Load Flow Solution of Distribution Systems - A Bibliometric Survey

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ABSTRACT

In this paper, Bibliometric Survey has been carried out on 'Load Flow Solution of Distribution Systems' from 2012 to 2021. Scopus database has been used for the analysis. There were total 1711 documents found on this topic. The statistical analysis is carried out source wise, year wise, area wise, Country wise, University wise, author wise, and based on funding agency. Network analysis is also carried out based on Co-authorship, Co-occurrence. Results are presented. During 2020 and 2018, there were 263 documents published which is the highest. 'IEEE Transactions on Power Systems' has published 90 documents during the period of study which is the highest in terms of articles under the category of sources. Highest citations were received by the article authored by Hung and Mithulanathan with 484 citations in the collected database with the chosen key words. VOSviewer 1.6.16 is the software that is used for the statistical analysis and network analysis on the database. It provides a very effective way to analyze the co-authorship, co-occurrences, citation and bibliometric analysis etc. The Source for all Tables and figures is www.scopus.com, The data is assessed on 6th July, 2021.

Key Words : Load flow solution, Distribution System, load flow analysis, Bibliometric Analysis, statistical analysis, network analysis.

1. INTRODUCTION

Distribution load flow is important for distribution automation systems, and distribution management systems. Network optimization, VAR planning, switching, state estimation etc. need the support of robust and efficient load flow solution. Traditional transmission system load flow methods Gauss-Siedel and Newton Raphson techniques, cannot be used for distribution systems as R/X ratio is high. Kresting and Mendive [1] have presented a load flow technique based on the ladder network theory. Teng and Lin (1994) proposed solution for meshed topology.

Majority of the 11KV rural distribution feeders are radial and too long. The voltages at the far end of many such feeders are very low with very high voltage regulation. D. Das and D. P. Kothari have proposed a load flow solution method by writing a algebraic equation for bus voltages [2]. Network topology based technique for three phase un-balanced systems is developed by J.H. Teng [3]. Equivalent current injection at each node is considered for the analysis in their work. Shirmohamadi *et al* [4] have presented a compensation based power flow for weakly meshed transmission and distribution systems. Baran and Wu [5] have obtained the load flow solution in a distribution system by iterative solution of three fundamental equations representing real power, reactive power and voltage magnitude. In many developing countries, the 11KV rural distribution feeders are radial and too long. The voltages at the far end are very low with very high regulation. Raju M R et al. proposed method involves only evaluation of a simple algebraic expression of voltage magnitude [6] and no trigonometric terms. Topology based approach is used for evaluating equivalent load at every node. This eliminates the complex process of identifying nodes connected beyond a particular node as described in [2]. The two developed matrices, '*bus injection to node power matrix'* and *'line loss to node power matrix'* are very easy to form. The features of this method are robustness and computer economy. Convergence is always guaranteed. The assumption is that shunt capacitance is negligible at the distribution voltage level.

When search is conducted in Scopus database on the 'Load Flow Solution of Distribution Systems', there were 1711 documents in Scopus Database. Literature Survey is presented in Section 2, Results and discussions were presented in Section 3 and Conclusions were presented in Section 4.

2. LITERATURE SURVEY

The following search is carried out on Scopus Database.

(TITLE-ABS-KEY (load AND flow AND solution AND of AND distributions AND systems) OR TITLE-ABS-KEY (loadflow AND analysis AND of AND distribution AND systems) OR TITLE-ABS-KEY (loadflow AND solution AND of AND distribution AND systems) AND TITLE-ABS-KEY (power AND system)) AND PUBYEAR > 2011

Load flow study is the fundamental requirement in planning studies. The applications of load flow is presented in this literature survey. Pareek et al developed Non-parametric probabilistic load flow using Gaussian process learning [7]. Qu et al proposed a global optimum flow pattern for feeder reconfiguration to minimize power losses of unbalanced distribution systems [8]. García-Muñoz et al. proposed a novel algorithm based on the combination of AC-OPF and GA for the optimal sizing and location of DERs into distribution networks [9]. Bayat et al. developed an efficient iterative approach for power flow solution of droop-controlled islanded AC micro-grids through conventional methods [10]. Parizad et al. employed load and irradiance profiles for the allocation of PV arrays with inverter reactive power and battery storage in distribution networks [11]. Chen et al. proposed a collaborative optimal operation of transmission system with integrated active distribution system and district heating system based on semi-definite programming relaxation method [12]. Duman et al. proposed a Symbiotic organisms search algorithm-based security-constrained AC–DC OPF regarding uncertainty of wind, PV and PEV systems [13]. Silveira et al. compared Mathematical optimization versus meta-heuristic techniques for reconfiguration of distribution systems [14]. Zhao et al. simulated three-port bidirectional operation scheme of modular-multilevel dc-dc converters interconnecting MVDC and LVDC Grids [15].

Zhou et al. worked on multi-energy system planning based on Cascade Hydro-Photovoltaic-Pumped Storage Hybrid Generation System [16]. Liu et al. developed a multi-objective differential evolutionary algorithm based optimal power flow calculation for integrated electricity and gas systems [17]. Sarda et al. developed a strategy for systems with electric vehicles and renewable generators using dynamic optimal power flow with cross entropy covariance matrix adaption [18]. Nou et al. studied the impact of voltage stability constraint index on power system optimization base on interior point algorithm by considering the integration of renewable energy [19]. Wang et al. proposed a power flow calculation method for multi-voltage dc distribution network considering different connection modes [20]. Caldora et al. carried out preliminary design of the electrical power systems for DTT nuclear fusion plant [21]. Srivastava et al. used a hybrid machine learning and meta-heuristic algorithm based service restoration scheme for radial power distribution system [22]. Foltyn et al. implemented OPF solution for a real Czech urban meshed distribution network using a genetic algorithm [23]. Borghei et al. worked on optimal planning of micro-grids for resilient distribution networks [24]. Kaymaz et al. proposed a optimal power flow solution with stochastic wind power using the Lévy coyote optimization algorithm [25].

Gao et al. implemented economic stimulation signal on power supply optimization from distribution cost allocation based on shapley value in integrated energy park [26]. Ju et al. implemented optimal power flow of three-phase hybrid ac-dc in active distribution network based on second order cone programming [27]. Zhang et al. proposed a multi-objective economic-environmental dispatch for power system with wind power and small runoff hydropower [28]. Shao et al. developed multi-objective optimal configuration of renewable distributed generation based on modified multi-scene Krawczyk interval power flow algorithm [29]. Paz-Rodríguez et al. worked on optimal integration of photovoltaic sources in distribution networks for daily energy losses minimization using the vortex search algorithm [30]. Dzafic et al. implemented complex variable perturbed Gauss-Newton method for tracking mode state estimation [31]. Asl et al. proposed new two-layer model for energy management in the smart distribution network containing flexi-renewable virtual power plant [32]. Dvorkin et al. proposed a differential private optimal power flow for distribution grids [33]. Bobo et al. compared various second-order cone relaxation methods of the optimal power flow for active distribution grids [34]. Liu et al. implemented a bi-level interval robust optimization model for service restoration in flexible distribution networks [35].

De Souza et al. assessed multiple operationally-stable power flow solutions in unbalanced impedance-grounded systems [36]. Shen et al. developed a frequency response model and its closed-form solution of two-machine equivalent power system [37]. Yi et al. worked on optimal allocation of ESSs in active distribution networks to achieve their dispatchability [38]. Szczesniak et al. proposed compensation for changes in AC voltage at the building terminals using a hybrid transformer [39]. Da et al. proposed a fault tolerant operation of active front end converter with high resistance grounding system [40].

Ge et al. developed a soft open point planning for active distribution network considering influence of access mode between feeder loops and reliability [41]. Dong et al. developed a unified power flow calculation method of flexible interconnected distribution network based on modified augmented nodal equation [42]. Ahmad et al. evaluated of instigation of voltage sags by distributed generation with anti islanding protection [43]. Wang et al. presented a comprehensive review on modeling and operational strategies [44]. Bai et al. developed a new lateral load distribution pattern for seismic design of deteriorating shear buildings considering soil-structure interaction [45]. Papalexopoulos et al. worked on the development of organized nodal local energy markets and a framework for the TSO-DSO coordination [46]. Fahmy et al. proposed grid-aware distributed control of electric vehicle charging stations in active distribution grids [47]. Engelmann et al. worked on decomposition of Non-convex Optimization via Bi-Level Distributed ALADIN [48]. Snodgrass et al. analyzed over voltages and developed a method for protection of lightning arresters in distribution systems with distributed generation [49]. Keihan et al. proposed multi-objective optimal operation of integrated thermal-natural gas-electrical energy distribution systems [50].

