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Optimal Capacitor Placement - A Bibliometric Survey

K V S Ramachandra Murthy
Aditya Engineering College, murthy.kvs@aec.edu.in

K Prabha Rani
Aditya College of Engineering and Technology, prabharani.koppisetti@acet.ac.in

Ramesh Adireddy
Aditya College of Engineering, principal@acoe.edu.in

Nandan D.
Symbiosis International University, durgesh.nandan@aec.edu.in

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K V S Ramachandra Murthy
Aditya Engineering College,
Surampalem, India

K Prabha Rani
Aditya College of Engineering & Technology
Surampalem, India

A Ramesh
Aditya College of Engineering
Surampalem, India

D. Nandan
Symbiosis International University,
Pune, India

Abstract : In this paper, Bibliometric survey has been carried out on Optimal Capacitor Placement from 1981 to 2021. Scopus database has been used for the analysis. There were total 909 documents found on the topic of Optimal Capacitor 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 2016, there were 77 documents published which is the highest. International Journal of Electrical Power and Energy Systems of Elsevier has published 37 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 etc. The Source for all Tables and figures is www.scopus.com, The data is assessed on 6th June, 2021.

Key Words : Optimal Capacitor Placement, Bibliometric Analysis, statistical analysis, network analysis, reactive power management.

1. INTRODUCTION

The most effective and useful method in reducing the active power losses in distribution networks is utilization of optimal capacitor placement. Capacitors are widely installed in distribution systems for reactive power compensation. They help in improving the efficiency and service quality. The solution for the Problem of Optimal Capacitor placement (POCP) is the process of determination of the location, size and number of the capacitor to be placed in a radial distribution system such that maximum benefits are achieved. When search is conducted in Scopus database on the “Optimal Capacitor Placement”, there were 909 papers. Several methods based Artificial Intelligence methods, Meta heuristic methods and empirical formulae

were implemented. Index Vector method, sensitivity analysis and power loss index method are some of the techniques used for determining optimal location. Few researchers worked on unbalanced radial distribution systems for capacitor placement. 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. Literature Survey is carried out in the decreasing order of number of citations. Highest citations were received by the article authored by Baran et al with 1309 citations. This section presents, those publications which have received more than 120 citations.

TITLE-ABS-KEY (optimal AND capacitor AND placement)

Capacitor placement problem on radial distribution systems is formulated by Baran et al. [1]. The location, type, and size of capacitors, voltage constraints, and load variations were considered in the problem. The objective of capacitor placement is peak power and energy loss reduction by taking into account the cost of capacitors. The problem was formulated as a mixed integer programming problem. The power flows in the system are explicitly represented and the voltage constraints are incorporated. Gallego et al. used a combinatorial search algorithm and formulated POCP as a mixed integer nonlinear program[2]. They proposed a hybrid method drawn upon the Tabu Search approach, extended with genetic algorithms and simulated annealing. Chang, C., proposed reconfiguration and capacitor placement for loss reduction of distribution systems by ant colony search algorithm [3]. Kansal, S.et al. proposed Optimal placement of different type of DG sources and capacitors in distribution networks [4]. K. Prakash et al. presented a solution for POCP with Loss Sensitivity Factors (LSF) and Particle Swarm Optimization (PSO) [5]. The concept of Loss sensitivity Factors was their contribution in the area of distribution systems. Loss Sensitivity Factors offer the important information about the sequence of potential nodes for capacitor placement.

D. Das presented a genetic algorithm (GA) based fuzzy multi-objective approach for determining the optimum values of fixed and switched shunt capacitors to improve the voltage

profile and maximize the net savings in a radial distribution system [6]. R. Srinivasa Rao et al. presented a new Plant Growth Simulation Algorithm and efficient approach for solving POCP [7]. The solution methodology has two parts: in part one the loss sensitivity factors are used to select the candidate locations for the capacitor placement and in part two a new algorithm that employs Plant Growth Simulation Algorithm is used to estimate the optimal size of capacitors at the optimal buses determined in part one. H. D. Chiang et al. worked on capacitor placement, replacement and control in large-scale unbalanced distribution systems considering different loading levels [8]. The problem is how to optimally determine the location to install capacitors, the types and sizes of the capacitors to be installed and during each load level, the control scheme for each capacitor. Sultana et al proposed Optimal capacitor placement in radial distribution systems using teaching learning based optimization [9]. Yann-Chang et al solved the capacitor placement problem in a radial distribution system using tabu search approach[10]. Gopiya Naik et al. proposed optimal allocation of DG and capacitor for real power loss minimization in distribution networks [11]. Masoum et al. proposed optimal placement, replacement and sizing of capacitor banks in distorted distribution networks by genetic algorithms [12]. Mohamed Shuaib et al. proposed optimal capacitor placement in radial distribution system using Gravitational Search Algorithm [13]. Delfanti et al. proposed optimal capacitor placement using deterministic and genetic algorithms, [14]. Eajal et al. proposed optimal capacitor placement and sizing in unbalanced distribution systems with harmonics consideration using particle swarm optimization [15]. Moradi, M.H., Zeinalzadeh, A., Mohammadi, Y., Abedini, M., An efficient hybrid method for solving the optimal sitting and sizing problem of DG and shunt capacitor banks simultaneously based on imperialist competitive algorithm and genetic algorithm [16]. Levitin, G., Kalyuzhny, A., Shenkman, A., Chertkov, M., Optimal capacitor allocation in distribution systems using a genetic algorithm and a fast energy loss computation technique [17]. Zeinalzadeh et al. proposed optimal multi objective placement and sizing of multiple DGs and shunt capacitor banks simultaneously considering load uncertainty via MOPSO approach, [18]. Grainger et al. worked on capacity release by shunt capacitor placement on distribution feeders: A new voltage-dependent model [19]. El-Fergany et al proposed optimal capacitor allocations using evolutionary algorithms [20]. Sultana, et al presented a review of optimum capacitor placement based on minimization of power losses and voltage stability enhancement of distribution system [21]. El-Fergany et al implemented cuckoo

