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Optimal Distributed Generator Placement - A Bibliometric Survey

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Abstract : In this paper, Bibliometric survey has been carried out on Optimal Distributed Generator Placement from 1982 to 2021. Data is extracted from Scopus database for the analysis. There were total 1298 documents found on the topic of 'Optimal Distributed Generator Placement'. 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, Citation Analysis and Bibliographic coupling. Results are presented. During 2019, there were 170 documents published which is the highest. International Journal of Electrical Power and Energy Systems of Elsevier has published 57 documents during the period of study which is highest under the category of sources. 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, citations and bibliometric couplings. The Source for all Tables and figures is www.scopus.com, The data is assessed on 12th June, 2021.

Key Words : Optimal DG Placement, Bibliometric Analysis, statistical analysis, network analysis, Distributed Generator.

1. INTRODUCTION

Optimal capacitor placement is carried out in the Distribution Systems for reducing the active power loss and for improving voltage profile and optimal DG placement is implemented for improving the reliability of the system and reduction of active power loss. Mini Hydro DG injects both real power and reactive powers and capacitor injects only reactive power. Wind Power Generator injects real power and draws reactive power. Solar injects only real power into the network. Mathematical methods used in the design and analysis of transmission system are good for convergence but, it is not so for distribution systems. Radial Distribution System design with compensation is very complex as usual optimization techniques cannot be implemented. Several researchers worked on reducing the active power loss by implementing placement of DGs and Capacitors at their optimal locations.

DGs may not be a complete substitution of the central power stations but augment the power system with increase in reliability. Technical and economic factors affect amount of DG installation and feasibility of DG at any place. The advantages of adopting DGs include improvement of voltage stability, saving of power loss, better utilization of system capacity, and improvement in system dependability. At peak load periods DG can reduce the total cost. There were several AI techniques implemented along with conventional optimization tools for DG placement.

This paper presents bibliometric survey of Optimal DG Placement across the world from 1982 to 2021. India has published highest number of papers in this area. The number of publications have increased drastically since 2015. Literature Survey is presented in Section 2, Results and discussions are presented in Section 3 and Conclusions were presented in Section 4.

2. LITERATURE SURVEY

The following search is carried out on Scopus Database. Literature Survey is carried out in the decreasing order of number of citations. Highest citations were received by the article authored by Wang and Nehrir (2004) with 859 citations. This section presents, those publications which have received more than 135 citations.

(TITLE-ABS-KEY (optimal AND dg AND placement) OR TITLE-ABS-KEY (optimal AND distribution AND generator AND placement))

Wang et al developed analytical approaches for optimal placement of distributed generation (OPDG) sources in power systems [1]. Acharya et al. also developed an analytical approach for DG allocation in primary distribution network [2]. Moradi et al. used a combination of genetic algorithm and particle swarm optimization for OPDG [3]. Rao et al. proposed power loss minimization methodology in distribution system using network reconfiguration in the presence of distributed generation [4]. Georgilakis et al. worked on OPDG in power distribution networks: Models, methods, and future research [5]. Hung et al. worked on multiple distributed generator placement in primary distribution networks for loss reduction

[6]. Gözel et al. developed an analytical method for the sizing and siting of distributed generators in radial systems [7].

Al Abri et al. implemented OPDG to improve the voltage stability margin in a distribution system [8]. Nara et al. implemented Tabu search to solve OPDG [9]. Ghosh et al. worked on OPDG in a network system [10]. Viral et al. presented a review on OPDG [11]. Kansal et al. implemented OPDG with different types of DG sources in distribution networks [12]. Wang et al. developed Robust optimization based optimal DG placement in microgrids [13]. El-Zonkoly et al. worked on OPDG with multi-distributed generation units including different load models using particle swarm optimization [14]. Aman et al. implemented OPDG based on a new power stability index and line losses [15]. Injeti et al. proposed a novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems [16]. Nekooei et al. proposed an improved multi-objective harmony search for optimal placement of DGs in distribution systems[17].

Martín García et al. proposed a modified teaching-learning based optimization algorithm to solve OPDG [18]. Gautam et al. worked on OPDG in deregulated electricity market [19]. El-Fergany et al. worked on optimal allocation of multi-type distributed generators using back tracking search optimization algorithm [20]. Kayal et al. implemented OPDG using wind and solar based DGs in distribution system for power loss minimization and voltage stability improvement [21]. Popović et al. proposed OPDG and re-closers for improving security and reliability [22]. Khatod et al. proposed evolutionary programming based optimal placement of renewable distributed generators [23]. Wang et al. proposed reliability-constrained optimum placement of re-closers and distributed generators in distribution networks using an ant colony system algorithm [24]. Ameli et al. proposed a multi objective particle swarm optimization for solving OPDG from DG owner's and distribution company's viewpoints [25]. Mohamed Imran et al proposed a novel integration technique for optimal network reconfiguration and for OPDG in power distribution networks [26]. Prakash et al presented a review on OPDG [27]. Abdmouleh et al. presented a eview of optimization techniques applied for the integration of distributed generation from renewable energy sources [28].

El-Zonkoly et al. proposed a technique to solve OPDG including different load models using particle swarm optimization [29]. Haghifam et al. worked on risk-based distributed generation placement [30]. Griffin et al Implemented OPDG for reduction of system losses

[31]. Gopiya et al. implemented OPDG and capacitor for real power loss minimization in distribution networks [32]. Murty, V.V.S.N. et al. solved OPDG using a new voltage stability index under load growth [33]. Fazelpour et al. proposed an intelligent optimization to integrate a plug-in hybrid electric vehicle smart parking IOT with renewable energy resources and enhance grid characteristics [34]. Zhu et al. implemented OPDG and studied its impact on reliability and efficiency with time-varying loads [35].

Bagheri et al. worked on simultaneous reconfiguration, optimal placement of DSTATCOM, and photovoltaic array in a distribution system based on fuzzy-ACO approach [36]. Niknam et al. proposed a modified honey bee mating optimization algorithm for multi-objective placement of renewable energy resources [37]. Devi et al. implemented PSO for solving OPDG and DSTATCOM [38]. Moradi et al. developed an efficient hybrid method for solving OPDG and shunt capacitor banks simultaneously based on imperialist competitive algorithm and genetic algorithm [39]. Viral et al. proposed an analytical approach for solving OPDG in balanced radial distribution networks for loss minimization [40].

3. RESULTS AND DISCUSSIONS

3.1 Statistical Analysis

There are 1298 documents found on the topic of "Optimal Distributed Generator Placement". 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. International Journal of Electrical Power and Energy Systems of Elsevier has published 57 documents during the period of study which is the highest under the category of sources. This is followed by Lecture Notes in Electrical Engineering with 26 documents.

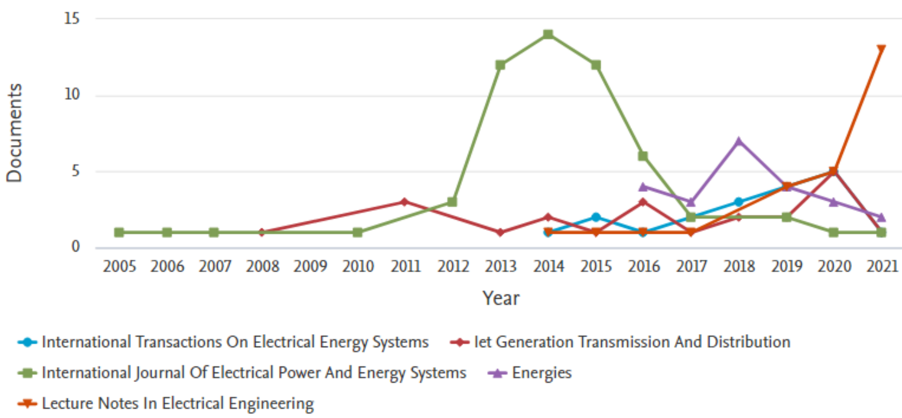

Fig. 1. Documents by Source

Table 1. Number of Documents by Source

S No.	SOURCE TITLE	NO. OF DOCUMENTS
1	International Journal of Electrical Power and Energy Systems	57
2	Lecture Notes in Electrical Engineering	26
3	Energies	23
4	IET Generation Transmission and Distribution	22
5	International Transactions On Electrical Energy Systems	17
6	Electric Power Systems Research	15
7	IEEE Transactions On Power Systems	15
8	International Review Of Electrical Engineering	14
9	International Journal Of Applied Engineering Research	13
10	Electric Power Components And Systems	12
11	Advances In Intelligent Systems And Computing	11
12	Renewable And Sustainable Energy Reviews	11
13	IEEE Region 10 Annual International Conference Proceedings TENCON	10
14	Applied Soft Computing Journal	9
15	International Journal Of Power And Energy Conversion	9

Fig. 2 shows the documents published year wise. Table 2 shows the number of documents by year. During 2019, there were 170 documents published which is the highest and followed by 2018. There were 147 documents published in the year 2018.