Yuan et al. developed an Analytical Probabilistic Load Flow method with GMM Models of Correlated der Generation [51]. Li et al. presented global energy interconnection [52]. Ullah et al. conducted a thorough review on distributed renewable generation, challenges of interconnection and opportunities for energy conversion based dc micro-grids [53]. Liang et al. a proposed chance-constrained Optimal Power Flow model based on second-order cone [54]. Zhang et al. developed an improved phase-coordinate fixed-point iterative method based on equivalent admittance approximation for power flow calculation in three-phase distribution systems [55]. Bocanegra et al. proposed a new iterative power flow method for ac distribution grids with radial and mesh topologies [56]. Liu et al. carried out assessment of pv hosting capacity in a small distribution system by an improved stochastic analysis method, [57]. Tunzi et al. developed a double loop network for combined heating and cooling in low heat density areas [58]. Givisiez et al. explored the use of an ADMM-based three-phase AC OPF in PV-rich MV-LV networks [59]. Glover et al. allocated multi-solar PV for optimal sizing and placement on distribution feeders [60]. Ji et al. implemented neural network based on immune algorithm for restoration in the power distribution system [61]. Li et al. developed Multi-objective Optimal Power Flow Study of Hybrid AC/DC System With DCPFC [62]

3. RESULTS AND DISCUSSIONS

3.1 Statistical Analysis

There are 1711 documents found on the topic of 'Load Flow Solution of Distribution Systems'. Scopus Database is used for collecting the data of publications. The following Statistical Analysis is carried out on database.

1. Documents by source
2. Documents by year
3. Documents by subject area
4. Documents by Type
5. Documents by Country
6. Documents by author
7. Documents by affiliation
8. Documents by top funding agencies

Fig. 1 shows the number of documents by source. Table 1 shows the number of documents published by each source. 'IEEE Transactions on Power Systems' has published 90 documents during the period of study which is the highest under the category of sources. This is followed by International Journal of Electrical Power and Energy Systems with 67 documents.

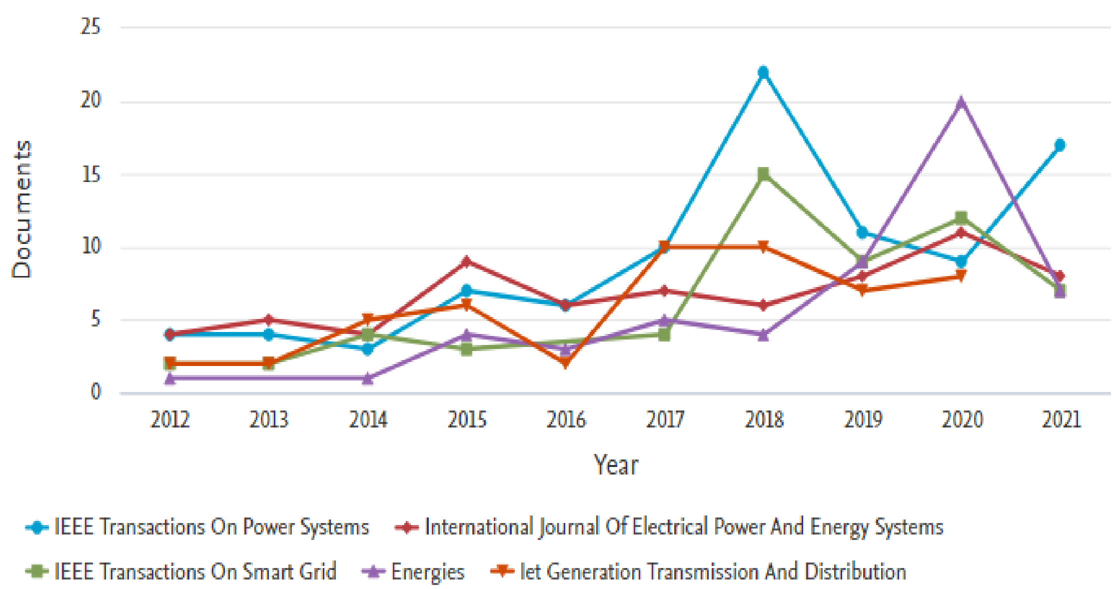

Fig. 1. Documents by Source

Table 1. Number of Documents by Source

S No.	SOURCE TITLE	NO. OF DOCUMENTS
1	IEEE Transactions on Power Systems	90
2	International Journal of Electrical Power And Energy Systems	67
3	IEEE Transactions on Smart Grid	56
4	Energies	50
5	IET Generation Transmission and Distribution	49
6	Electric Power Systems Research	49
7	Applied Energy	33
8	IEEE Access	27
9	Applied Mechanics And Materials	26
10	Dianli Xitong Zidonghua Automation of Electric Power Systems	25
11	Advanced Materials Research	19
12	Energy	19
13	Journal Of Physics Conference Series	17

Fig. 2 shows the documents published year wise. Table 2 shows the number of documents by year. During 2020 and 2018, there were 263 documents published which is the highest and followed by 2019. There were 257 documents published in the year 2019.

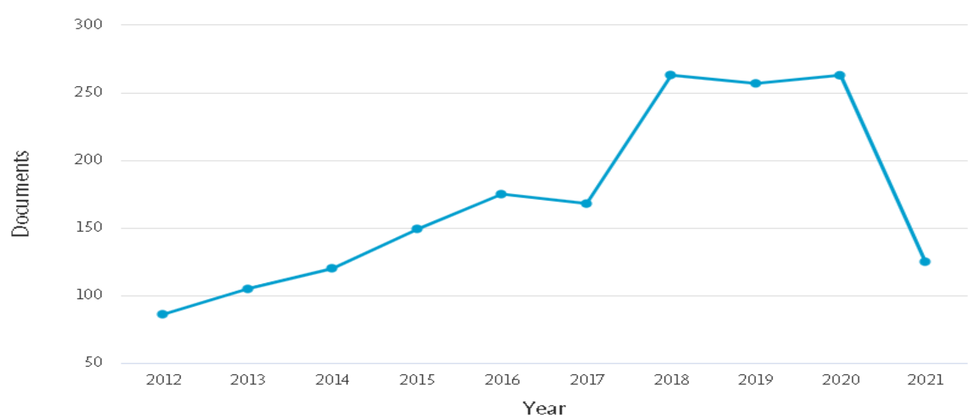

Fig. 2. Documents by year

Table2. Documents by Year

S. No.	YEAR	Number of Documents
1	2021	127
2	2020	263
3	2019	257
4	2018	263
5	2017	168
6	2016	175
7	2015	149
8	2014	120
9	2013	105
10	2012	86

Fig. 3 shows the documents by subject area. Highest percentage of documents are published in the Engineering area equal to 36.8 % and followed by Energy area with 28.2%. The reason for having highest papers in the area of Engineering, is 'load flow solution' belongs to the Electrical Engineering field.

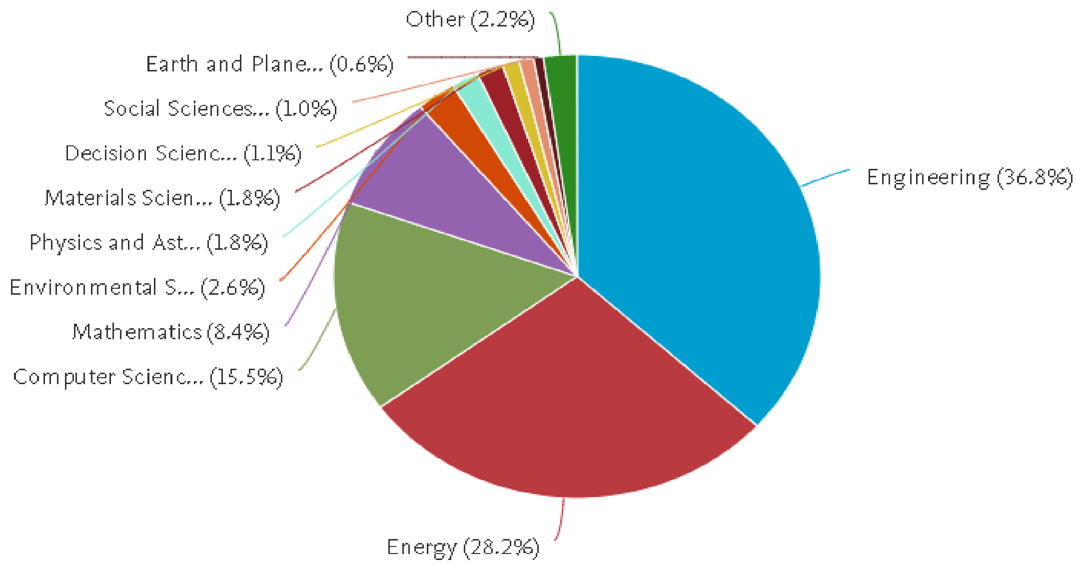

Fig. 3. Documents by Subject Area

Fig. 4 shows the distribution based on type of documents. Majority of the published documents are articles followed by conference papers. There are 53.1% Conference papers and 42.6 % Articles.