search algorithm for solving POCP [22]. Farahani et al proposed reconfiguration and capacitor placement simultaneously for energy loss reduction based on an improved reconfiguration method [23]. Abido et al used pole placement technique for PSS and TCSC-based stabilizer design using simulated annealing [24]. Haque determined the sizes of the capacitor by optimizing the loss saving equation [25].

3. RESULTS AND DISCUSSIONS

3.1 Statistical Analysis

There are 909 documents found on the topic of "Optimal Capacitor 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 37 documents during the period of study which is highest under the category of sources. This is followed by IEEE Transactions on Power Delivery with 20 documents.

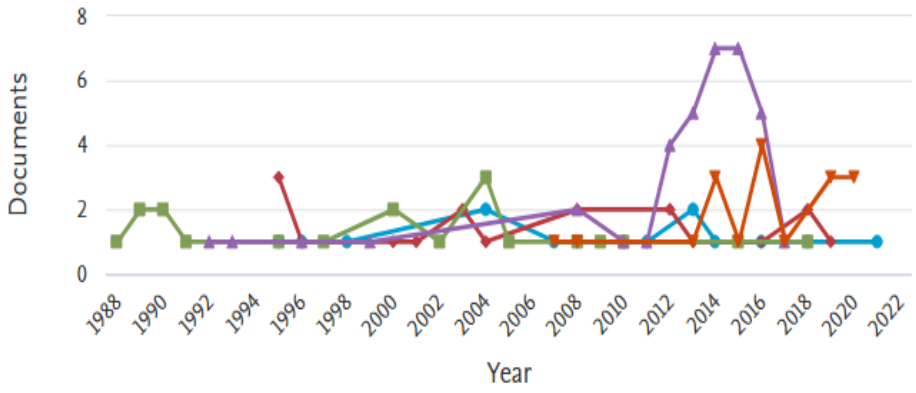

Fig. 1. Documents by Source

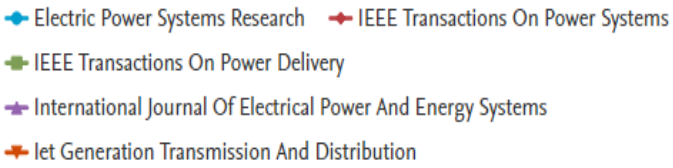

Table 1. Number of Documents by Source

SOURCE TITLE	NO. OF DOCUMENTS
International Journal Of Electrical Power And Energy Systems	37
IEEE Transactions On Power Delivery	20
IEEE Transactions On Power Systems	18
Iet Generation Transmission And Distribution	18
Electric Power Systems Research	15
International Journal Of Applied Engineering Research	13
Electric Power Components And Systems	12
International Transactions On Electrical Energy Systems	11
Proceedings Of The IEEE Power Engineering Society Transmission And Distribution Conference	11
International Review Of Electrical Engineering	10
International Review On Modelling And Simulations	9
Arpn Journal Of Engineering And Applied Sciences	8
IEEE Power Engineering Review	8
Journal Of Electrical Engineering	8
Lecture Notes In Electrical Engineering	8

Fig. 2 shows the documents published year wise. Table 2 shows the number of documents by year. During 2016, there were 77 documents published which is the highest and followed by 2019. There were 75 documents published in the year 2019.

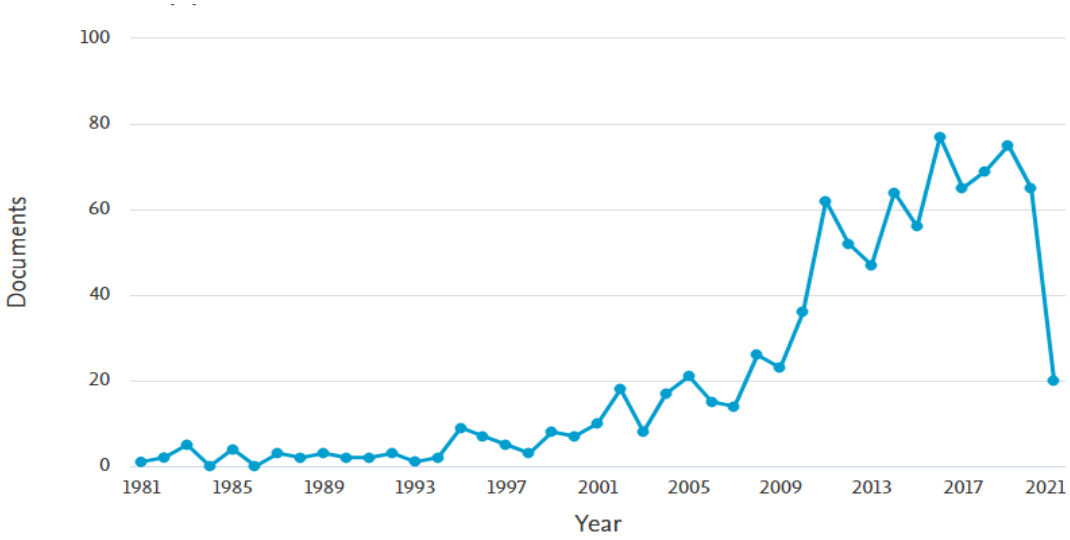

Fig. 2. Documents by year

Table2. Documents by Year

YEAR	Number of Documents
2016	77
2019	75
2018	69
2020	65
2017	65
2014	64
2011	62
2015	56
2012	52
2013	47
2010	36

Fig. 3 shows the documents by subject area. Highest percentage of documents published in the Engineering area equal to 40.7% and followed by Energy area with 23.5%. The reason for having highest papers in the area of Engineering, is POCP belongs to Electrical Engineering.