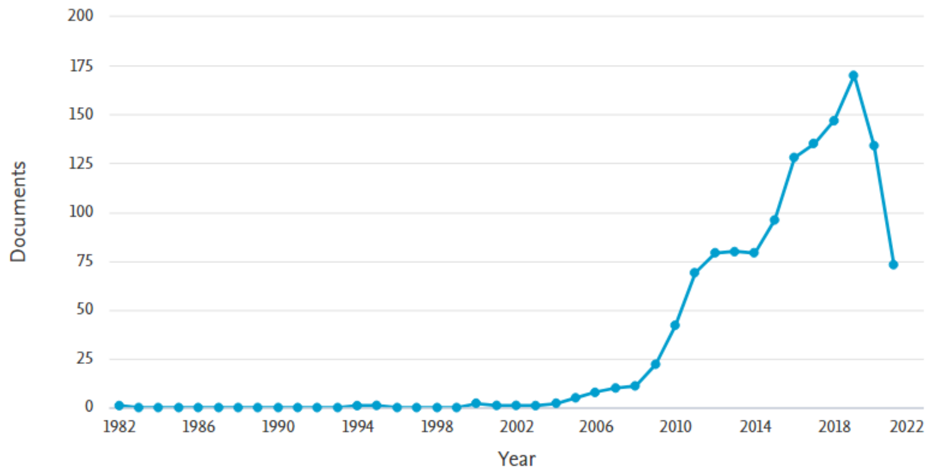

Fig. 2. Documents by year

Table2. Documents by Year

S. No.	YEAR	Number of Documents
1	2021	73
2	2020	134
3	2019	170
4	2018	147
5	2017	135
6	2016	128
7	2015	96
8	2014	79
9	2013	80
10	2012	79
11	2011	69

Fig. 3 shows the documents by subject area. Highest percentage of documents published in the Engineering area equal to 35.5% and followed by Energy area with 24.8%. The reason for having highest papers in the area of Engineering, is OPDG belongs to the area of Electrical Engineering.

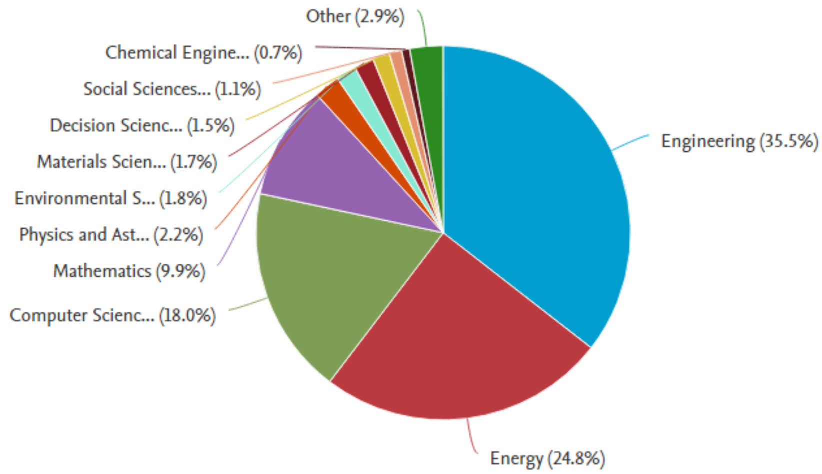

Fig. 3. Documents by Subject Area

Fig. 4 shows the distribution based on type of documents. Majority of the published documents are articles and conferences papers. There are 47.4% Articles and 46.9% Conference papers.

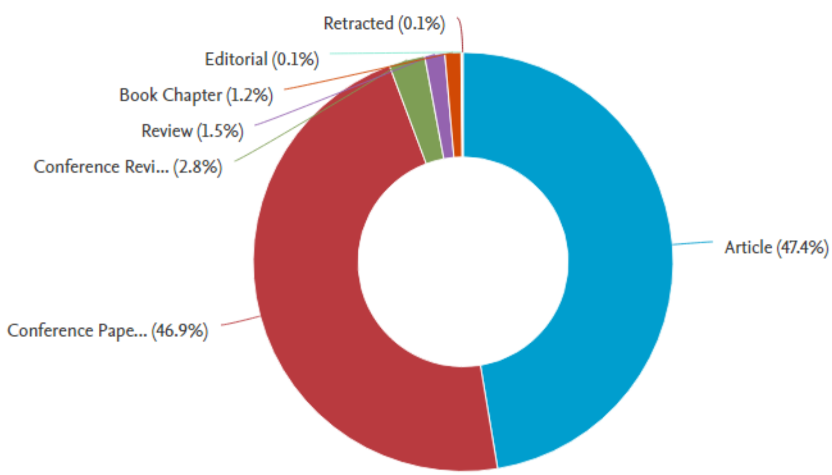

Fig. 4. Distribution based on type of document

Fig. 5 shows documents by country/territory. Table 3 presents documents by country. India has published 514 documents followed by Iran and USA. Iran has published 212 documents and USA has published 82 documents during 1982-2021

Table 3. Documents by Country

S. No.	Country / Territory	Number of Documents
1	India	514
2	Iran	212
3	United States	82
4	China	71
5	Malaysia	68
6	Egypt	56
7	Australia	32
8	Thailand	32
9	Indonesia	25
10	Pakistan	24

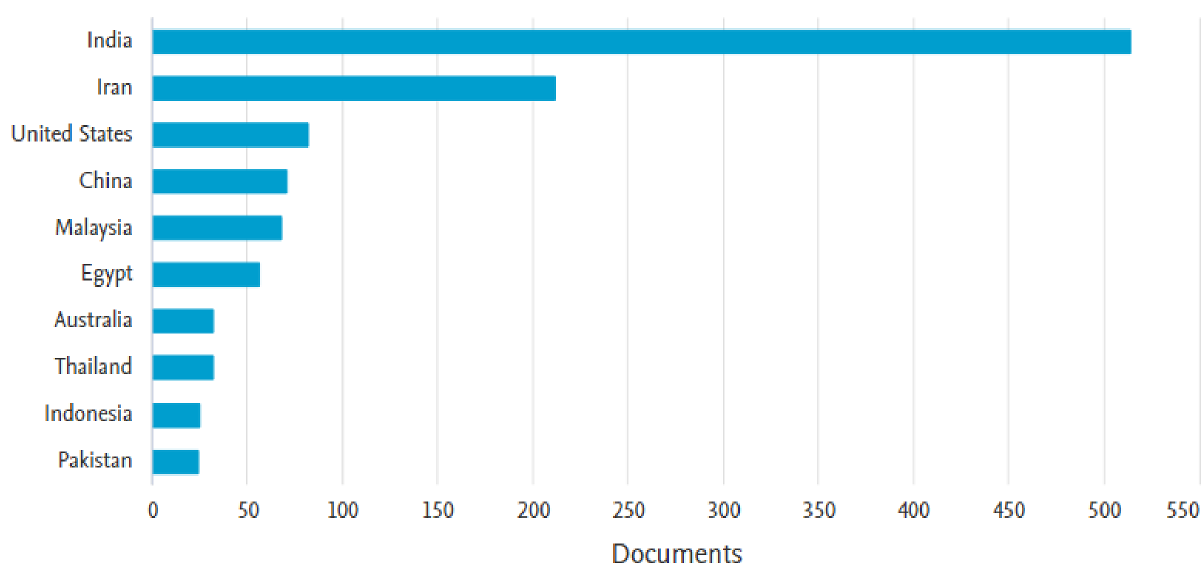

Fig. 5. Documents by Country

Fig. 6 shows documents by author. Table 4 presents the number of documents by author. Haghifam has published 12 documents in the area of ODGP which is highest and followed by Abdelaziz. Kamel and Kathod with 10 documents each.