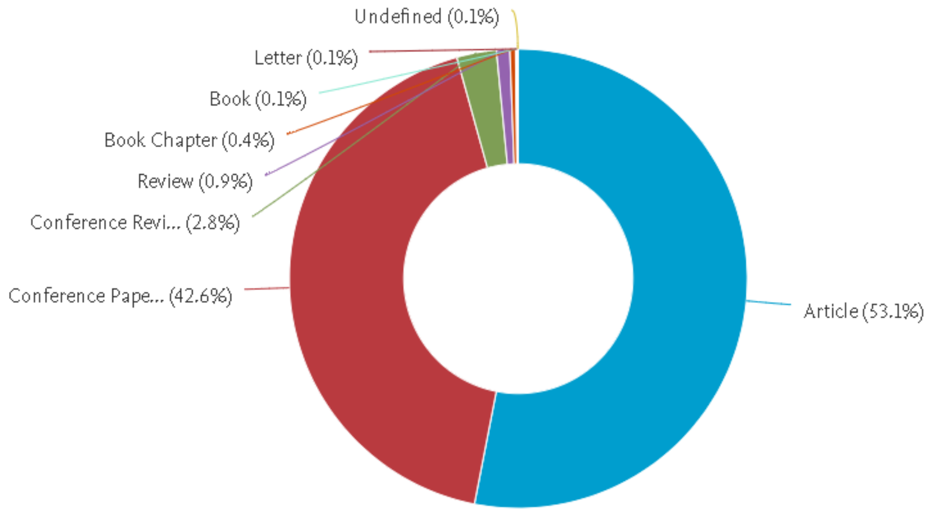

Fig. 4. Distribution based on type of document

Fig. 5 shows documents by country/territory. Table 3 presents documents by country. China has published 379 documents followed by USA. USA has published 279 documents and India has published 233 documents during 2012-2021.

Table 3. Documents by Country

S. No.	Country / Territory	Number of Documents
1	China	379
2	United States	279
3	India	233
4	Iran	86
5	Italy	79
6	Brazil	78
7	United Kingdom	70
8	Germany	59
9	Canada	51
10	Australia	47

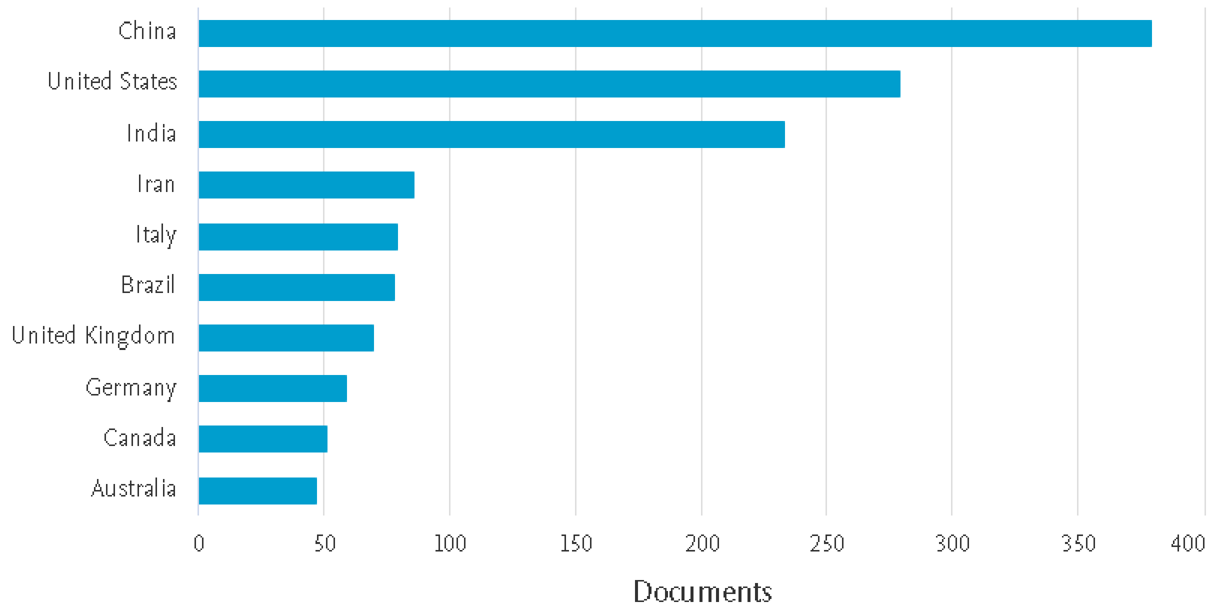

Fig. 5. Documents by Country

Fig. 6 shows documents by author. Table 4 presents the number of documents by each author. Jabr R. A. has published 15 documents each in the area of 'load flow solution' which is the highest and followed by Montoya, O.D. with 14 documents.

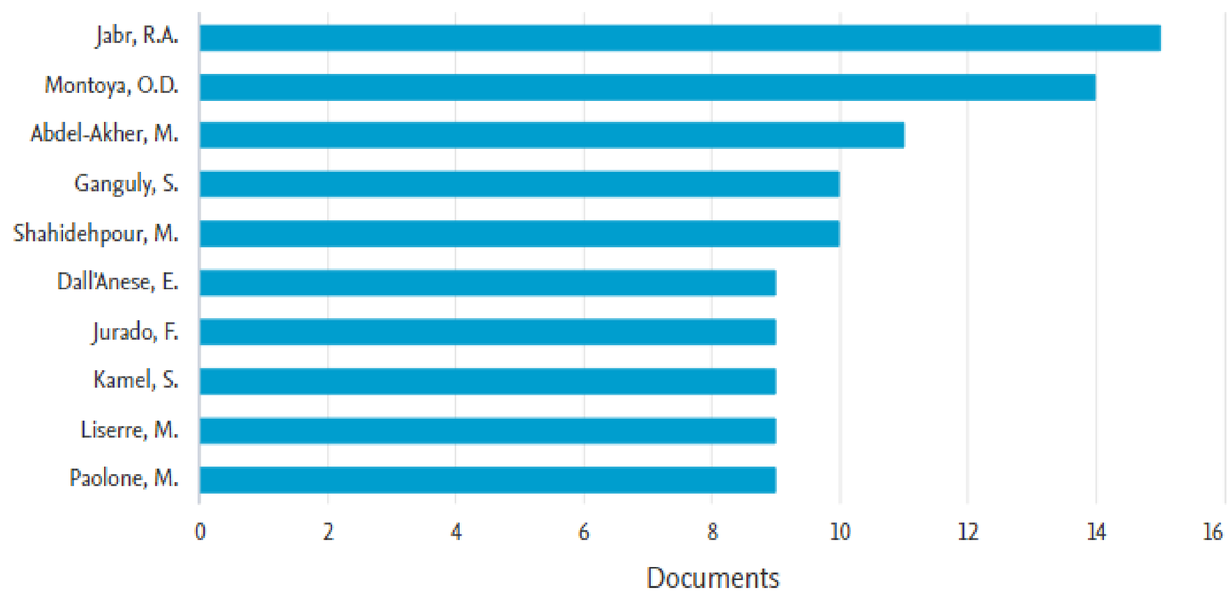

Fig. 6. Documents by author

Table. 4. Number of Documents by author

S. No.	AUTHOR NAME	Number of Documents
1	Jabr, R.A.	15
2	Montoya, O.D.	14
3	Abdel-Akher, M.	11
4	Ganguly, S.	10
5	Shahidehpour, M.	10
6	Dall'Anese, E.	9
7	Jurado, F.	9
8	Kamel, S.	9
9	Liserre, M.	9
10	Paolone, M.	9
11	Gil-GonzÃ¡lez, W.	8

Fig. 7 shows documents by author's affiliation. Table 5 presents documents by author's affiliation. Ministry of Education, China has published 36 number of documents which is the highest followed by North China Electric Power University with 29 documents.

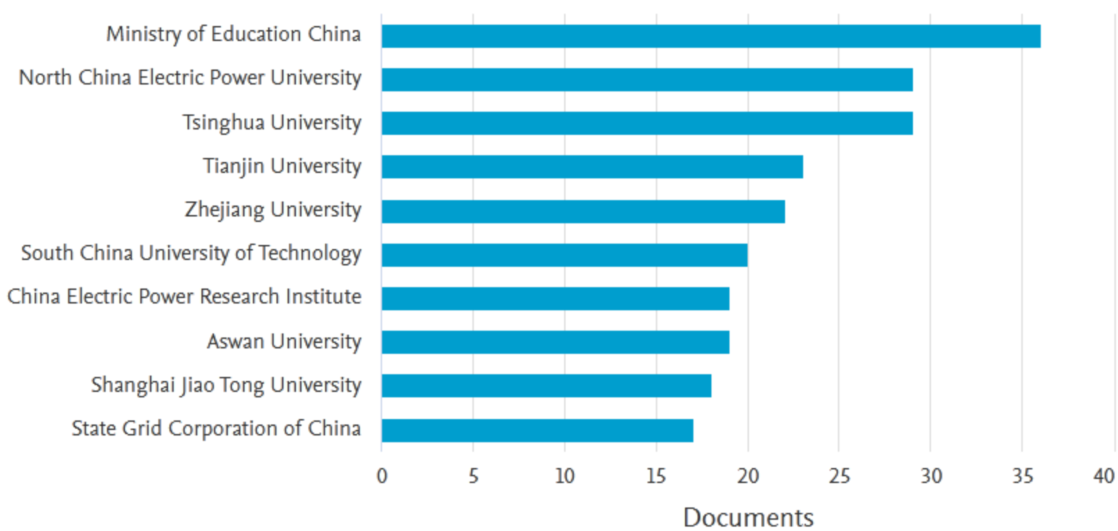

Fig. 7. Documents by affiliation

Table 5. Documents by affiliation

S. No.	AFFILIATION	No. of Documents
1	Ministry of Education China	36
2	North China Electric Power University	29
3	Tsinghua University	29
4	Tianjin University	23
5	Zhejiang University	22
6	South China University of Technology	20
7	Aswan University	19
8	China Electric Power Research Institute	19
9	Shanghai Jiao Tong University	18

Fig. 8 shows the documents by funding agency. National Natural Science foundation, China has sponsored 133 documents which is highest in the category of funding agencies.

