín, 2015; Mulder et al., 2010; Nottrott et al., 2013; Stroe et al., 2017). In (Stroe et al., 2017), control strategies of grid integrated LIB ESS to mitigate the effect of frequency regulation and SoC and lifetime of LIB are estimated whereas in (Arcos-Aviles et al., 2018), 25 rules-based fuzzy logic-based EMS system is integrated with residential MG. In (Mulder et al., 2010), the sizing of a grid-connected household PV system is presented. In (Dufo-López and Bernal-Agustín, 2015), a techno-economic analysis of a PV and BESS-based hybrid renewable energy storage system, (HRESS) is presented where the main objective function is LCOE. A comparative analysis of 2 different battery banks such as; lead-acid battery + converter + control and LIB + converter + control are presented and the result shows that two extreme round-trip efficiency of the lead-acid battery is 15% less than the LIB. Moreover, the acquisition cost per kWh of the capacity of the lead-acid battery is 0.025 €/kWh_{cycled} higher than the Lib which is considered as more economically profitable. All these methods and attempts help to promote renewable energy's integration into the grid.

5. Issues and challenges

Designing and implementing grid-connected LIB ESS is a difficult task because of the numerous aspects that must be considered such as; economic viability, reliability, power and frequency management, battery characteristics uncertainty, and environmental concerns. However, an effective combination of technological development and implementation can overcome such issues. The following is a list of the most significant issues and challenges in the field of grid-connected LIB ESS.

5.1. Economic impact

To develop and implement an efficient grid-connected LIB ESS most frequently faced issue is cost reduction. According to Table 5, "Cost analysis and economic assessment" is the third most common area of research. About 21% of the selected articles in the last 12 years were based on cost optimization and economic analysis of the development of BESS and integration with the grid. The cost analysis of grid-connected BESS is determined by a variety of parameters, including the kind of BESS chosen, the number of storage types integrated, the climatic conditions, the aspects of the implemented area, the installation, and the maintenance cost (Hannan et al., 2021). Moreover, both oversized and undersized BESS will have resulted in a power loss and frequency deviation respectively, and which cases failure to balance the supply and demand. LIB is currently costing around 200 EUR per kWh on average (Gabrielli et al., 2020) which is costly due to the limitation of lithium. An effective cost-optimized system with smooth integration with the grid along with the RES can be the solution to the current power generation and distribution problem. In the grid-connected BESS system, the cost minimization is also dependent on two issues such as peak shaving and load shifting. Leveling out the surges on the demand side is the most efficient means of lowering demand costs is known as peak shaving whereas load shifting is the alternation of electricity uses from one time frame to another to reduce cost (Mehr et al., 2013; Yang et al., 2014).

Different approaches were made by various researchers over the last decade to reduce the overall cost of the system using LIB ESS (Dragičević et al., 2014; Islam et al., 2019; Kumar et al., 2020; Lai and McCulloch, 2017; Liu et al., 2020; Marchi et al., 2016; Naumann et al., 2015; Tant et al., 2013; Taylor and Duvall, 2006; Uddin et al., 2017; Zhou et al., 2011). In (Tant et al., 2013), the application of BESS in a low-voltage distribution grid and a comparative study between li-ion and the lead-acid battery are provided. The main objective function is voltage regulation, peak current, and annual cost where the outcome shows a very minimal difference between li-ion and lead-acid battery. In (Naumann et al., 2015), a techno-economic analysis of BESS in the PV-based home storage system is presented whereas in (Uddin et al., 2017), techno-economic analysis of household PV system with the integration of LIB is presented. In (Uddin et al., 2017), the result shows a significant annual loss of integrating BESS in residential PV systems in the UK considering battery degradation. The main reason identified is excessive frequency cycling with an SoC swing of 80%. HOMER is also used in (Chowdhury et al., 2020, 2021) to develop a stand-alone system to optimize system cost along with various sensitivity analysis. Therefore, it can be concluded that establishing an efficient, economically feasible grid-connected LIB ESS for real-time implementation is a tedious job, and numerous factors must be assessed.

5.2. Power quality impact

Lithium-ion BESS can be used as a backup power as an existing low-voltage grid or as a part of MG with the integration of RES. RE integration at grid level may cause some uncertainty such as; unexpected fluctuation of power dissipation, voltage and frequency regulations, and power management issues. LIB ESS along with RES can be a great alternative for reducing the uncertainties and improving reliability because of its rapid response, high efficiency, and large power capacity. In (Kim et al., 2017), a LIB ESS with a capacity of 8 MW/2 MWh was built and operated for frequency regulation in New York. Later the system capacity expanded to 16 MW in 2011. Integration of RES into the grid level may cause some uncertainty to the power generation and reliability as the RES is highly dependent on the environmental condition, weather, and geographical locations (Hannan et al., 2021). For example, wind power is considered as one of the key RES which can be used in both on-grid or off-grid situations. But a common occurrence is the mismatch between peak generated power and demand. LIB ESS can be used to store the excess energy and supply when the power is needed. A LIB ESS with a capacity of 6 MW/10 MWh was constructed in the UK to compensate for the intermittent nature of RES (Chen et al., 2020).