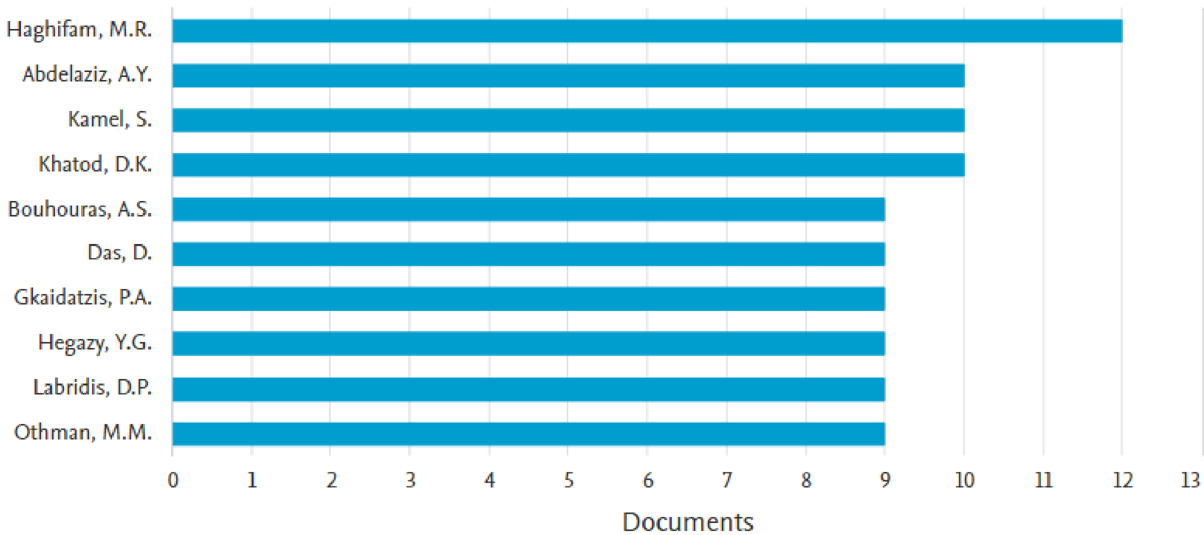

Fig. 6. Documents by author

Table. 4. Number of Documents by author

S. No.	AUTHOR NAME	Number of Documents
1	Haghifam, M.R.	12
2	Abdelaziz, A.Y.	10
3	Kamel, S.	10
4	Khatod, D.K.	10
5	Bouhouras, A.S.	9
6	Das, D.	9
7	Gkaidatzis, P.A.	9
8	Hegazy, Y.G.	9
9	Labridis, D.P.	9
10	Othman, M.M.	9
11	Sinha, S.K.	9

Fig. 7 shows documents by author's affiliation. Table 5 presents documents by author's affiliation. Islamic Azad University has published 28 number of documents which is the highest followed by Sharif University of Technology with 22 documents.

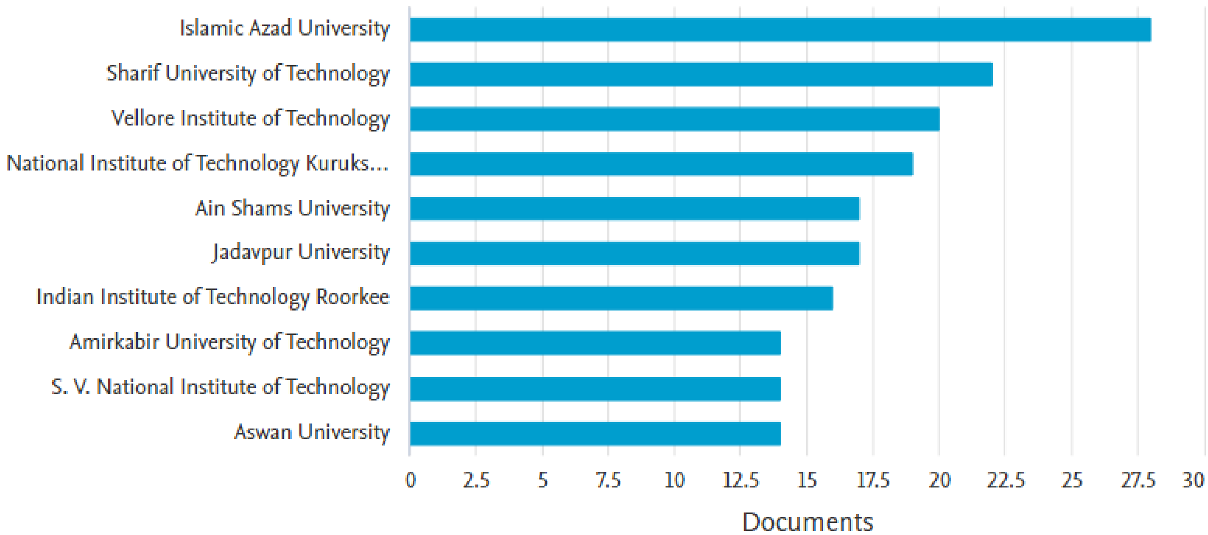

Fig. 7. Documents by affiliation

Table 5. Documents by affiliation

S. No.	AFFILIATION	No. of Documents
1	Islamic Azad University	28
2	Sharif University of Technology	22
3	Vellore Institute of Technology	20
4	National Institute of Technology Kurukshetra	19
5	Ain Shams University	17
6	Jadavpur University	17
7	Indian Institute of Technology Roorkee	16
8	Amirkabir University of Technology	14
9	S. V. National Institute of Technology	14
10	Aswan University	14
11	Tarbiat Modares University	13

Fig. 8 shows the documents by funding agency. National Natural Science Foundation of China has sponsored 18 documents which is highest in the category of funding agencies.

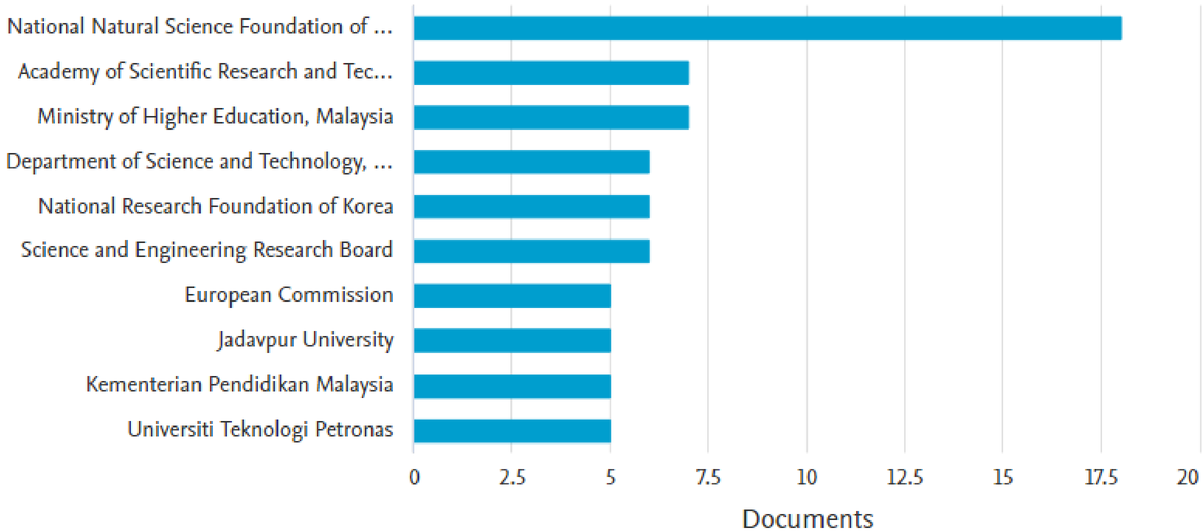

Fig. 8. Documents by Funding agency

3. 2 Network Analysis

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

1. Co-authorship: Authors, organizations, country
2. Co-occurrence: All keywords, Author keywords, Index keywords
3. Citation Analysis: Sources, authors, organizations, country
4. Bibliographic coupling: Documents, Authors

3.2.1 Co-authorship Analysis

In this section, Co-authorship analysis is considered with 03 different parameters related to it. The authors, organizations, and countries are considered for analyzing this parameter.