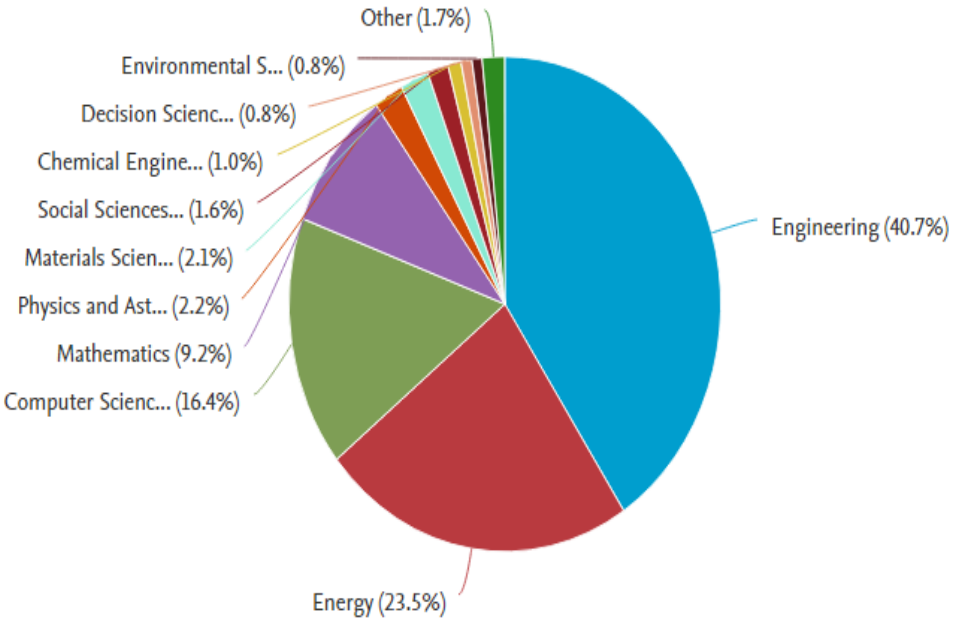

Fig. 3. Documents by Subject Area

Fig. 4 shows the distribution based on type of documents. Majority of the published documents are articles followed by conference papers. There are 50.3% Articles and 44.3% Conference papers.

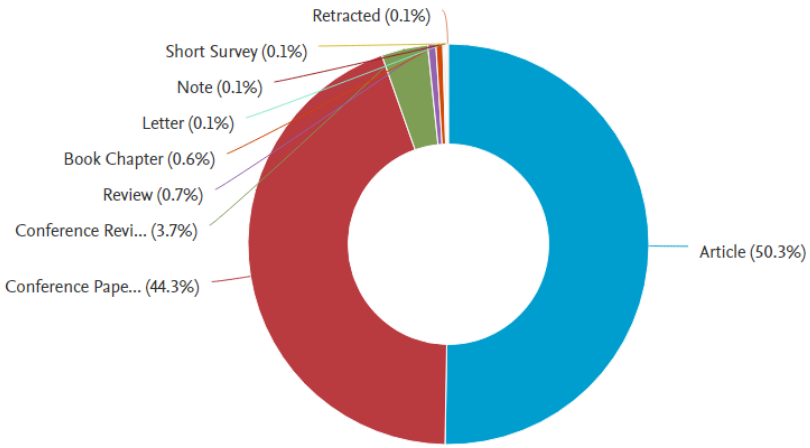

Fig. 4. Distribution based on type of document

Fig. 5 shows documents by country/territory. Table 3 presents documents by country. India has published 277 documents followed by Iran and USA. Iran has published 135 documents and USA has published 95 documents during 1981-2001

Table 3. Documents by Country

Country / Territory	Number of Documents
India	277
Iran	135
United States	95
Egypt	64
China	37
Taiwan	35
Brazil	29
Canada	28
Malaysia	23
Australia	17