The power management system is a critical component of the battery's capacity to meet the demands of grid-level BESS applications. Power management not only has a significant impact on the whole battery stack's functioning but also the safety and cost reduction (Chen et al., 2020). Moreover, high penetration of PV and wind can cause serious grid instability. In addition, according to the research, concerns of power quality can occur while integrating the RES with the grid (Basit et al., 2020). The harmonic generation is another undesirable occurrence for the power system. In the PV system, the conversion of DC to AC power is placed for the injection of power to the grid may result in the harmonics creation in the plant. Convertors can be used to compensate the harmonic compensation which is broadly described in (Li and He, 2014). To ensure reliability with the RES integrated grid and reduce the uncertainty, a monitoring system that is compatible with the wide-range devices associated with the grid as well as the RE and battery BESS. LIB ESS demonstrates high energy density, fast response time, and high capacity which can be a great potential while integrating with RES at the grid level.

5.3. Impact of battery characteristics

The lithium-ion battery consists of four components, namely cathode, anode, electrolyte, and separator (Dehghani-Sanij et al., 2019). The battery characteristics of lithium-ion have a significant impact on the overall system performance. Battery thermal energy management performs a crucial part in the thermal characteristics of LIB ESS. According to (Stroe et al., 2017), when the temperature drops below −20 °C, the capacity of $LiPF_6$ and $LiBF_4$ batteries drops drastically, but at 25 °C, the capacity drops by less than 10%. As, the Li-ion battery is a sealed system; therefore, no sensor can be placed directly inside it to detect aging. Furthermore, temperature, SOC, and rate of current can increase the rate of battery aging. The temperature rise of LIB causes a reduction of battery life while also increasing the risk of serious damage whereas low temperature will increase the internal resistance cases shortened battery life. Moreover, overcharging a lithium-ion battery results in distortion, leakage, and an increase in pressure, which leads to cell explosion (Li et al., 2012). In addition, self-discharge and aging are another two key issues that are needed to be considered while LIB ESS for large-scale grid level. Self-discharge is defined as the loss of charge over time. It is demonstrated in (Seong et al., 2018) that, when a LIB is subjected to even a short-term heat exposure, the battery's self-discharge might be drastically accelerated. The aging of LIB is not only calendric aging but also dependent on the number of charging-discharging cycles. The cathode/anode material of the battery cell, internal resistance, and capacitance degradation, and temperature rise have a significant impact on the aging of the battery. Different state of health (SOH) estimation technique has been introduced by various researchers. In (Tanim and Rahn, 2015), the SEI layer growth-based aging method has been introduced whereas in (Meng et al., 2020) support vector regression and self-adaptive differential evolution (SaDE) algorithm-based model is introduced for SOH estimation. Another key factor about lithium batteries is, they can create a fire if they are exposed to humidity for a duration sufficient to lead to the corrosion of cells (Pellow et al., 2020).

Therefore, an optimized algorithm is needed which will consider all the issues related to battery health for applying the LIB ESS at the grid level.

5.4. Environmental impact

Lithium-ion batteries are used to power portable gadgets all around the world. Due to the rapid increase of LIB use, it is needed to be supplied from all around the world through mining. Australia is the biggest producer of lithium followed by Chile. Researchers have mentioned the environmental impact of the LIB in the literature (Hidalgo-Leon et al., 2018; Pellow et al., 2020). The environmental impact of lithium-ion batteries can be divided into three categories, such as; lithium mining stage, battery cell damping stage, and recycling stage. It has been reported that local ecosystems are being destroyed, while adjacent grasslands and rivers are being polluted by lithium-ion mining. 500,000 gallons of water are needed for every ton of lithium production which affected the environment (Pellow et al., 2020). It is reported that, in Australia, only 2% of total Lithium-ion waste is recycled every year and the rest is dumped (Miao et al., 2019). This huge amount of toxic waste can have a severe impact on the environment which needed a concern. In designing LIB, there are two key factors responsible for the negative environmental impact of the LIB such as ingredients of LIB and lack of recycling concern of LIB. However, in general, LIB has many positive impacts on the environment such as less GHG emission, wide temperature range operation and protecting the energy waste by storing the excess energy, respectively. Also, LIB stores PV and wind energy and supplies when necessary for balancing supply and demand inequalities towards leading to a reliable and cleaner energy.

6. Conclusion and future directions

The LIB has some positive factors over the existing energy storage technologies which makes it a highly possible alternative to the existing fossil fuel-based energy generation system. Although, more factors such as; cost, the lithium extraction process, recycling are needed to be addressed and extensive research is required for the implementation of LIB at the grid level. The aim of the presented bibliometric analysis is to summarize the impactful research considering the highly cited articles and to investigate the issues, and challenges, to identify existing constraints and research gaps in the field of grid-connected LIB ESS.