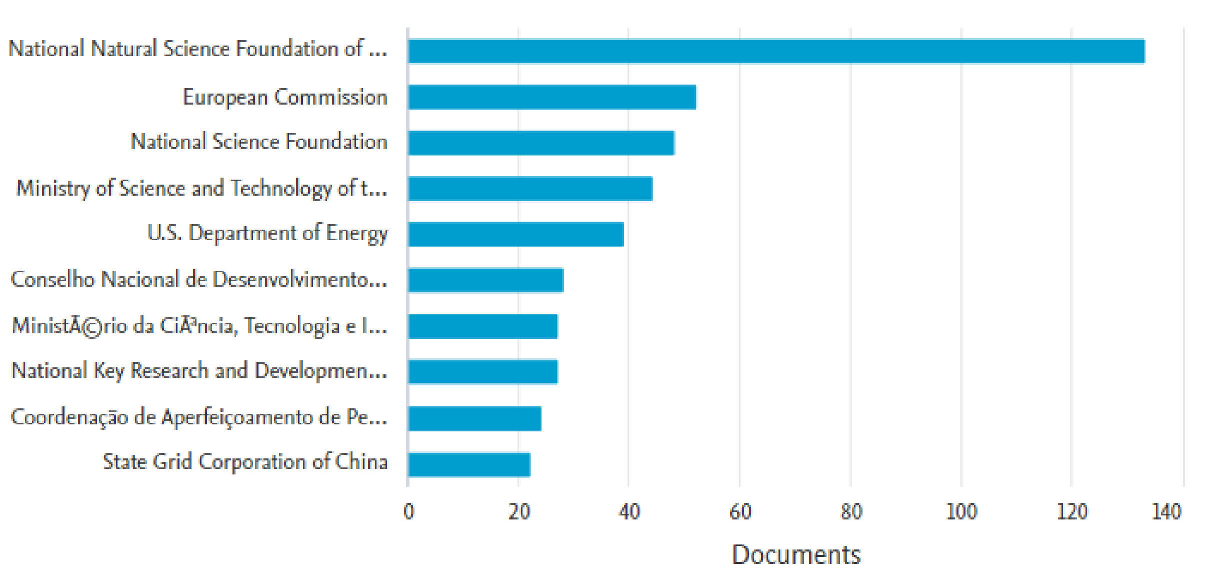

Fig. 8. Documents by Funding agency

3. 2 Network Analysis

The following topics were considered for the Network Analysis of Database.

1. Co-authorship: Authors, organizations and country
2. Co-occurrence: keywords, title and abstract terms, terms of the title field
3. Citation Analysis: Sources, authors, organizations, country
4. Bibliographic coupling: Documents, Authors

3.2.1 Co-authorship Analysis

A) Co-authorship analysis in terms of Authors

In this section, Co-authorship analysis is considered with other authors. Documents with a very large number of authors are ignored in this analysis. The documents with more than 25 authors are ignored.

Table 6. Co-authorship Network Analysis in terms of Authors

Selected	Author	Documents	Total link strength
✓	li, j.	19	33
✓	wang, c.	22	31
✓	zhang, y.	22	30
✓	li, y.	13	25
✓	li, z.	15	25
✓	liu, j.	15	23
✓	liu, y.	13	21
✓	wang, j.	14	21
✓	wang, z.	18	21
✓	zhang, x.	11	21
✓	wang, y.	21	20
✓	li, g.	10	19
✓	li, h.	17	19
✓	xu, y.	8	19
✓	han, x.	9	18
✓	shafie-khah, m.	8	18
✓	cao, y.	5	17
✓	catalão, j.p.s.	7	17
✓	sun, h.	8	17
✓	wang, s.	12	17

Threshold is considered as 5 for minimum number of documents of an author. It is seen that out of 3995 authors, 142 authors met the criteria. The total link strength of the co-authorship is calculated with other authors. Li J. has total link strength of 33 which is the highest in the co-authorship analysis in terms of authors with 19 documents. Table 6 presents Co-authorship analysis in terms of authors. Fig. 9 presents the network of Co-authorship links with other authors.

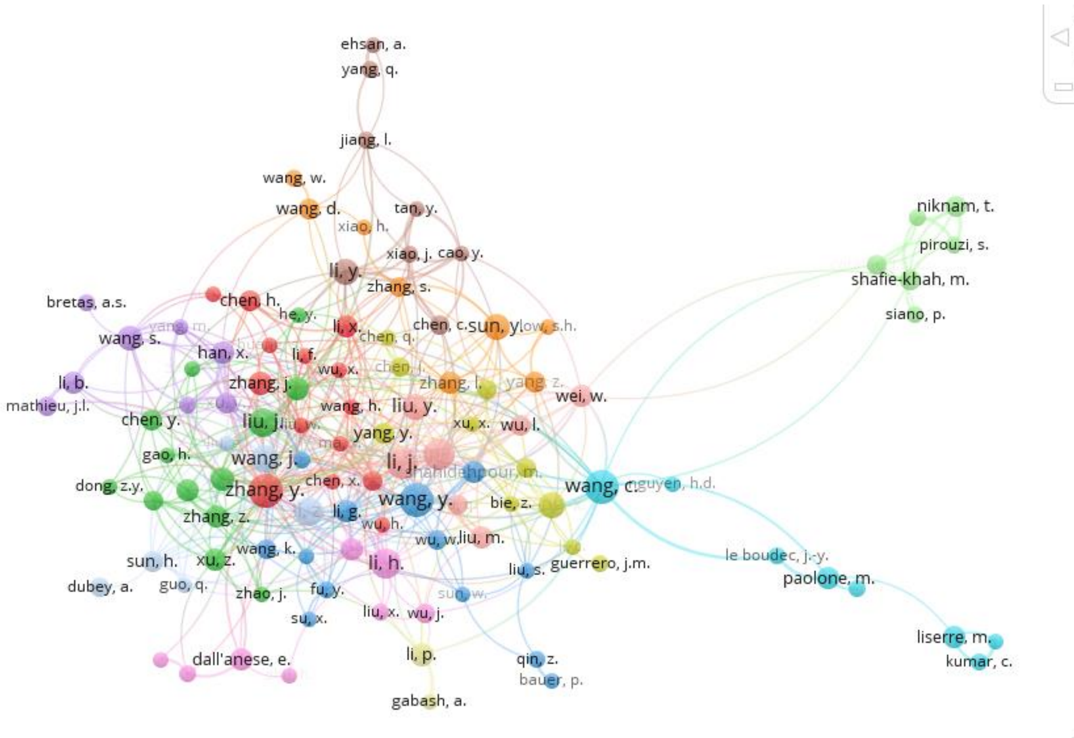

Fig. 9. Co-author relationship with other authors

B) Co-authorship in terms of Organizations :

Co-authorship in the unit of organizations is calculated considering minimum 03 documents in organizations by neglecting the citation of the same. 50 organizations met the criteria out of 2597 number of total organizations, that are shown in the figure 10. Department of Electrical and Computer Engineering, University of Minnesota has highest link strength of 4 and number of citations 123 for 6 documents. Fig. 10 shows the network of co-authorship in terms of organizations.

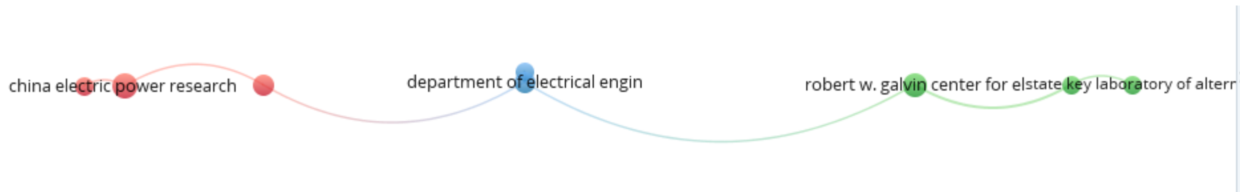

Figure 10: Co-authorship analysis in terms of Organizations

C) Co-authorship in terms of Country

Co-authorship is also obtained in relation to the country. A total of 102 countries are there, in this database. After considering the threshold of minimum 5 documents in a country, 48 countries met the threshold. 47 countries have connection with each other. Here, United States found to have the highest citations of 5643, and the link strength of 145. This is followed by China with link strength of 98. As far as the number of document is concerned, China has the highest of all with 361 documents and link strength of 98. Fig. 11 shows the network of co-authorship in terms of country. Table 7 shows the data of number of documents, citations and link strength for top 15 countries in the descending order of the link strengths.