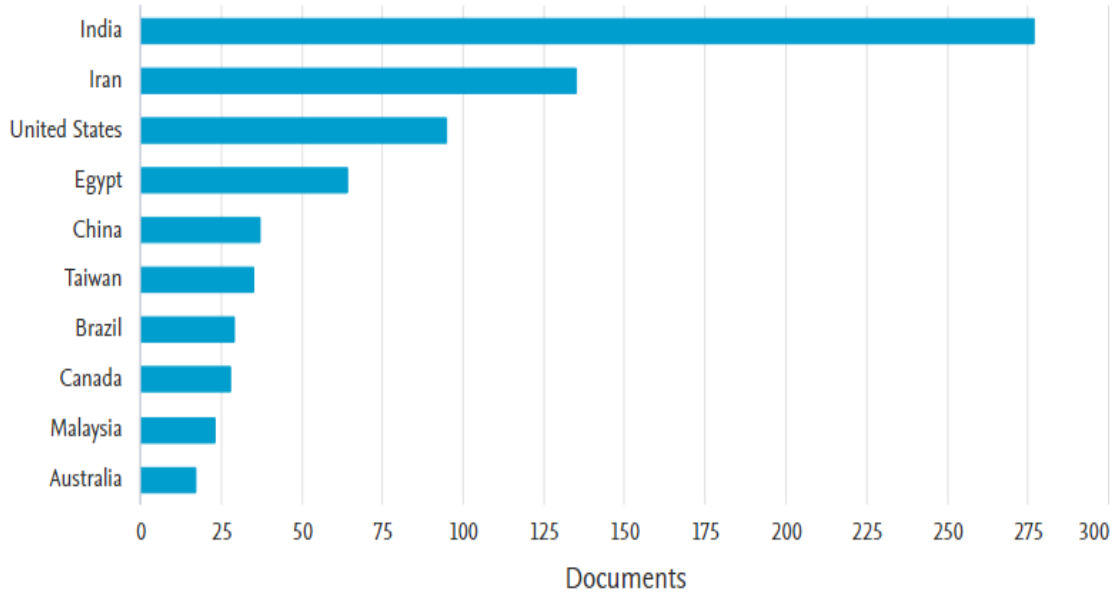

Fig. 5. Documents by Country

Fig. 6 shows documents by author. Table 4 presents the number of documents by author. El-Hawary and Grainger have published eleven documents each in the area of OCP which is highest and followed by Abdelaziz with 9 documents.

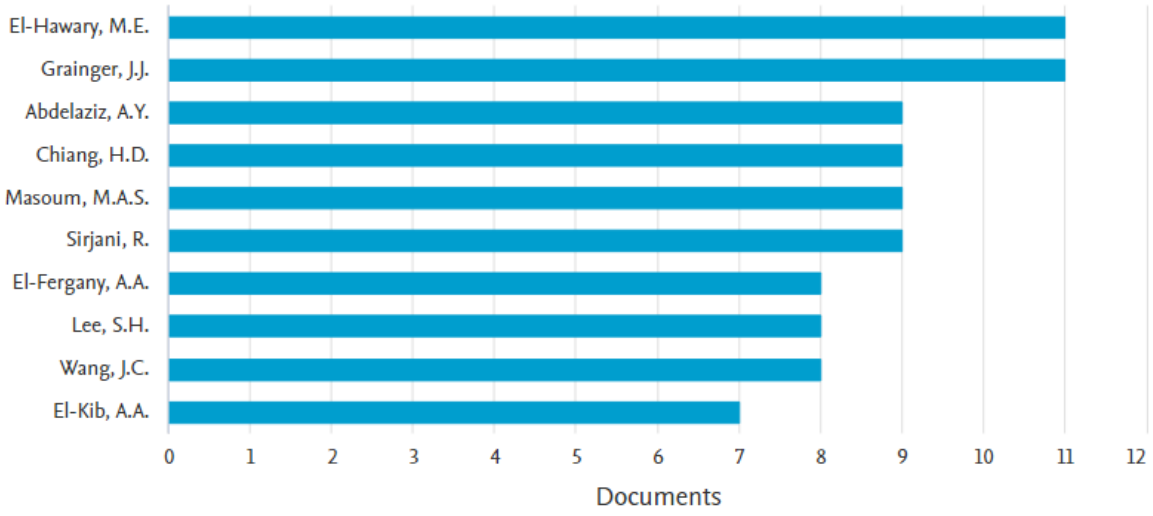

Fig. 6. Documents by author

Table. 4. Number of Documents by author

AUTHOR NAME	Number of Documents
El-Hawary, M.E.	11
Grainger, J.J.	11
Abdelaziz, A.Y.	9
Chiang, H.D.	9
Masoum, M.A.S.	9
Sirjani, R.	9
El-Fergany, A.A.	8
Lee, S.H.	8
Wang, J.C.	8
El-Kib, A.A.	7
Jayalalitha, S.	7

Fig. 7 shows documents by author's affiliation. Table 5 presents documents by author's affiliation. Ain Shams University has published 21 number of documents which is highest followed by Iran University of Science and Technology with 18 documents.