6.1. Conclusion

Bibliometric analysis is a popular research method for identifying recent advancements, determining the evaluation of a specific field of study, and assessing the influence and correlations of numerous separate disciplines. The approach is adequate to describe the trends of publishing within a specific period using statistical analysis. Although, there are a few drawbacks to our study that should be acknowledged. First, the selected top 100 highly cited articles were extracted using the Scopus database only. The integration of Web of Science and Google Scholar with Scopus can be considered as a future recommendation. Second, as the inclusion criteria, the literature conducted only in the “English language” is considered. Third, the publications within the year 2010–2021 are considered whereas the initial research on the grid-connected Lithium-ion BESS is not mentioned in the research. Fourth, as the selection of articles is based on citation, current high-impact articles would not have enough period to have the citation. Finally, the specific subject category is considered and publication on subjects such as chemical and biochemical materials, biochemistry, nanoscience, nanomaterials, molecular analysis. and catholyte analysis is not included in the dataset. Regardless of the limitations previously mentioned, bibliometric analysis is a crucial approach used across many subject areas. Citation analysis can be an important matrix to analyze and identify the impactful publications, authors, and research of a particular field of study.

A bibliometric analysis of the articles is presented including the distribution of an article in terms of the year, originated country, journals, ACY, study types, and subject areas. A detailed keyword analysis is presented to identify more recent research focus from various researchers. Highly cited publications have a significant contribution to the development of a study. The developed article includes the 100 highly cited publications including hot publications from recent years, to give future researchers a broad overview of grid-connected LIB ESS, as well as current issues and concerns. There are numerous advantages to analyzing the attributes of the highly cited publications which is described below:

- By understanding and acquiring the knowledge for the most cited articles in the grid-connected LIB ESS can offer future researchers a comprehensive overview.
- By identifying the current research trends through the highly cited articles can inspire a lot of researchers, leading to newer and more advanced technologies and development in the area.
- The bibliometric analysis may give new researchers a lot of information about the journals that could be interested in publishing research articles.
- Researchers and journal editors may use the analysis on the highly cited articles to assist them to assess submitted publications.
- Moreover, the presented bibliometric analysis on grid-connected LIB ESS considerably reduces the work and time necessary for a conventional literature review.

6.2. Future direction

The focus of this research is to provide insight to the researchers regarding the research trends and to understand the impact and developments of grid-connected lithium-ion energy storage systems which leads to a cleaner energy scenario. This article focuses on various challenges, potential solutions, and future recommendations related to grid-connected LIB ESS, economic and power quality impact, battery degradation, environmental impacts as follows:

- The most challenging factor of integrating LIB into a grid-connected system is to minimize overall system cost. Numerous studies based on cost optimization were performed but due to the industrial application of LIB being expensive, cost minimization is required not only in the system application phase but also in the material production phase.
- High penetration of RES with the integration of the grid may cause grid instability, frequency, and voltage regulations. With further studies and effective application, LIB can be a great alternative to conventional methods due to its fast response and high specific energy.
- Excessive usage of Lithium-ion batteries in harsh environments might result in an explosion or possibly a fire. Therefore, an effective BMS is intended along with monitoring and estimating the battery SOH to guarantee that Lithium-ion batteries operate reliably and safely.
- It is critical to have a comprehensive and successful LIB recovery and recycling program. The energy market must focus on developing methods in reducing the environmental effect of extraction of raw materials and battery disposal, as well as mitigating material shortages and their pricing implications.
- As EOL is a substantial contributor to the LIB life cycle, it is tough to determine the impact of EOL due to the lack of research that can be considered as future research. Moreover, future studies should reflect a variety of EOL situations, including dumping, recycling, remanufacturing, and reusing.
- For EV applications, improving LIB material would necessitate sophisticated research. To obtain suitable system operation and

longevity, several concerns with LIB in terms of safety, mobility, and durability must be solved.
- To mitigate the impact of LIB's thermal runaway, a thermal management module and advanced monitoring and switching techniques should be installed inside the BMS for safety and security.
- The enhancement of battery performance, particularly operating voltage, aging, lifecycle, energy and power density, safety, environmental susceptibility, and cost. must be the emphasis of grid-connected LIB ESS research.

Therefore, LIB is expected to remain the most popular grid-scale stationary energy storage technology because of its various benefits over other storage systems. Moreover, LIB can have the possibility to become a great alternative to the existing fossil fuel-based energy production system which will lead to a cleaner environment. Furthermore, it is believed that identifying and analyzing the most frequently referenced publications over the previous twelve years would aid future studies in the subject grid-connected LIB ESS and developments.

Credit roles in preparing the manuscript are as follows

Conceptualization by MAH, Data curation by SBW, Formal analysis by SBW, Funding acquisition by MAH and PJK, Investigation by MSAR and MM, Methodology by SBW and MAH, Project administration by MAH, Resources by KMM, Software by PJK, MSAM, and MM, Supervision by MAH and PJK, Validation by KMM, Visualization by MM, KMM, TMIM and RAB, Writing - original draft by SBW, Writing - review & editing by MAH, PJK, MM, KMM, TMIM, and RAB.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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