Table 7. **Co-authorship in terms of Country**

Selected	Country	Documents	Citations	Total link strength
✓	united states	268	5643	145
✓	china	361	3317	98
✓	iran	83	1501	48
✓	united kingdom	66	1189	43
✓	italy	79	956	40
✓	portugal	23	432	34
✓	australia	44	1065	31
✓	spain	44	691	30
✓	brazil	76	575	27
✓	germany	56	748	26
✓	hong kong	23	645	26
✓	canada	51	876	24
✓	finland	15	508	23
✓	egypt	43	575	22
✓	denmark	20	318	20
✓	singapore	15	315	20
✓	france	28	318	17
✓	turkey	17	229	17
✓	saudi arabia	15	157	16
✓	colombia	25	193	14

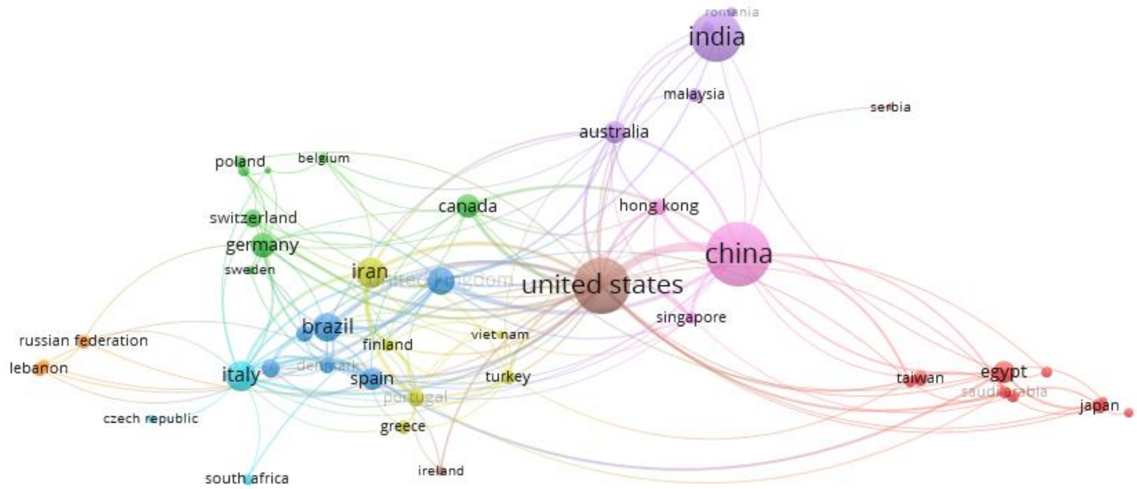

Fig. **11. Co-authorship in terms of Country**

3.2.2. Network Analysis of Co-occurrences

A) Co-occurrence in terms of Keywords

Co-occurrence analysis in terms of keywords is considered in this section. Minimum number of occurrences of keywords is considered to be 5. Out of 9749 keywords, 911 keywords met the threshold. The keyword "electric load flow" is having 13182 link strength with 1196 occurrences in various documents as shown in figure 10. Table 8 presents keywords in the decreasing order of the link strength.

Table 8. Occurrences and Link Strength of Keywords

Selected	Keyword	Occurrences	Total link strength
✓	electric load flow	1196	13182
✓	electric power transmission networks	316	3838
✓	distribution systems	359	3802
✓	optimization	269	3577
✓	distributed power generation	283	3481
✓	electric power distribution	226	2781
✓	acoustic generators	190	2418
✓	optimal power flows	188	2332
✓	smart power grids	166	2029
✓	reactive power	153	1978
✓	electric power transmission	175	1909
✓	renewable energy resources	138	1801
✓	optimal power flow	136	1755
✓	distributed generation	143	1697

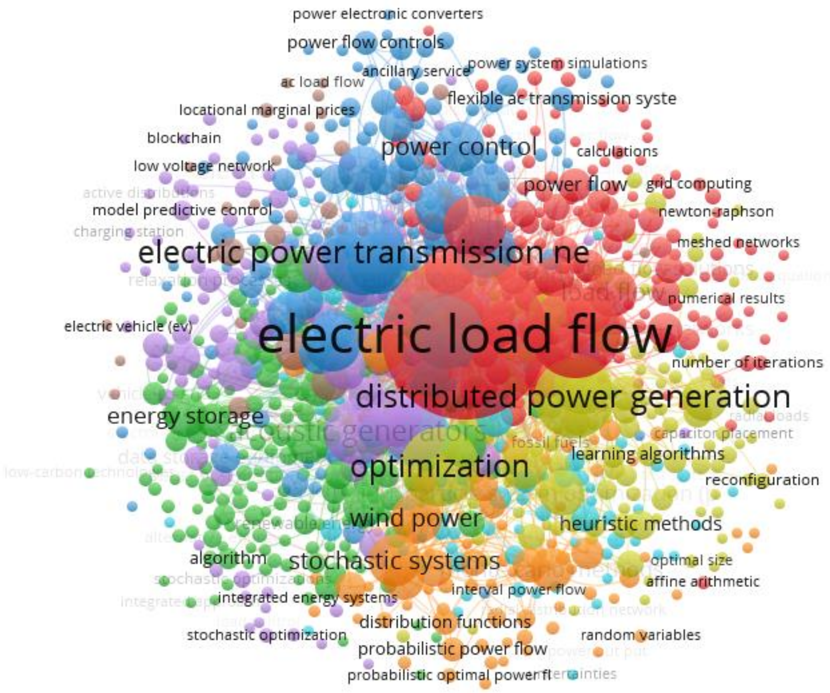

Figure 12: Co-occurrence Analysis in Terms of Keywords

B) Term co-occurrences of Title and Abstract Fields

Co-occurrence analysis in terms of Title and abstract fields is considered in this section. Minimum number of occurrences of a term is considered to be 10. Out of 37578 terms, 897 terms met the threshold. Relevance score is calculated for each term. 60% most relevant terms were selected. Out of 538 terms, "mechanical property" term is having relevance score of 2.56 with 11 times occurrence in various documents as shown in figure 13. Table 9 presents keywords and their relevance score. 'Proceeding' has highest occurrences of 49.

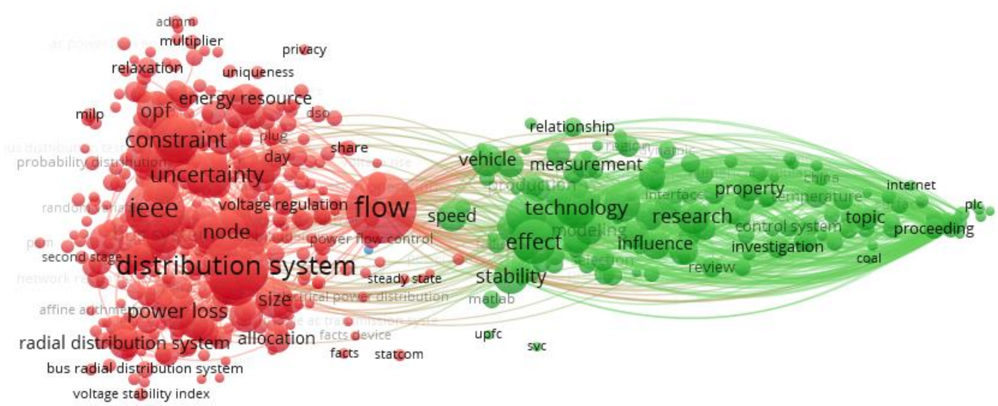

Fig 13. Term occurrences of Title & Abstract fields

Table 9. Term occurrences of Title & Abstract fields

Selected	Term	Occurrences	Relevance
✓	mechanical property	11	2.56
✓	microstructure	15	2.53
✓	plc	10	2.51
✓	experimental research	12	2.49
✓	finite element analysis	17	2.44
✓	preparation	23	2.43
✓	diesel engine	16	2.43
✓	special focus	43	2.39
✓	international conference	39	2.39
✓	conference	45	2.34
✓	experimental study	27	2.32
✓	proceeding	49	2.27
✓	internet	15	2.25
✓	synthesis	20	2.18
✓	admm	20	2.16
✓	pressure	28	2.15
✓	surface	32	2.09

C) Term co-occurrences of Title Field

Co-occurrence analysis in terms of Title field is considered in this section. Minimum number of occurrences of a term is considered to be 10. Out of 3921 terms, 58 terms met the threshold. 60% most relevant terms were selected. "international conference" is having relevance strength of 2.4 with 39 times occurrence in various documents as shown in figure 14. 'Distribution network' has occurrences of 29 with relevance score of 2.22. Table 10 presents terms in the decreasing order of their relevance strength.