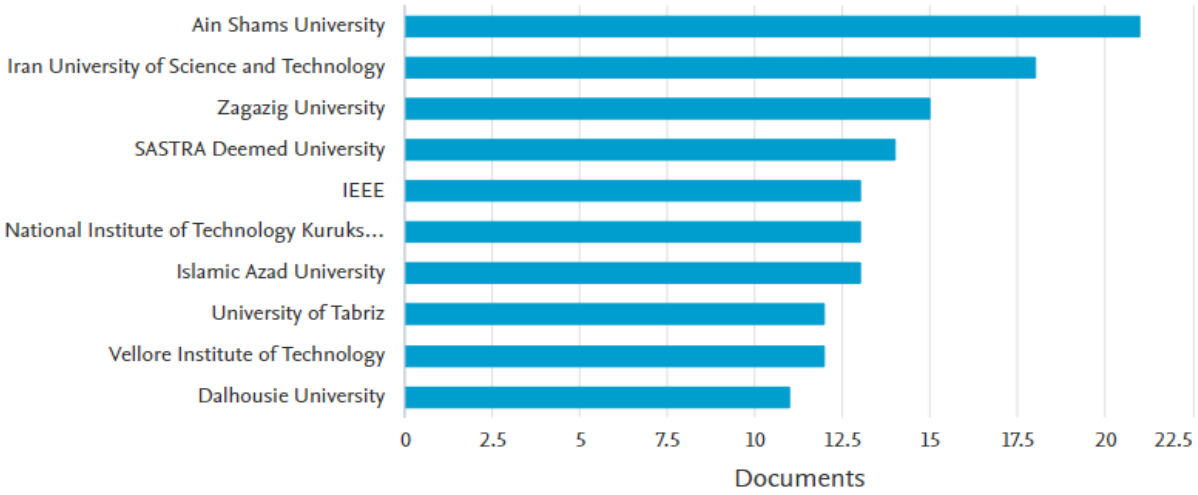

Fig. 7. Documents by affiliation

Table 5. Documents by affiliation

AFFILIATION	No. of Documents
Ain Shams University	21
Iran University of Science and Technology	18
Zagazig University	15
SASTRA Deemed University	14
IEEE	13
National Institute of Technology Kurukshetra	13
Islamic Azad University	13
University of Tabriz	12
Vellore Institute of Technology	12
Dalhousie University	11
Jadavpur University	10

Fig. 8 shows the documents by funding agency. National Natural Science Foundation of China and National Science Foundation have sponsored 6 documents which is highest in the category of funding agencies.

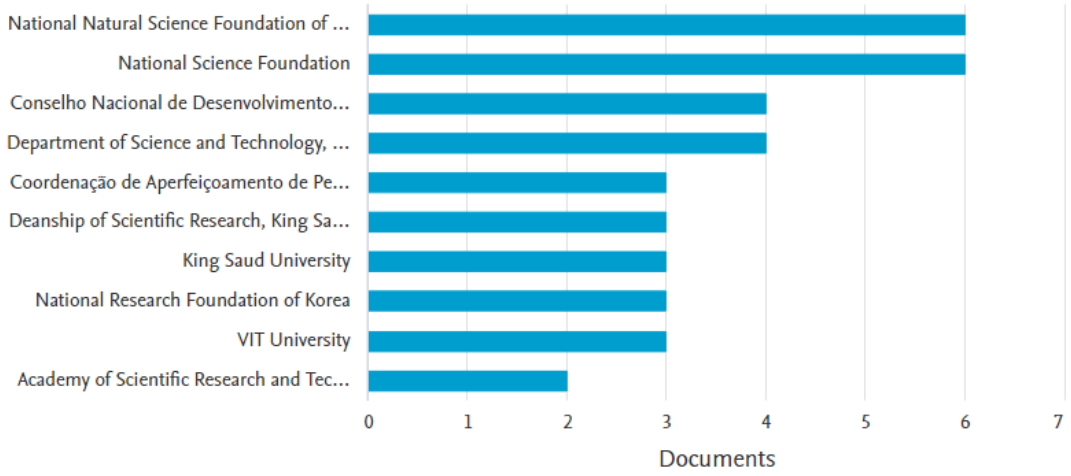

Fig. 8. Documents by Funding agency

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 2 for minimum number of documents of an author. It is seen that out of 1810 authors, 407 authors met the criteria. The

total strength of the co-authorship is calculated with other authors. El-hawary has total link strength of 26 which is the highest in the co-authorship analysis in terms of authors with 352 citations for 11 documents. Here a largest set of 14 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
☑	el-hawary m.e.	11	352	26
☑	grainger j.j.	11	182	22
☑	mekhamer s.f.	7	175	22
☑	moustafa m.a.	6	173	22
☑	soliman s.a.	6	173	22
☑	ladjevardi m.	6	309	18
☑	masoum m.a.s.	9	390	18
☑	el-kib a.a.	7	34	16
☑	fuchs e.f.	5	309	16
☑	mansour m.m.	4	95	16
☑	gupta n.	5	34	15
☑	abdelaziz a.y.	9	414	14
☑	malik r.	3	11	14
☑	mukherjee j.	3	11	14
☑	nagpal r.k.	3	11	14
☑	tripathi j.n.	3	11	14
☑	varilone p.	5	63	14

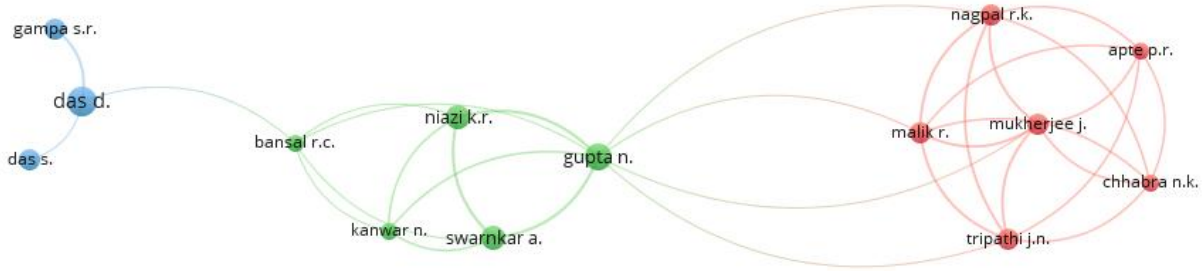

Fig. 9. Co-author relationship with each other

B) Co-authorship in terms of Organizations :

Co-authorship in the unit of organizations is calculated considering minimum 02 documents in organizations by neglecting the citation of the same. 94 organizations met the criteria out of 1384 number of total organizations, that are shown in the figure 10. A total of 8 organizations have highest link strength of 4. The highest citations of 44 by both University of Texas, Austin and University of Colorado, Boulder. Fig. 10 shows the network of co-authorship in terms of organizations.