A) Co-authorship in terms of 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 3 for minimum number of documents of an author. It is seen that out of 2563 authors, 266 authors met the criteria. The total strength of the co-authorship is calculated with other authors. Bouhouras has total link strength of 33 which is the highest in the co-authorship analysis in terms of authors with 89 citations for 9 documents. Here a largest set of 45 authors found to have the relation in terms of co-authorship.

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

Selected	Author	Documents	Citations	Total link strength
☑	bouhouras a.s.	9	89	33
☑	gkaidatzis p.a.	9	89	33
☑	labridis d.p.	9	89	33
☑	doukas d.i.	8	88	31
☑	othman m.m.	12	238	28
☑	sgouras k.i.	7	80	28
☑	hegazy y.g.	9	235	22
☑	abdelaziz a.y.	10	242	21
☑	sinha s.k.	9	10	21
☑	kamel s.	10	68	20
☑	selim a.	8	60	18
☑	porkar s.	6	68	17
☑	poure p.	6	68	17
☑	saadate s.	6	68	17
☑	liu k.-y.	5	210	16
☑	liu y.	5	210	16
☑	sheng w.	5	210	16
☑	abbaspour-tehrani-fard a.	5	64	15
☑	el-khattam w.	5	197	15
☑	elamvazuthi i.	7	70	14

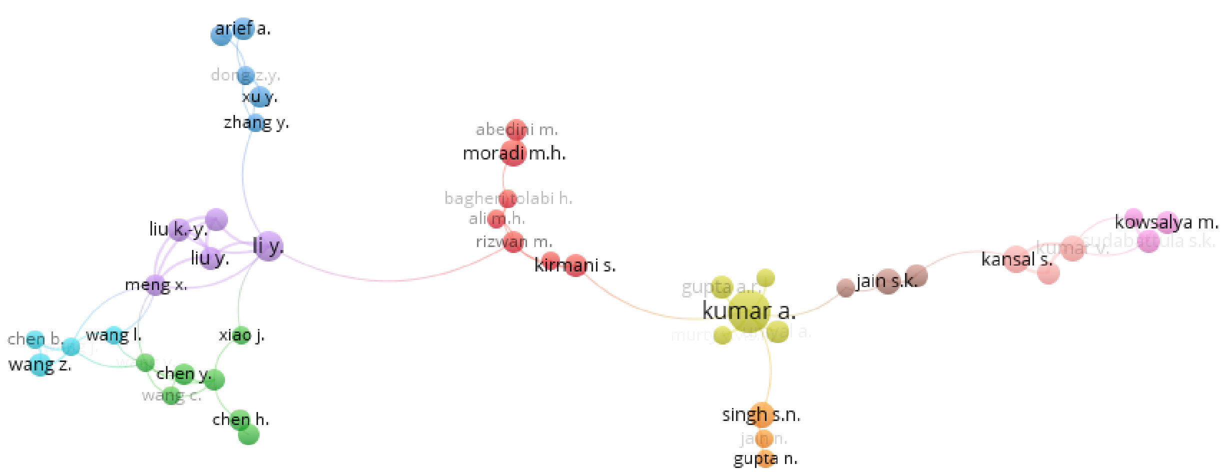

Fig. 9. Co-author relationship with each other

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. 43 organizations met the criteria out of 2004 number of total organizations, that are shown in the figure 10. UTB in Cartagena, De Boliver, Colombia has highest link strength of 7. The highest number of citations, 247 received by Sharif University of Technology, Tehran. Fig. 10 shows the network of co-authorship in terms of organizations.

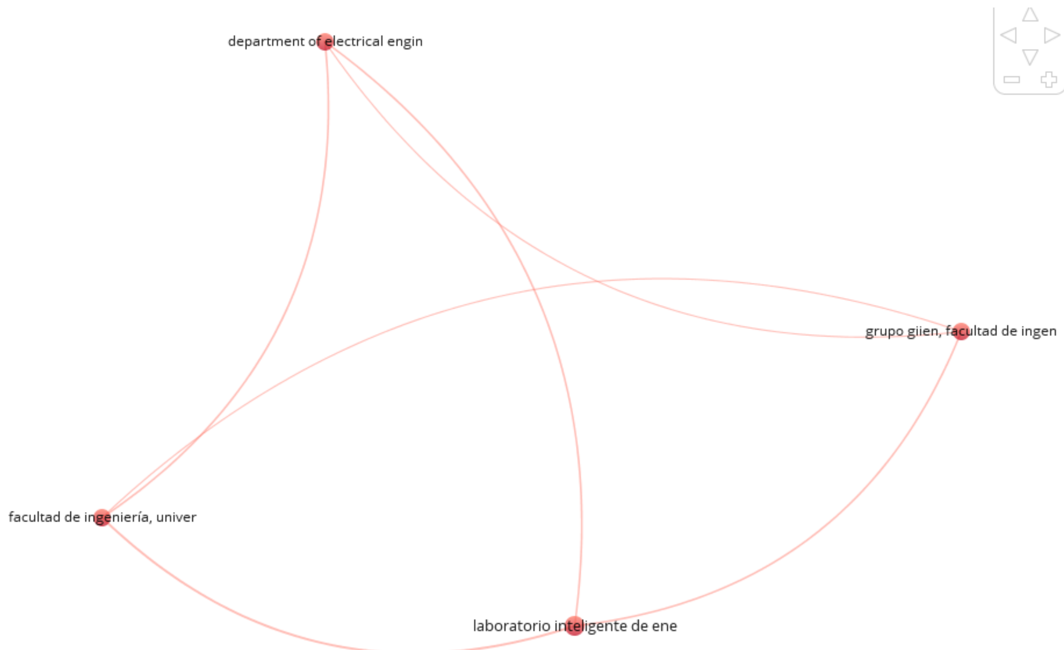

Figure 10: Co-authorship analysis in terms of Organizations

C) Co-authorship in terms of Country

Co-authorship is also obtained in relation to the country. A total of 77 countries are there, in this database. After considering the threshold of minimum 5 documents in a country, 37 countries met the threshold. Only 34 countries have connection with each other. Here, Iran found to have the highest link strength of 59 and 5082 citations for 211 documents and the. This is followed by United States with link strength of 45. Malaysia has link strength of 33 and India has 29. As far as the number of document is concerned, India has the highest of all with 514 documents with citations of 7218. 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
☑	iran	211	5082	59
☑	united states	82	3397	45
☑	malaysia	68	1044	33
☑	india	514	7218	29
☑	china	71	717	24
☑	australia	32	1138	22
☑	pakistan	24	251	21
☑	united kingdom	21	327	19
☑	egypt	56	1330	18
☑	saudi arabia	13	91	16
☑	south korea	16	410	13
☑	denmark	9	29	12
☑	spain	20	604	12
☑	france	14	337	11
☑	italy	18	190	11
☑	canada	17	1000	10