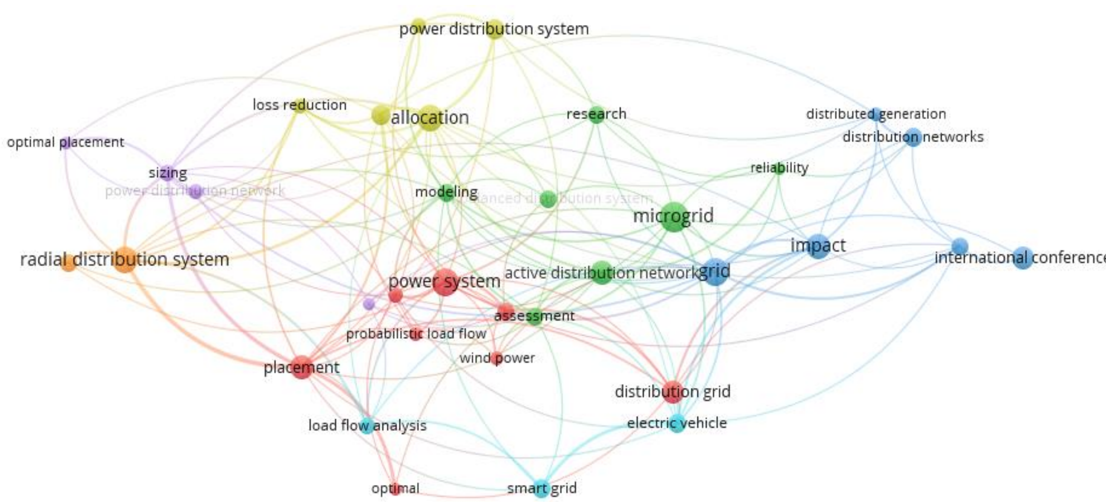

Fig 14. Term occurrences of Title field

Table 10. Term occurrences of Title field

Selected	Term	Occurrences	Relevance
☑	international conference	39	2.40
☑	distribution networks	29	2.22
☑	load flow solution	17	1.68
☑	power flow analysis	24	1.59
☑	optimal placement	14	1.56
☑	distributed generation	16	1.56
☑	smart grid	28	1.31
☑	load flow	23	1.27
☑	reliability	14	1.25
☑	power	26	1.17
☑	power distribution network	18	1.15
☑	power distribution system	32	1.12
☑	wind power	16	1.06
☑	optimal	13	1.04
☑	radial distribution system	52	0.94
☑	electric vehicle	29	0.87
☑	unbalanced distribution system	23	0.86

3.2.3. Network Analysis of Citations

This analysis is done with the units of documents, sources, authors, country and organization.

A) Citation Analysis of Documents

Out of total of 1635 documents, minimum 5 citations are considered as a threshold per document. 646 documents met the threshold. Document authored by Bologani (2016) has the highest link strength 13 with 217 number of citations. The largest set of connected items consists of only 174 in the network. Table 11 presents the data of documents, citations and links. Fig. 15 presents the network analysis of citations in terms of documents.

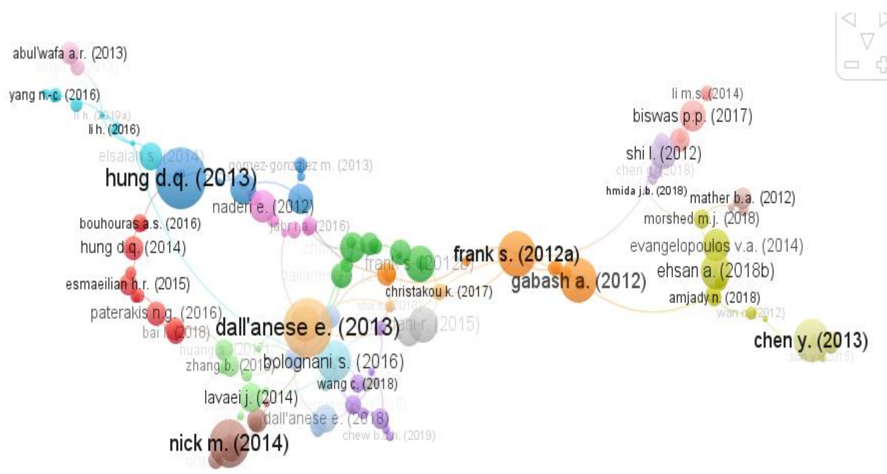

Figure 15: Network Analysis of Citations (In terms of Documents)

Table 11. Network Analysis of Citations (In terms of Documents)

Selected	Document	Citations	Links
☑	bolognani s. (2016)	217	13
☑	dall'anese e. (2013)	433	11
☑	zhang y. (2017)	118	7
☑	christakou k. (2017)	38	7
☑	chen y. (2013)	235	7
☑	hung d.q. (2013)	484	7
☑	bernstein a. (2018)	50	6
☑	gao h. (2018b)	66	6
☑	gabash a. (2012)	249	6
☑	montoya o.d. (2020a)	11	5
☑	li h. (2019a)	5	5
☑	ehsan a. (2019)	43	5
☑	li h. (2019b)	6	5
☑	hmida j.b. (2018)	9	5
☑	bucciarelli m. (2018)	31	5
☑	peng q. (2018)	72	5
☑	nick m. (2014)	301	5

B) Citation Analysis of Sources

Citation analysis of sources is obtained by considering the threshold of 5 citations per source. Out of the 610 sources only 53 met the threshold. IEEE Transactions on Power Systems has got maximum citations of 3562 and link strength of 125 with other sources. Fig 16 presents the Network Analysis of citation by sources

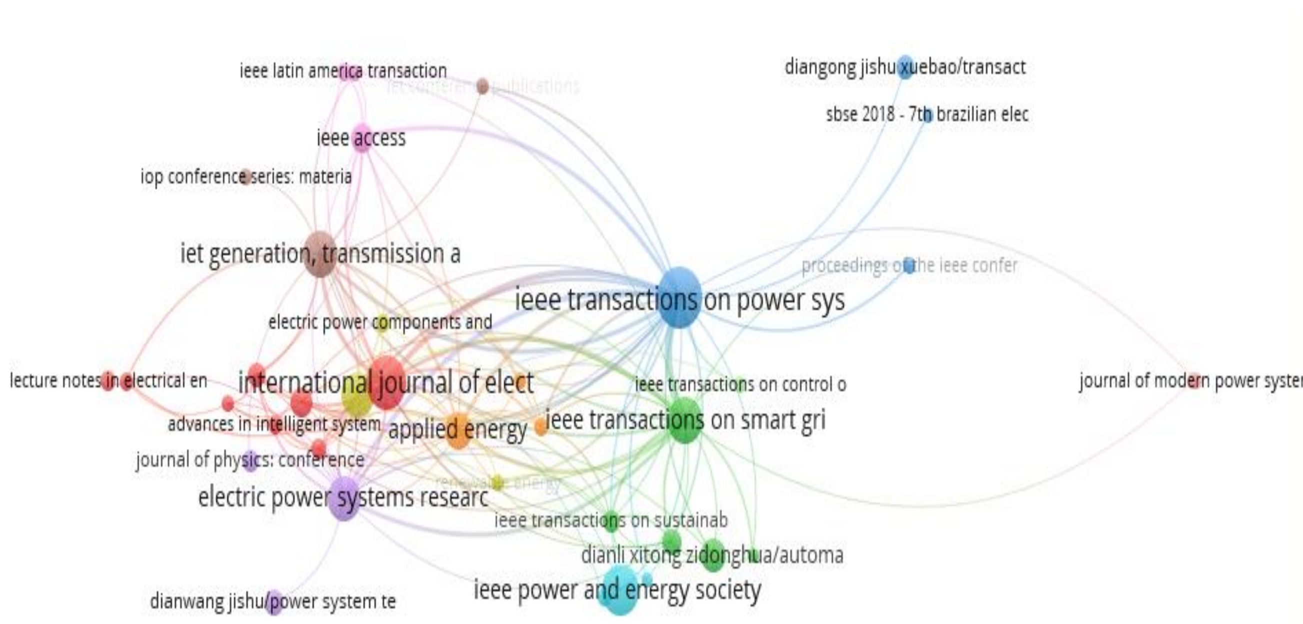

Figure 16: Network Analysis of citation by sources

C) Citation analysis by Authors

Threshold considered here is 5 citations per author. A total of 130 authors met the threshold amongst the total of 3826 authors. Dallanese has maximum link strength of 66 with other authors only for 9 documents with 647 citations. Fig 17 shows the Citation analysis by Authors