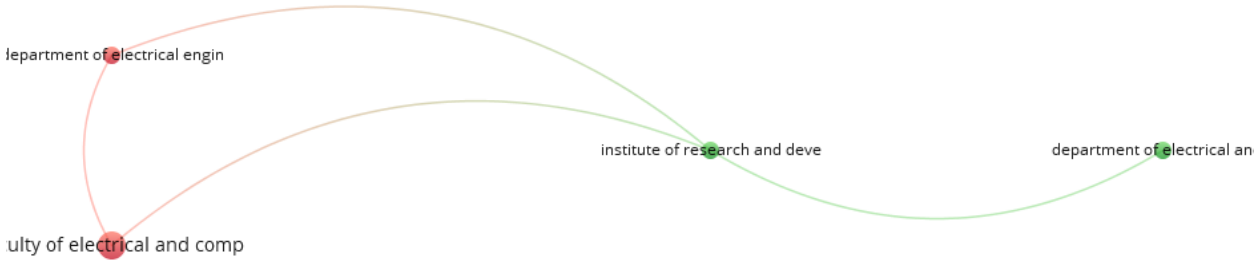

Figure 10: Co-authorship analysis in terms of Organizations

C) Co-authorship in terms of Country

Co-authorship is also obtained in relation to the country. A total of 73 countries are there, in this database. After considering the threshold of minimum 5 documents in a country, 30 countries met the threshold. Only 27 countries have connection with each other. Here, United States found to have the highest citations of 4323, and the link strength of 34. This is followed by Iran with link strength of 30. As far as the number of document is concerned, India has the highest of all with 278 documents. 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	96	4323	34
☑	iran	135	2436	30
☑	egypt	64	1468	20
☑	india	278	3668	17
☑	canada	28	614	16
☑	saudi arabia	16	272	12
☑	australia	17	544	11
☑	italy	15	267	10
☑	russian federation	8	44	9
☑	libyan arab jamahiriya	7	169	8
☑	malaysia	23	406	8
☑	ieee	7	286	7
☑	south korea	12	103	7
☑	china	37	399	6
☑	pakistan	11	174	6

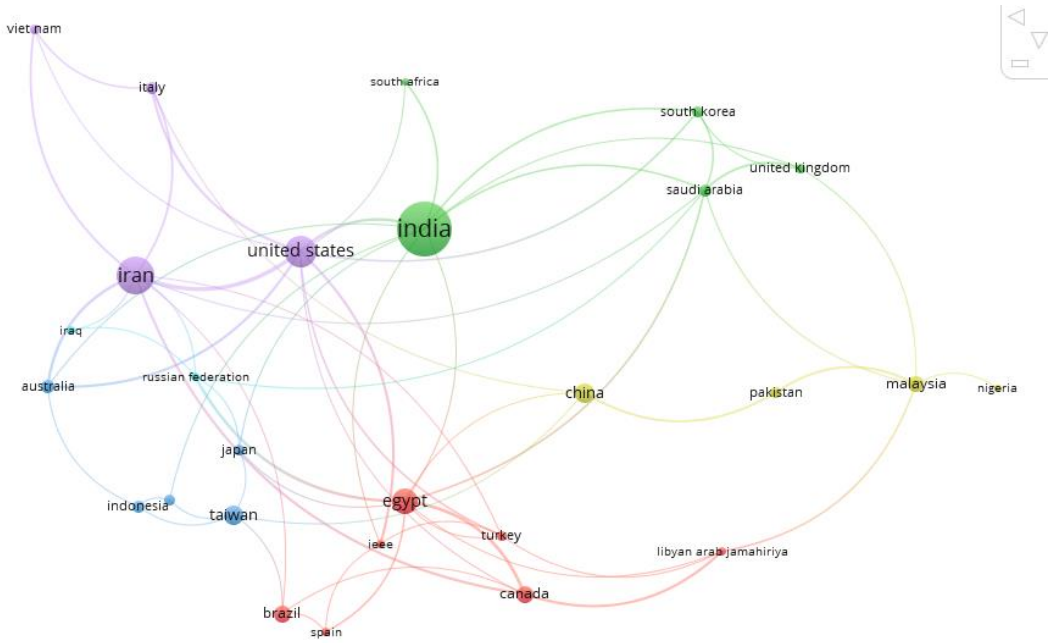

Fig. **11. Co-authorship in terms of Country**

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 4104 keywords, 403 keywords met the threshold. The keyword "Capacitors" having 4169 link strength with 376 times occurrence in various documents as shown in figure 10.