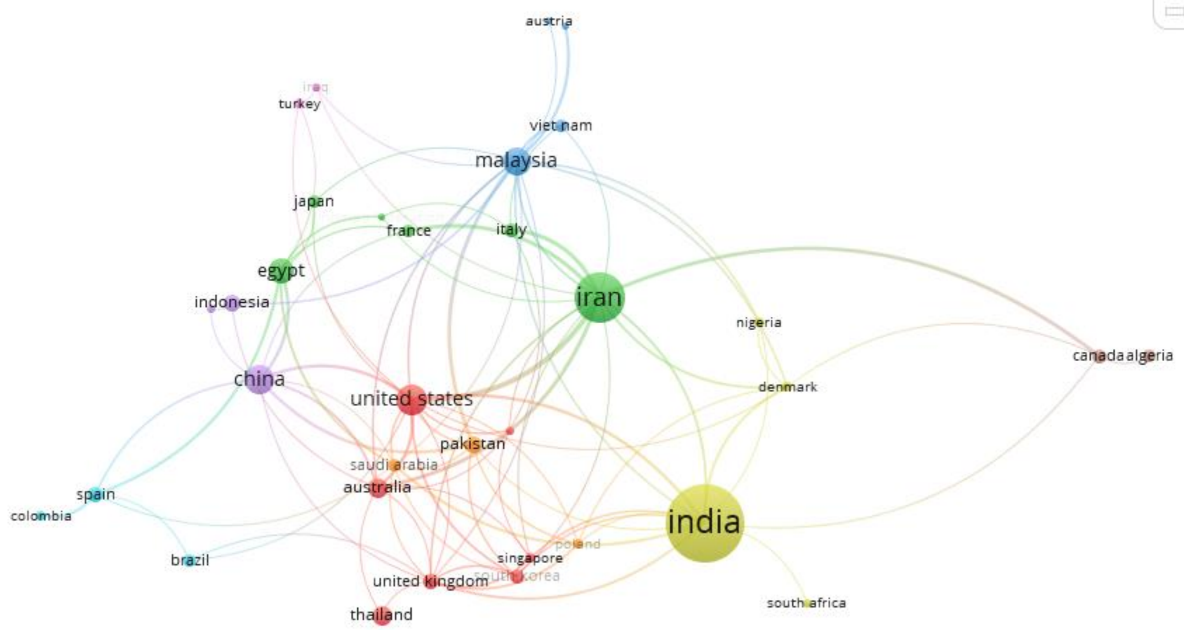

Fig. **11. Co-authorship in terms of Country**

3.2.2. Network Analysis of Co-occurrences

A) Co-occurrence analysis in terms of all keywords

For the analysis of co-occurrences, different keywords are considered. Minimum number of occurrences in the keywords is considered to be 5. Out of 5200 keywords, 618 keywords met the threshold. The keyword "distributed power generation" is having 8649 link strength with 741 times occurrence in various documents as shown in figure 10.

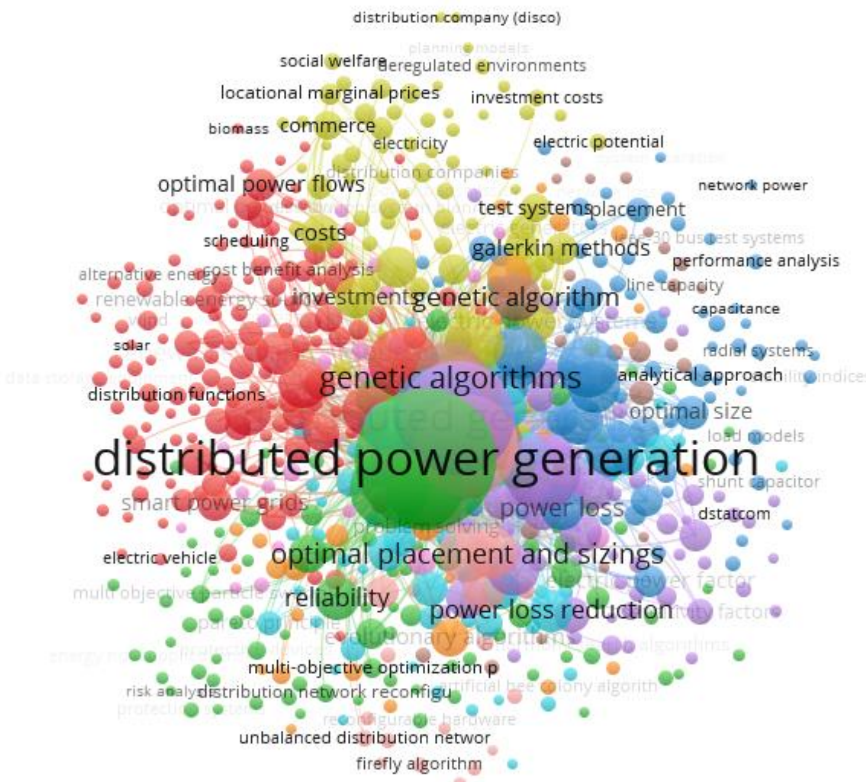

Figure 12: Co-occurrence Analysis in Terms of All Keywords

B) Co-occurrence analysis in terms of Author keywords

Co-occurrence of author keywords is analyzed with the minimum threshold of 5 per author. Out of 2333 keywords by the authors, 144 keywords met the threshold. 'Distributed Generation' keyword occurrence is 478 times with link strength of 944. This is followed by the keyword 'Optimal Placement' with 115 occurrences and link strength of 265. Table 8 shows the data of keywords and occurrences. Fig. 13 shows the occurrence analysis in terms of author keywords.

Table 8. Co-occurrence Analysis in Terms of Author Keywords

Selected	Keyword	Occurrences	Total link strength
☑	distributed generation	478	944
☑	optimal placement	115	265
☑	distributed generation (dg)	130	246
☑	voltage profile	76	203
☑	genetic algorithm	88	201
☑	distribution system	79	185
☑	power loss	69	174
☑	radial distribution system	68	161
☑	particle swarm optimization	60	159
☑	optimization	59	144
☑	loss reduction	55	128
☑	voltage stability	46	113
☑	power losses	43	112
☑	optimal location	39	111
☑	power loss reduction	41	109
☑	distribution network	47	98
☑	loss minimization	40	95
☑	reliability	42	94
☑	dg	48	91
☑	distributed generators	39	90

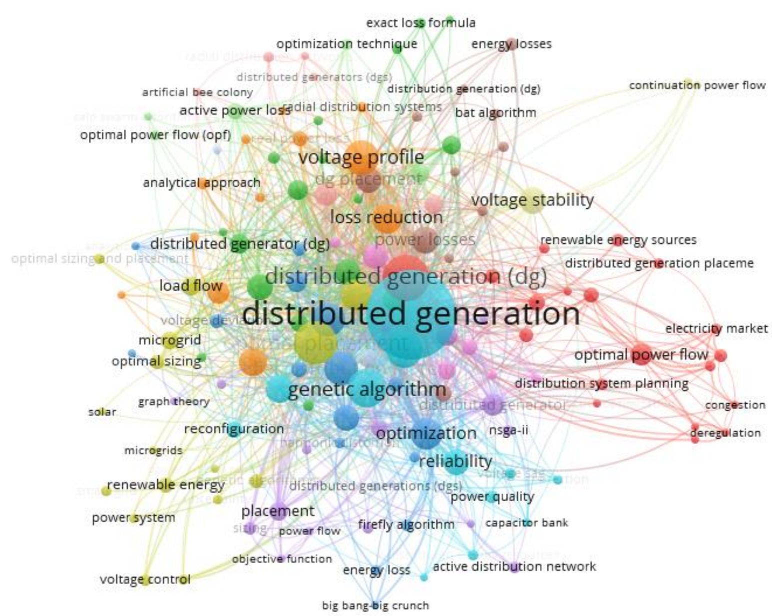

Figure 13: Co-occurrence Analysis in Terms of Author Keywords

C) Co-occurrence in terms of Index Keywords

Co-occurrence of index keywords is analyzed with the minimum threshold of 5 per author. Co-concurrence is considered by 3690 index keywords. Only 533 met the threshold. ‘Distributed Power Generation’ keyword has the highest occurrences of 741 times with link strength of 7343. Fig 14 shows the Co-occurrence Analysis in Terms of Index Keywords.