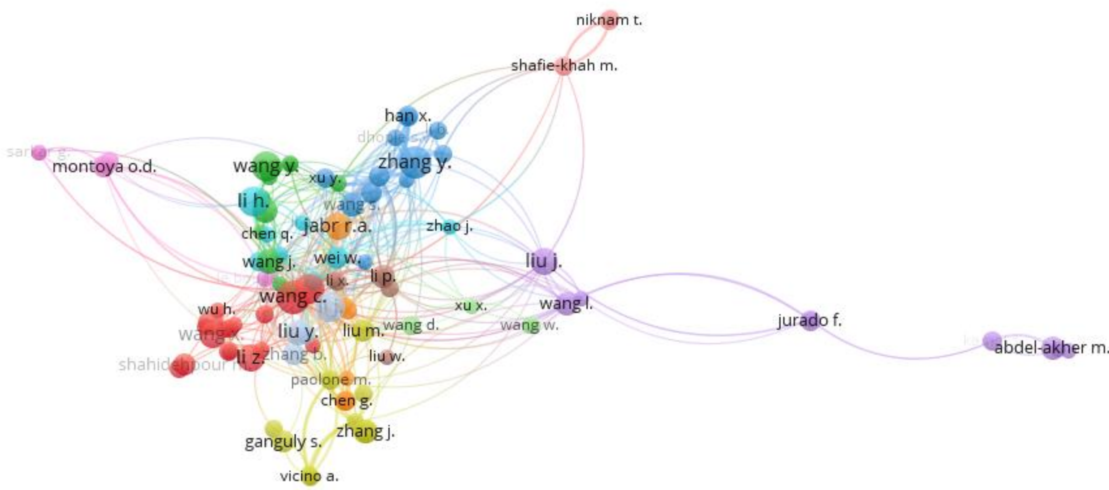

Figure 17: Citation analysis by Authors

D) Citation analysis by organization

There are total of 2596 organizations linked with this database. Threshold value considered in this analysis is 5 citations per organization. Total of 12 organizations met the threshold. Maximum link strength for citations is 2 for the University of Minnesota with 123 citations for 6 documents. Figure 18 shows the Citations by Organizations,

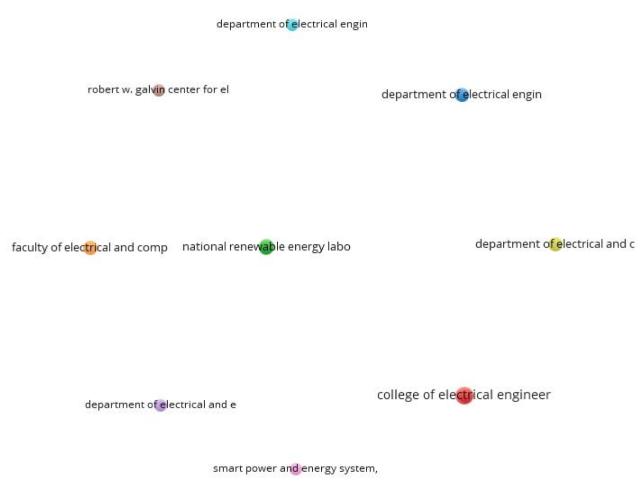

Figure 18: Citations by Organizations,

E) Citation analysis by country

Out of a total of 102 countries present in the database of the current search, 48 met the threshold criteria. Analysis has a threshold of minimum of 5 documents with minimum 5 citations. Fig. 19 shows Citation analysis by country. USA has highest link strength with 291 with 5643 citations for 268 documents.

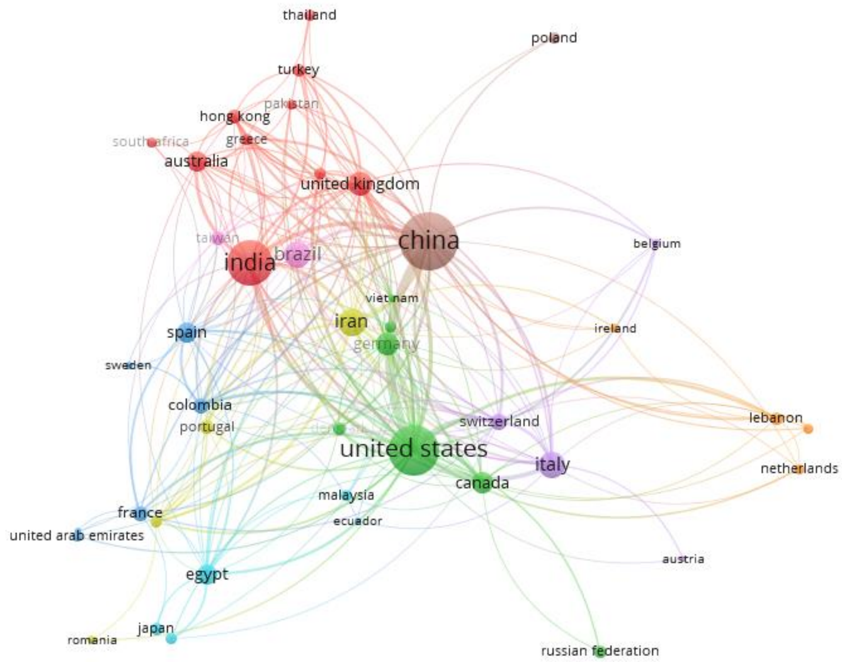

Figure 19. Citation analysis by country

3.2.4. Network Analysis of Bibliographic Coupling

A) Bibliographic Coupling of Documents

Total strength of bibliographic coupling links with other documents is calculated. Out of 1634 documents 646 documents met the criteria. Documents with minimum 5 citations are considered. Gao is found to have highest Bibliographic coupling strength of 190 with 66 citations.

B) Bibliographic coupling of Sources

In this analysis, 44 sources met the threshold amongst a total of 610 sources. Threshold considered here is 5 documents per source. IEEE Transactions on Power Systems has highest bibliographic coupling strength of 3389 with other sources with 3562 citations for 81 documents. Fig 21 shows the Bibliographic coupling by Sources.