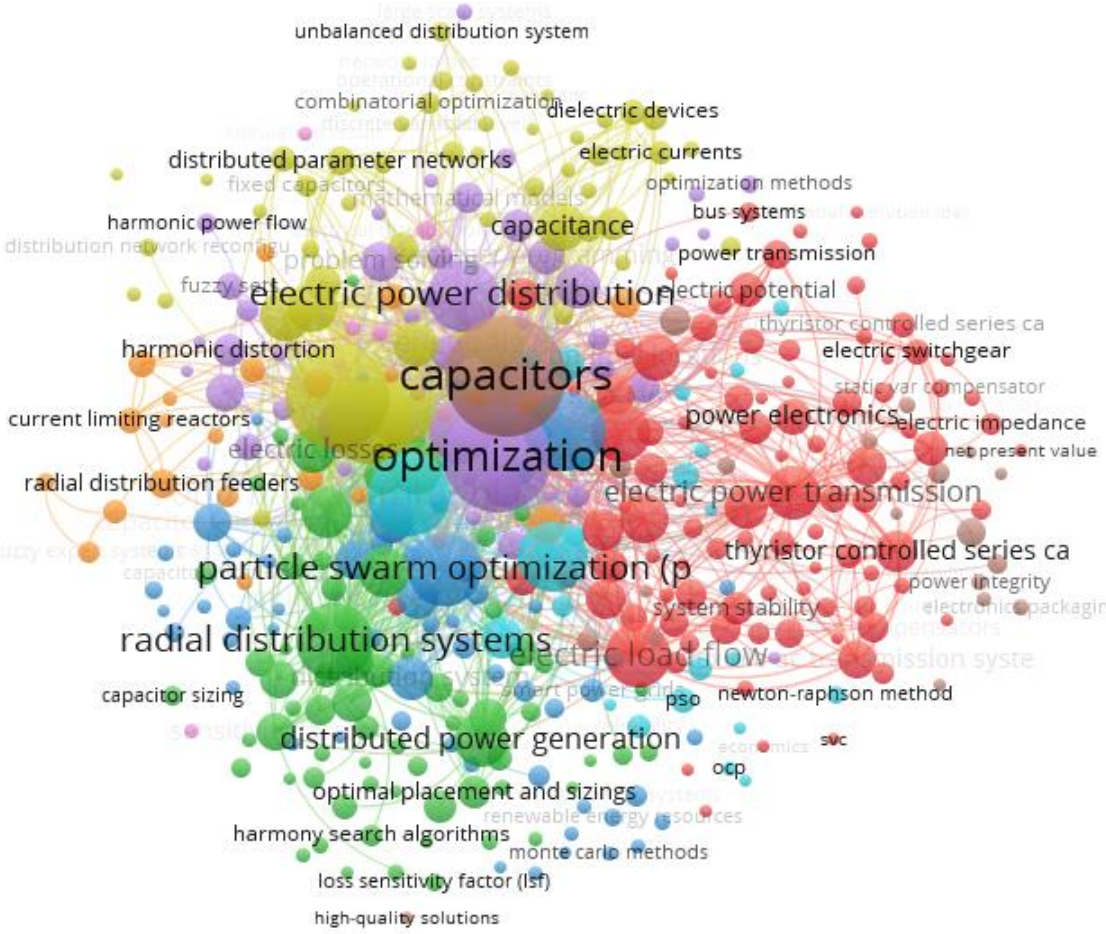

Figure 12: Co-occurrence Analysis in Terms of All Keywords

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 1613 keywords by the authors, 110 keywords met the threshold. 'Capacitor Placement' keyword occurrence is 201 times with 393 link strength. This is followed by the keyword

'Genetic Algorithm' with 70 occurrences and link strength of 147. 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
☑	capacitor placement	201	393
☑	genetic algorithm	70	147
☑	voltage profile	52	132
☑	loss reduction	46	117
☑	optimization	42	103
☑	distribution system	45	96
☑	distribution systems	39	91
☑	distributed generation	39	88
☑	optimal capacitor placement	59	81
☑	radial distribution system	38	81
☑	particle swarm optimization	37	73
☑	power loss	30	70
☑	loss minimization	30	67
☑	distribution network	23	59
☑	particle swarm optimization (pso)	23	54
☑	shunt capacitors	22	54
☑	optimal location	19	51

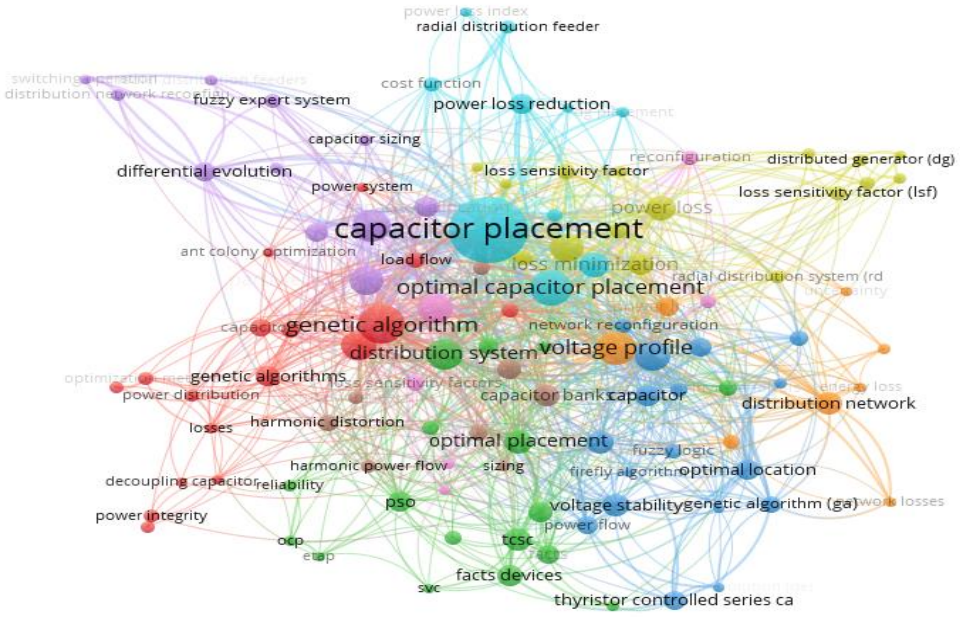

Figure 13: Co-occurrence Analysis in Terms of Author Keywords

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 1371 index keywords. Only 331 met the threshold. Fig 14 shows the Co-occurrence Analysis in Terms of Index Keywords.