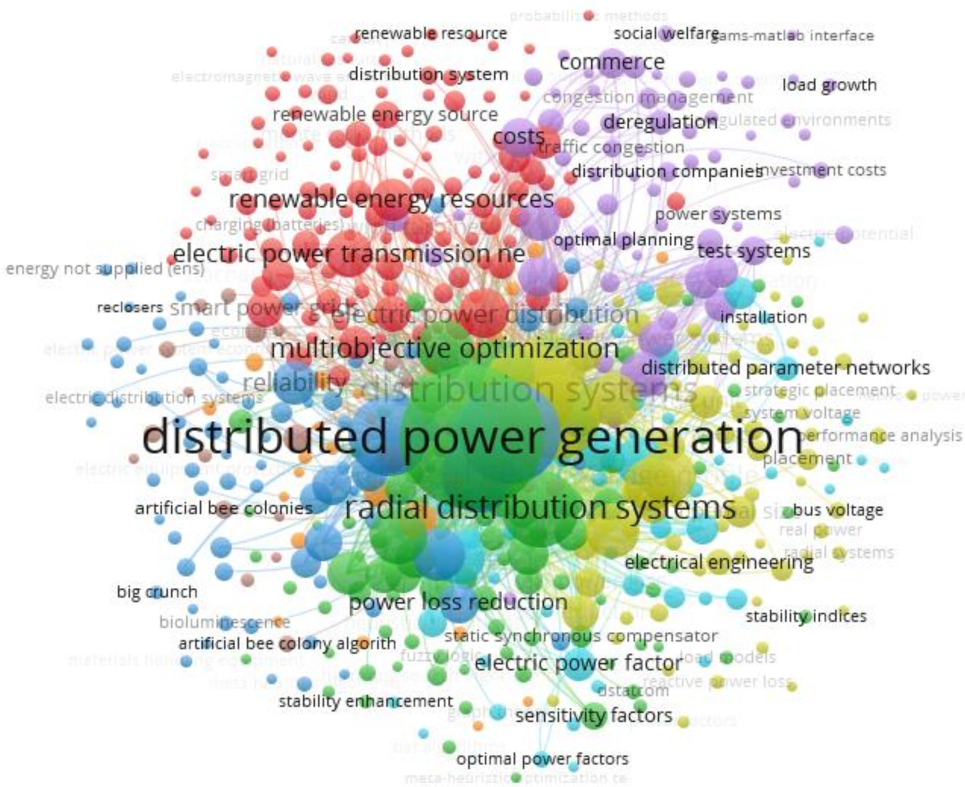

Figure 14: Co-occurrence Analysis in Terms of Index Keywords

3.2.3. Network Analysis of Citations

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

A) Citation Analysis of Documents

Out of total of 1298 documents, minimum 5 citations are considered as a threshold per document. 581 documents met the threshold. Document authored by Acharya (2006) has the highest link strength is 129 with 754 number of citations. The largest set of connected items consists of only 437 in the network. Table 9 presents the data of documents, citations and links. Fig. 15 presents the network analysis of citations in terms of documents.

Table 9. Network Analysis of Citations (In terms of Documents)

Selected	Document	Citations	Links
☑	acharya n. (2006)	754	129
☑	wang c. (2004)	859	122
☑	moradi m.h. (2012)	697	97
☑	hung d.q. (2013)	478	72
☑	georgilakis p.s. (2013)	570	63
☑	ghosh s. (2010)	272	43
☑	kansal s. (2013)	244	43
☑	prakash p. (2016)	173	43
☑	aman m.m. (2012)	206	38
☑	el-zonkoly a.m. (2011a)	211	36
☑	gautam d. (2007a)	199	35
☑	wang l. (2008)	179	33
☑	viral r. (2015)	137	32
☑	haghifam m.-r. (2008)	171	31
☑	rao r.s. (2013)	615	30
☑	al abri r.s. (2013)	351	30
☑	kayal p. (2013)	195	29

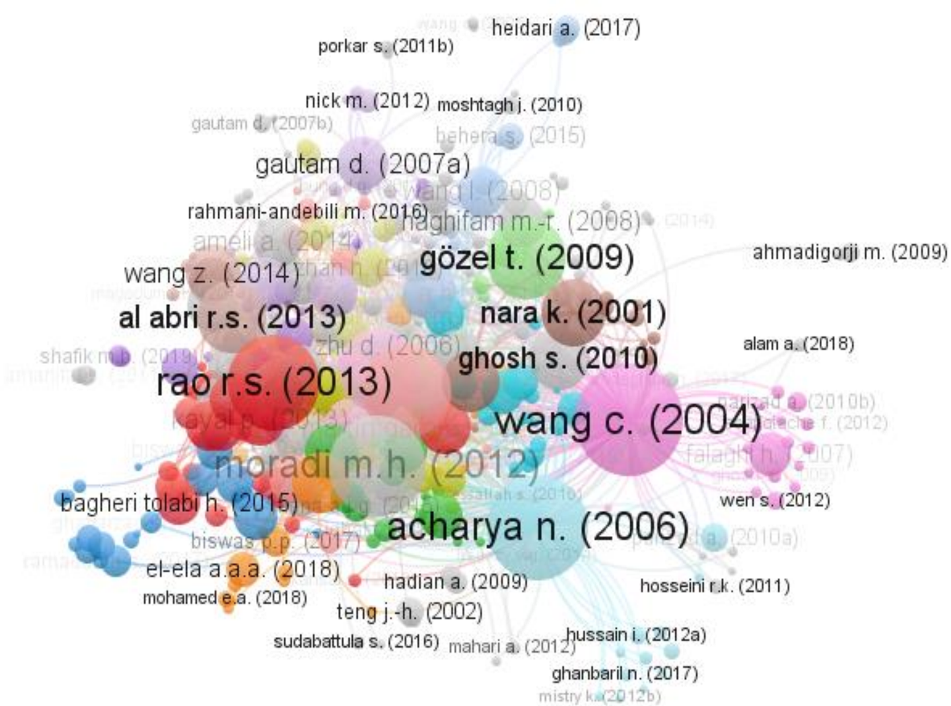

Figure 15: Network Analysis of Citations (In terms of Documents)

B) Citation Analysis of Sources

Citation analysis of sources is obtained by considering the threshold of 5 citations per source. Out of the 597 sources only 44 met the threshold. International Journal of Electrical Power and Energy Systems has got maximum link strength of 696 with citations of 6261 for 57 documents. Fig 16 presents the Network Analysis of citation by sources

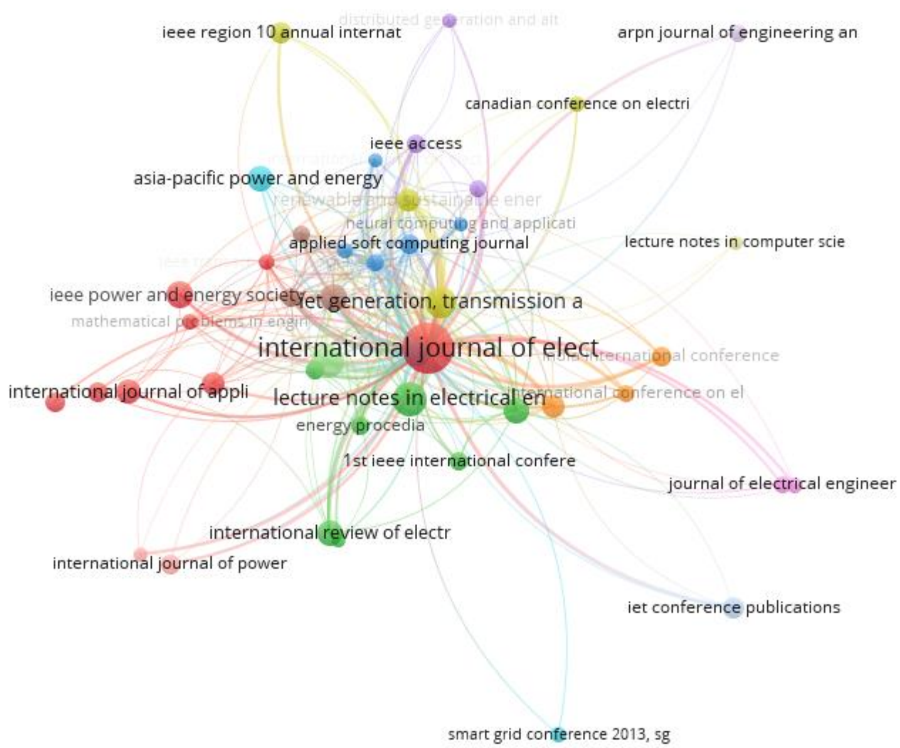

Figure 16: Network Analysis of citation by sources

C) Citation analysis by Authors

Threshold considered here is 5 citations per author. A total of 91 authors met the threshold amongst the total of 2563 authors. Mithulanathan has maximum link strength of 280 with other authors only for 8 documents with 1621 citations.   Fig 17 shows the Citation analysis by Authors.