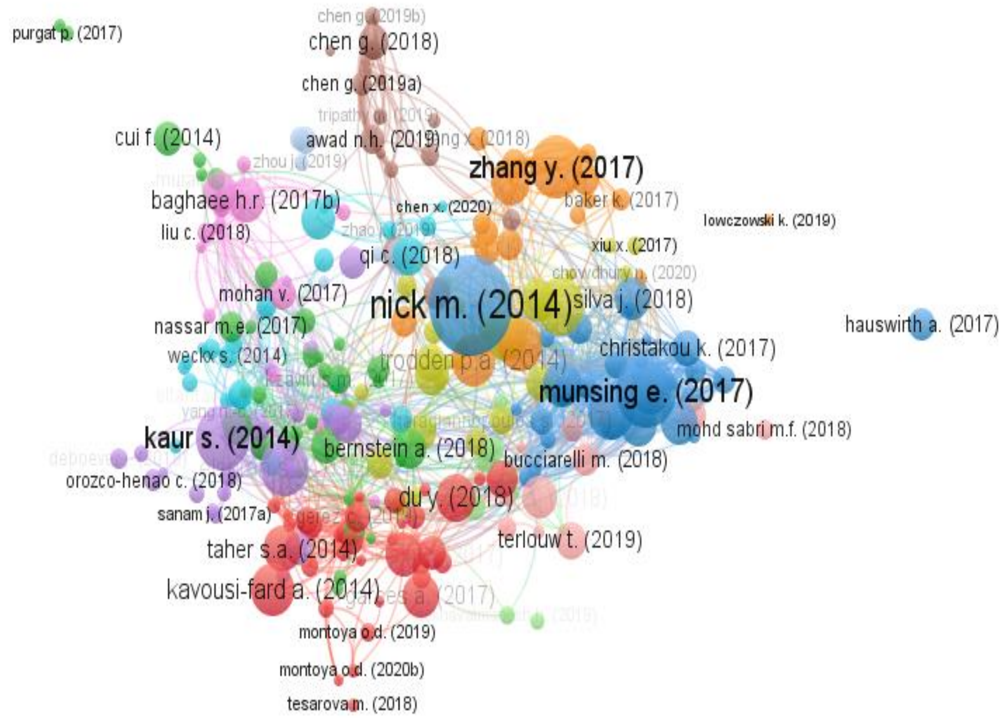

Fig. 20. Bibliographic coupling of Documents

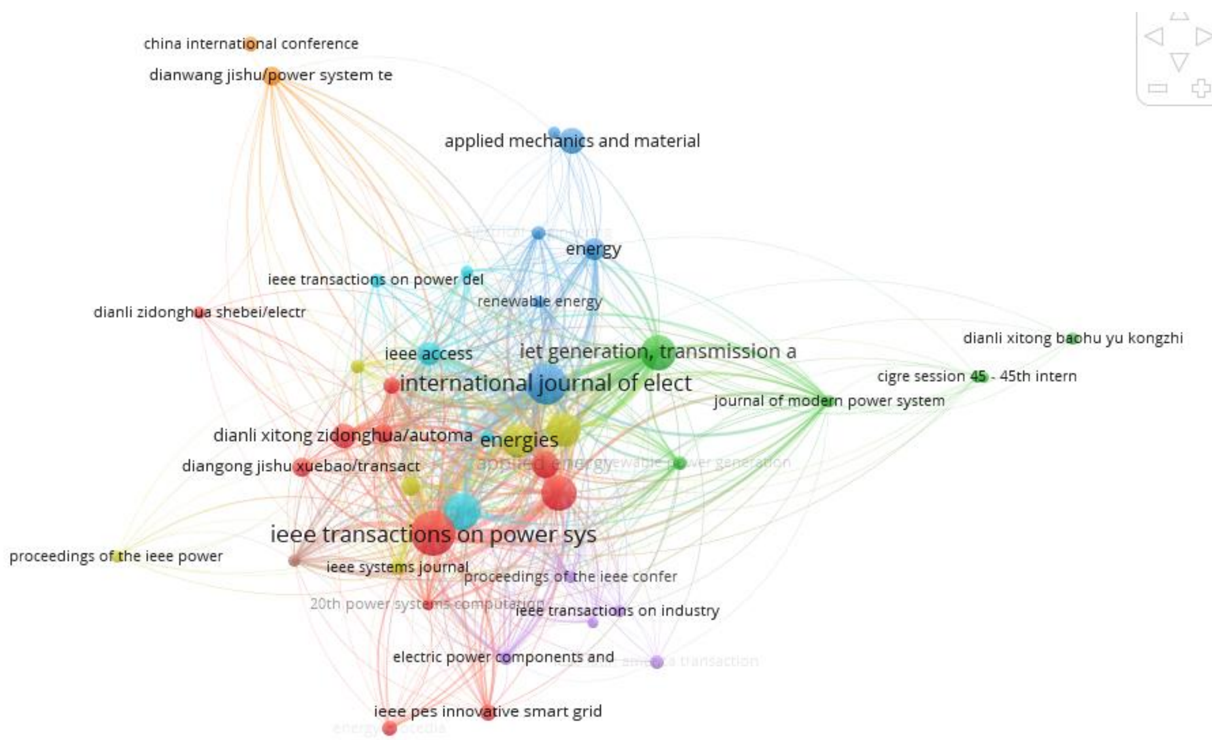

Fig. 21. Bibliographic coupling by Sources

C) Bibliographic coupling of Authors

Considering, 5 documents per author as a minimum threshold value. Out of total 3826 authors, 130 authors met the threshold criteria. Li J having maximum bibliographic coupling strength of 2028 with 9 documents and 210 citations for 18 documents. Fig 22 shows the Bibliographic coupling by Authors

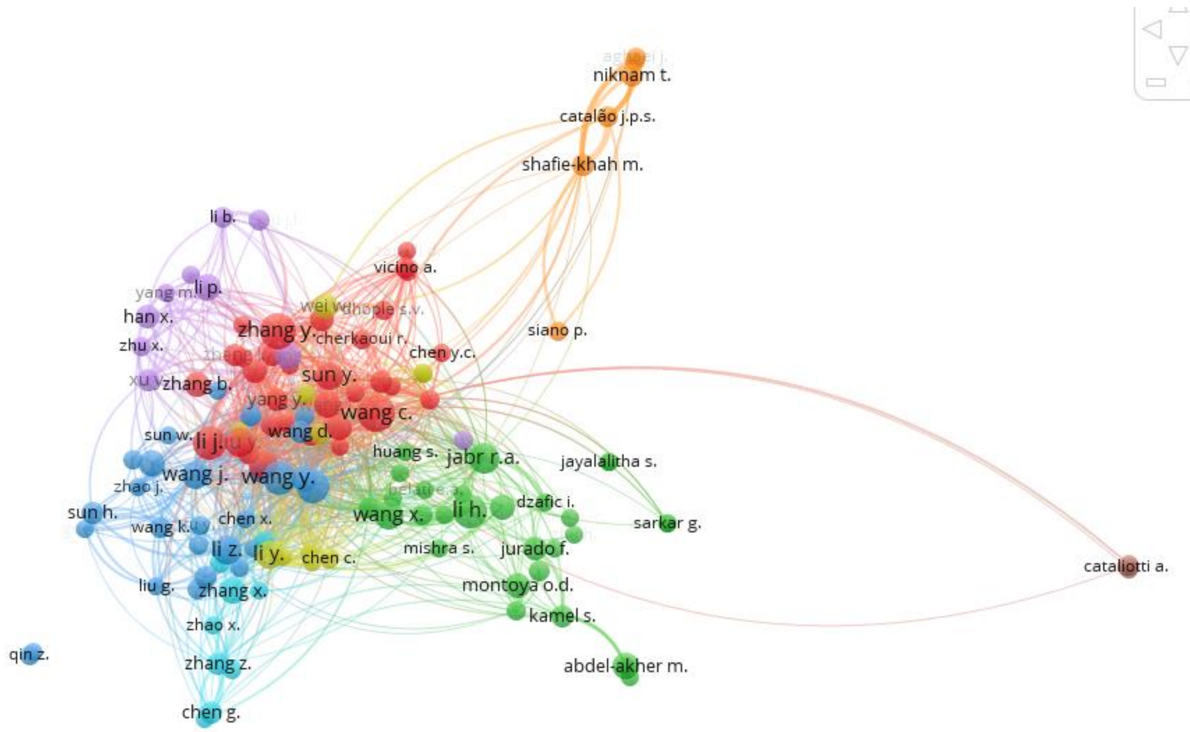

Figure 22. Bibliographic coupling by Authors

4. Conclusions

Bibliometric Survey is carried out on the topic of 'Load Flow Solution of Distribution Systems' using Scopus Database. There were 1711 documents found on this topic. Some of the highlights of observations are presented here. Majority of the published documents are articles and conferences papers. There are 53.1% articles and 42.6% conference papers. China has published 379 documents followed by USA. USA has published 280 documentsduring 2012-2021. Jabr published 15 documents in the chosen topic which is highest and followed by Montoya with 14 documents. Ministry of Education, China has published 36 number of documents which is the highest followed by North China Electric Power University with 29 documents. National Natural Science Foundation of China has sponsored 133 documents which is highest in the category of funding agencies followed by European Commission with 52 documents.

VOSviewer is used to carry out the network analysis. Co-authorship analysis is considered with other authors. Documents with a very large number of authors are ignored in this analysis. The documents with more than 25 authors are ignored. Threshold is considered as 5 for minimum number of documents of an author. It is seen that out of 3995 authors, 142 authors met the criteria. The total link strength of the co-authorship is calculated with other authors. Li J. has total link strength of 33 which is the highest in the co-authorship analysis in terms of authors with 19 documents.

Co-authorship in the unit of organizations is calculated considering minimum 03 documents in organizations by neglecting the citation of the same. 50 organizations met the criteria out of 2597 number of total organizations. Department of Electrical and Computer Engineering, University of Minnesota has highest link strength of 4 and number of citations 123 for 6 documents.

Co-authorship is also obtained in relation to the country. A total of 102 countries are there, in this database. After considering the threshold of minimum 5 documents in a country, 48 countries met the threshold. 47 countries have connection with each other. Here, United States found to have the highest citations of 5643, and the link strength of 145. This is followed by China with link strength of 98. As far as the number of document is concerned, China has the highest of all with 361 documents and link strength of 98.

Co-occurrence analysis in terms of keywords is considered in this section. Minimum number of occurrences of keywords is considered to be 5. Out of 9749 keywords, 911 keywords met the threshold. The keyword “electric load flow” is having 13182 link strength with 1196 occurrences in various documents.

In citation analysis of documents, out of total of 1635 documents, minimum 5 citations are considered as a threshold per document. 646 documents met the threshold. Document authored by Bologani (2016) has the highest link strength 13 with 217 number of citations. The largest set of connected items consists of only 174 in the network.

Citation analysis of sources is obtained by considering the threshold of 5 citations per source. Out of the 610 sources only 53 met the threshold. IEEE Transactions on Power Systems has got maximum citations of 3562 and link strength of 125 with other sources.

In citation analysis in terms of authors, threshold considered is 5 citations per author. A total of 130 authors met the threshold amongst the total of 3826 authors. Dallanese has maximum link strength of 66 with other authors only for 9 documents with 647 citations. There are total of 2596 organizations linked with this database.

In citation analysis by organizations, there are total of 2596 organizations linked with this database. Threshold value considered in this analysis is 5 citations per organization. Threshold value considered in this analysis is 5 citations per organization. Total of 12 organizations met the threshold. Maximum link strength for citations is 2 for the University of Minnesota with 123 citations for 6 documents.

In citation analysis by countries, out of a total of 102 countries present in the database of the current search, 48 met the threshold criteria. Analysis has a threshold of minimum of 5 documents with minimum 5 citations. USA has highest link strength with 291 with 5643 citations for 268 documents. Total strength of bibliographic coupling links with other documents is calculated. Out of 1634 documents 646 documents met the criteria. Documents with minimum 5 citations are considered. Gao is found to have highest Bibliographic coupling strength of 190 with 66 citations.

In Bibliographic analysis of sources, 44 sources met the threshold amongst a total of 610 sources. Threshold considered here is 5 documents per source. IEEE Transactions on Power Systems has highest bibliographic coupling strength of 3389 with other sources with 3562 citations for 81 documents.

In Bibliographic analysis of authors, considering, 5 documents per author as a minimum threshold value. Out of total 3826 authors, 130 authors met the threshold criteria. Li J having maximum bibliographic coupling strength of 2028 with 9 documents and 210 citations for 18 documents.

This can be concluded that the ‘Sliding Mode Control of Voltage Source Inverter’ is having lot of potential for research in future also.

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