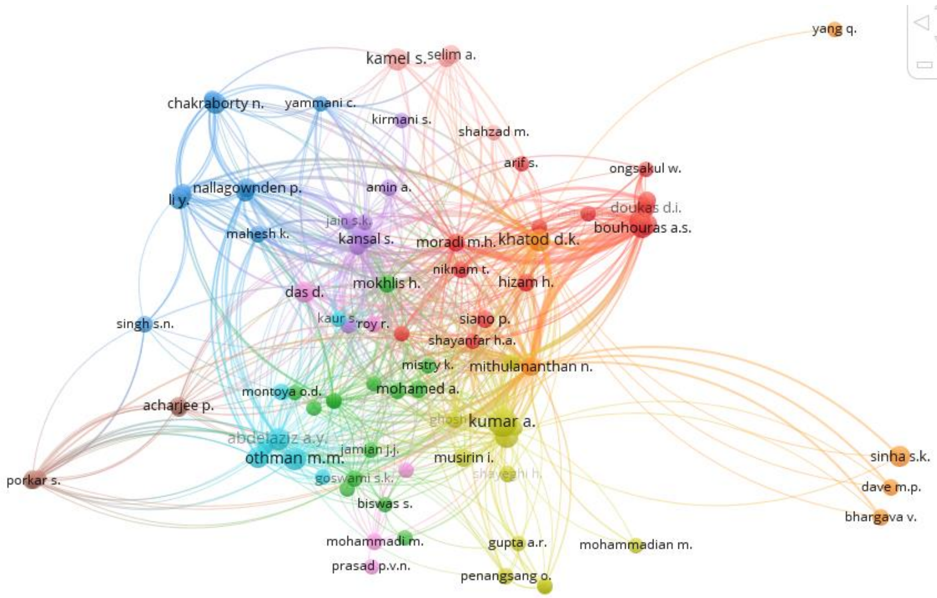

Figure 17: Citation analysis by Authors

D) Citation analysis by organization

There are total of 2004 organizations linked with this database. Threshold value considered in this analysis is 3 citations per organization. Total of 43 organizations met the threshold. Maximum citations are with the School of Information Technology & Electrical Engineering, University of Queensland. It has highest link strength of 20 with 629 citations for 3 documents. Figure 18 shows the Citation analysis by Organizations.

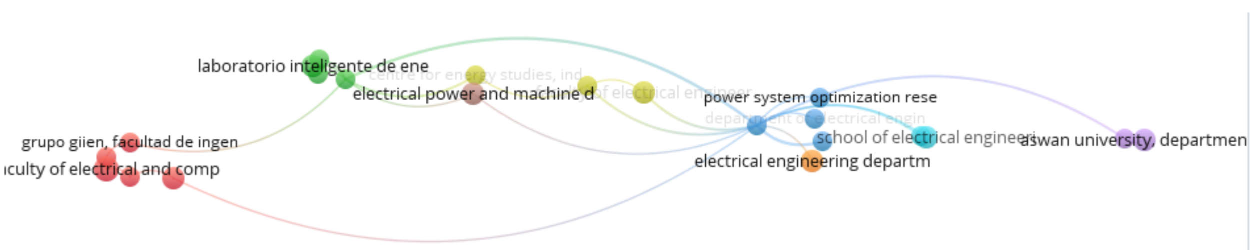

Figure 18: Citations by Organizations,

E) Citation analysis by country

Out of a total of 77 countries present in the database of the current search, 37 met the threshold criteria. Analysis has a threshold of minimum of 5 documents per country. Fig. 19 shows Citation analysis by country. India has highest link strength of 2080 with 7218 citations for 514 documents.

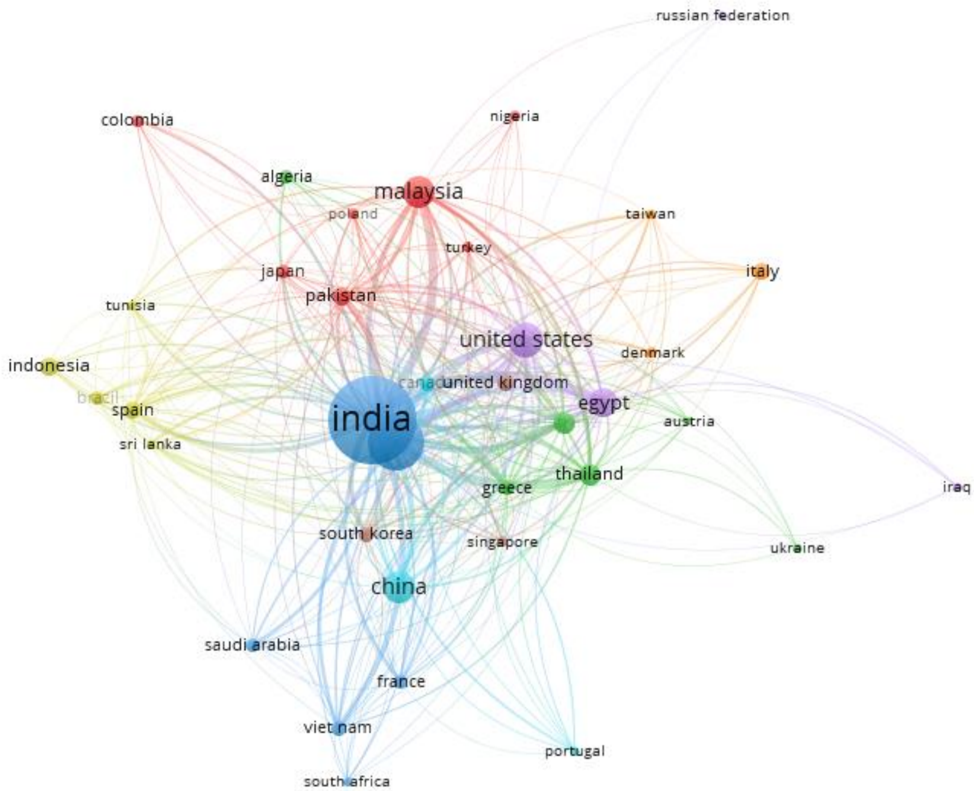

Figure 19. Citation analysis by country

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 1298 documents 225 documents met the criteria. Documents with minimum 20 citations are considered. Singh B (2015) is found to have highest Bibliographic coupling strength of 2340 with 72 citations.

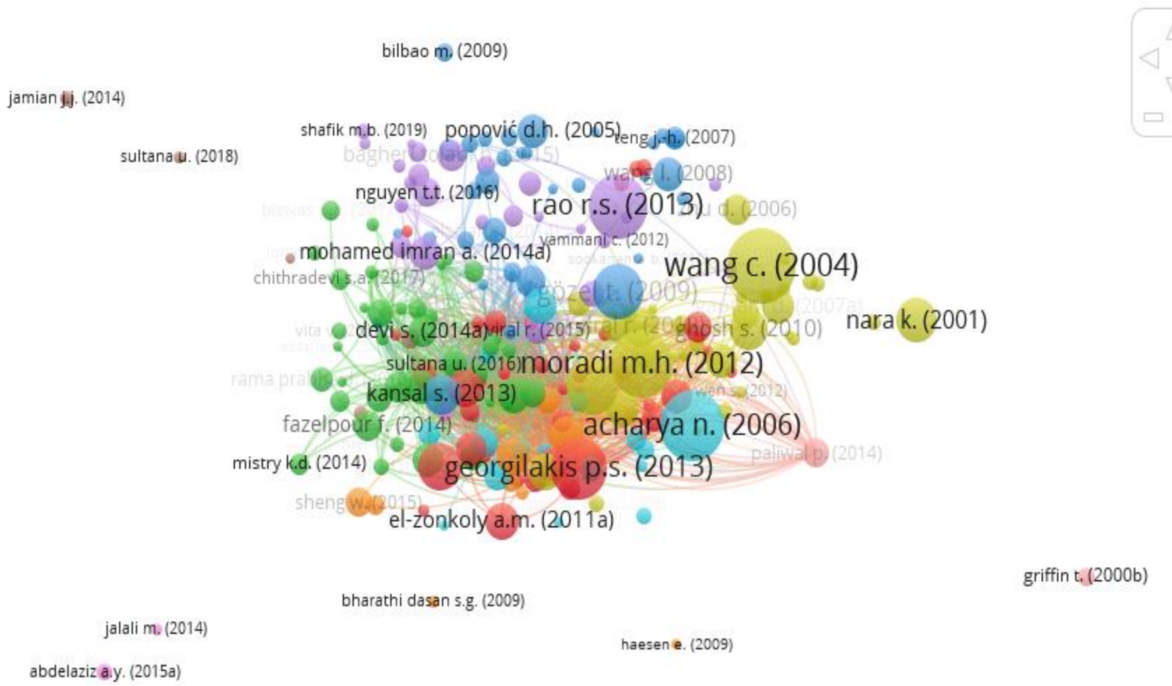

Fig. 20. Bibliographic coupling of Documents

Table 10. Bibliographic coupling of Documents

Selected	Document	Citations	Total link strength
☑	singh b. (2015)	72	2340
☑	georgilakis p.s. (2013)	570	1173
☑	jain s. (2017)	26	986
☑	abdmouleh z. (2017)	172	941
☑	prakash p. (2016)	173	917
☑	sultana u. (2016)	122	795
☑	viral r. (2012)	248	749
☑	kaur s. (2014)	122	725
☑	gampa s.r. (2015)	79	703
☑	viral r. (2015)	137	633
☑	gopiya naik s.n. (2015)	111	625
☑	othman m.m. (2015)	63	621
☑	saha s. (2016)	71	594
☑	paliwal p. (2014)	129	578
☑	martín garcía j.a. (2013)	203	558
☑	sultana s. (2016)	82	530
☑	hung d.q. (2014)	129	526
☑	das b. (2016)	56	523
☑	gkaidatzis p.a. (2017)	20	514
☑	kayal p. (2013)	195	509

B) Bibliographic coupling of Sources

In this analysis, 45 sources met the threshold amongst a total of 597 sources. Threshold considered here is 5 documents per source. International Journal of Electrical Power and Energy Systems has highest bibliographic coupling strength of 20452 with other sources with 6261 citations for 57 documents. Fig 21 shows the Bibliographic coupling by Sources.

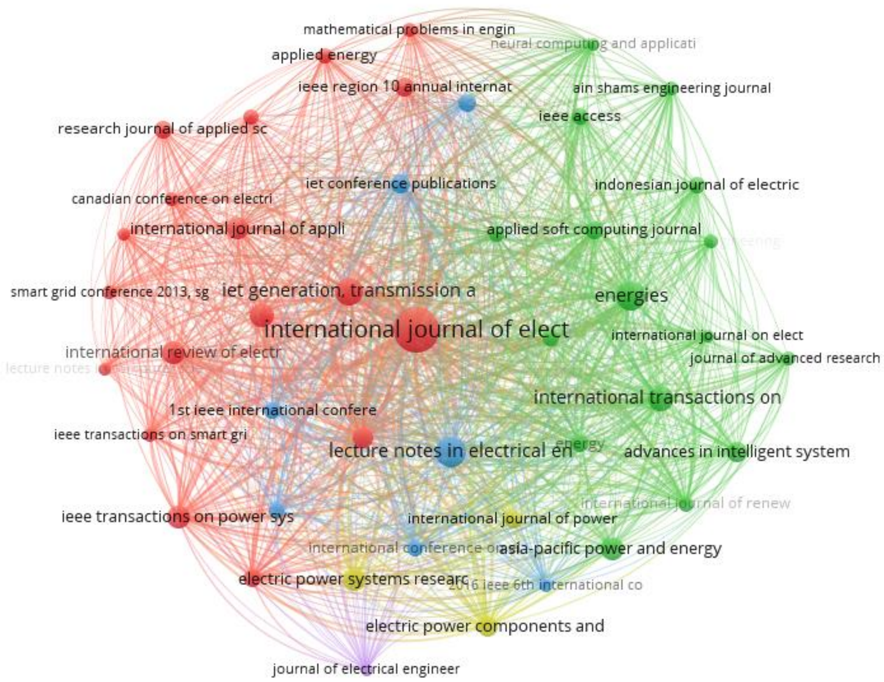

Fig. 21. Bibliographic coupling by Sources

C) Bibliographic coupling of Authors

Considering, 5 documents per author as a minimum threshold value. Out of total 2563 authors, 91 authors met the threshold criteria. Khatod is having maximum bibliographic coupling strength of 9358 with 10 documents and 1063 citations. Fig 22 shows the Bibliographic coupling by Authors

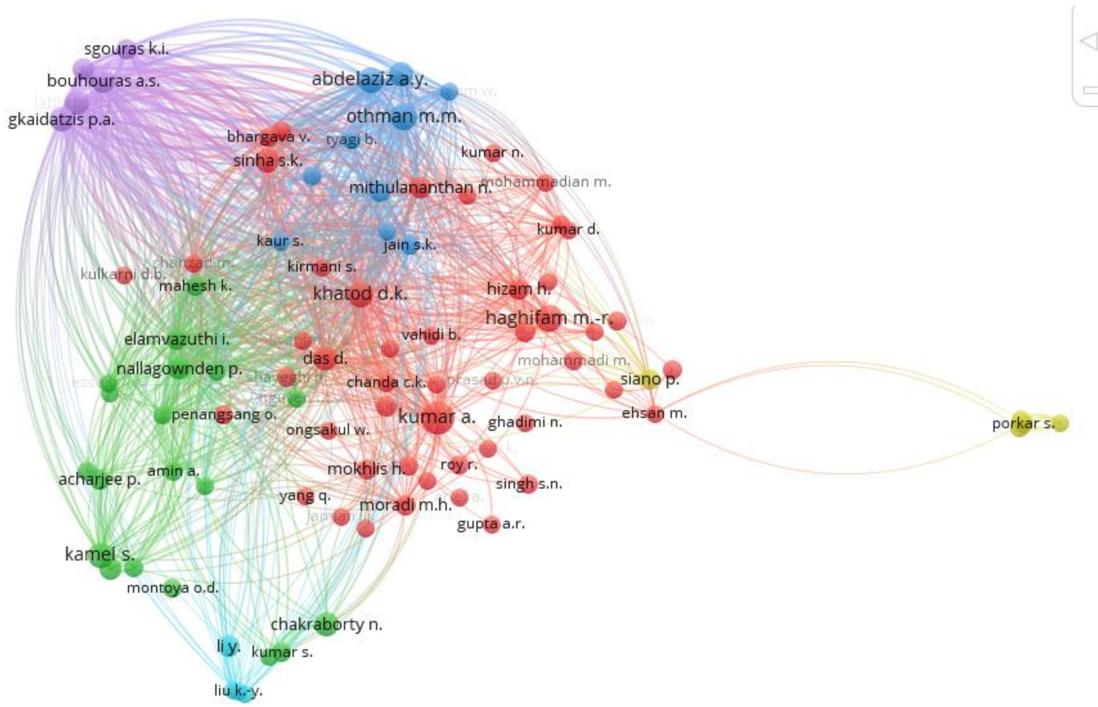

Figure 22. Bibliographic coupling by Authors

4. Conclusions

Bibliometric Survey is carried out on the topic of 'Optimal Distributed Generator Placement' using Scopus Database. There were 1298 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 47.4% Articles and 46.9% Conference papers. India has published 514 documents followed by Iran and USA. Iran has published 212 documents and USA has published 82 documents during 1982-2021. Haghifam has published 12 documents in the area of ODGP which is highest and followed by Abdelaziz. Kamel and Kathod with 10 documents each. Islamic Azad University has published 28 number of documents which is the highest followed by Sharif University of Technology with 22 documents. National Natural Science Foundation of China has sponsored 18 documents which is highest in the category of funding agencies.

VOSviewer is used to carry out the network analysis. Bouhouras has total link strength of 33 which is the highest in the co-authorship analysis in terms of authors with 89 citations for 9 documents. UTB in Cartagena, De Boliver – Colombia has highest link strength of 7. The highest citations of 247 by Sharif University of Technology, Tehran. Iran found to have the highest link strength of 59 and 5082 citations for 211 documents and the. This is followed by United States with link strength of 45. Malaysia has link strength of 33 and India has 29. As far as the number of document is concerned, India has the highest of all with 514 documents with citations of 7218. The keyword "distributed power generation" is having 8649 link strength with 741 times occurrence in various documents. 'Distributed Generation' keyword occurrence is 478 times with link strength of 944. This is followed by the keyword 'Optimal Placement' with 115 occurrences and link strength of 265. This can be concluded that the Optimal Distributed Generator Placement is having lot of potential for research in future also.

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