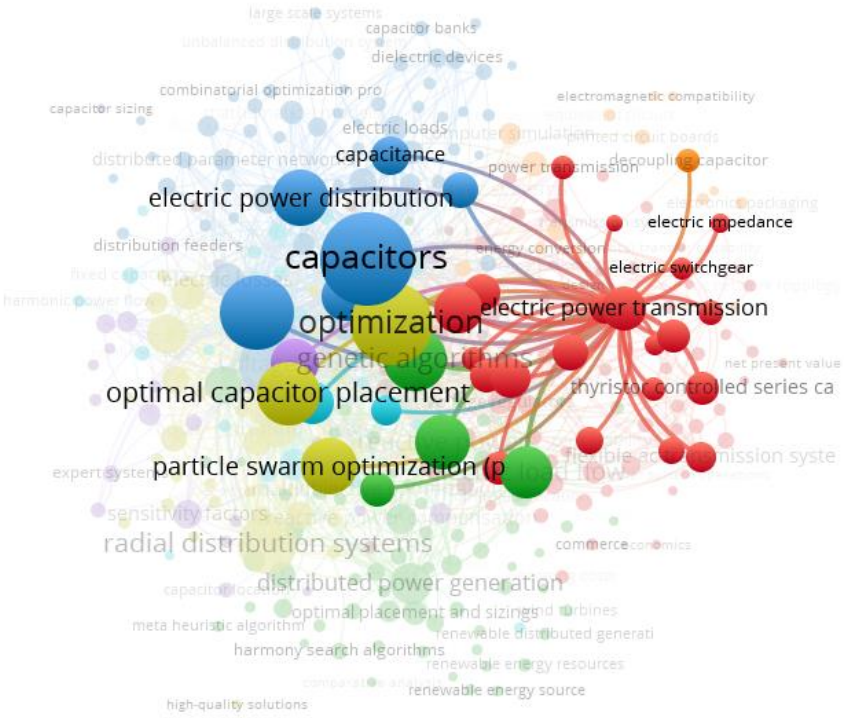

Figure 14: Co-occurrence Analysis in Terms of Index Keywords

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 909 documents, minimum 5 citations are considered as a threshold per document. 425 documents met the threshold. Document authored by Baran M. E. (1989a) has the highest number of citations 1306 while the link strength is 91 which is the highest. The largest set of connected items consists of only 296 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
☑	baran m.e. (1989a)	1306	91
☑	gallego r.a. (2001)	251	51
☑	chiang h.-d. (1990a)	217	48
☑	sultana s. (2014)	196	47
☑	das d. (2008)	227	45
☑	baran m.e. (1989b)	893	40
☑	chang c.-f. (2008)	249	39
☑	masoum m.a.s. (2004a)	163	39
☑	masoum m.a.s. (2004b)	101	35
☑	el-fergany a.a. (2013a)	125	34
☑	taher s.a. (2013)	56	32
☑	rao r.s. (2011)	220	31
☑	levitin g. (2000)	138	31
☑	el-fergany a.a. (2014a)	122	31
☑	nojavan s. (2014)	86	31
☑	yu x.-m. (2004)	112	27
☑	tabatabaei s.m. (2011)	78	27
☑	eajal a.a. (2010)	144	26
☑	segura s. (2010)	75	24
☑	sirjani r. (2012b)	21	24
☑	abdelaziz a.y. (2016a)	103	22

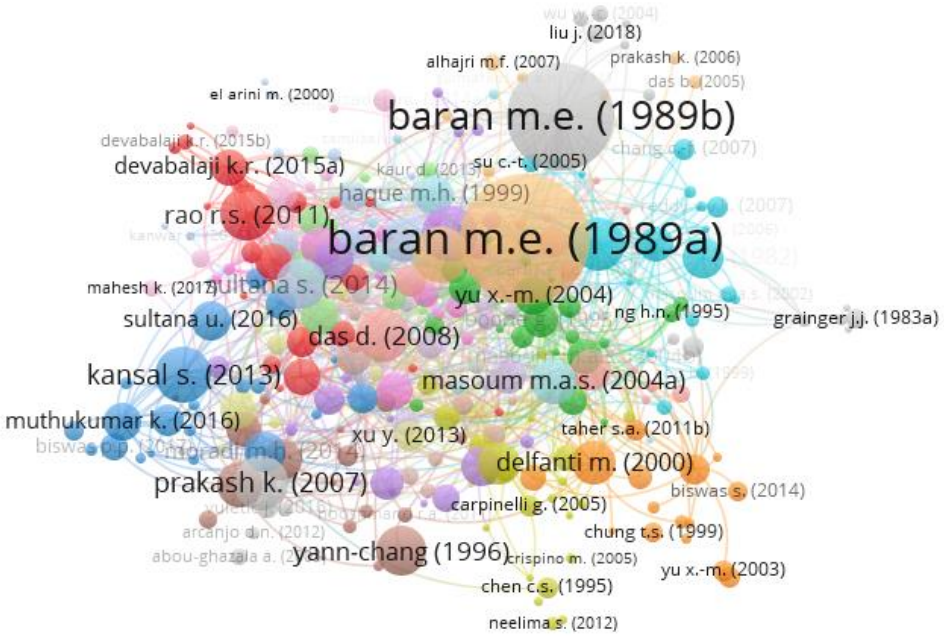

Figure 15: Network Analysis of Citations (In terms of Documents)

B) Citation Analysis of Sources

Citation analysis of sources is obtained by considering the threshold of 5 citations per source. Out of the 461 sources only 37 met the threshold. International Journal of Electrical Power and Energy Systems has got maximum citations of 2999 and link strength of 312 with other sources. Fig 16 presents the Network Analysis of citation by sources

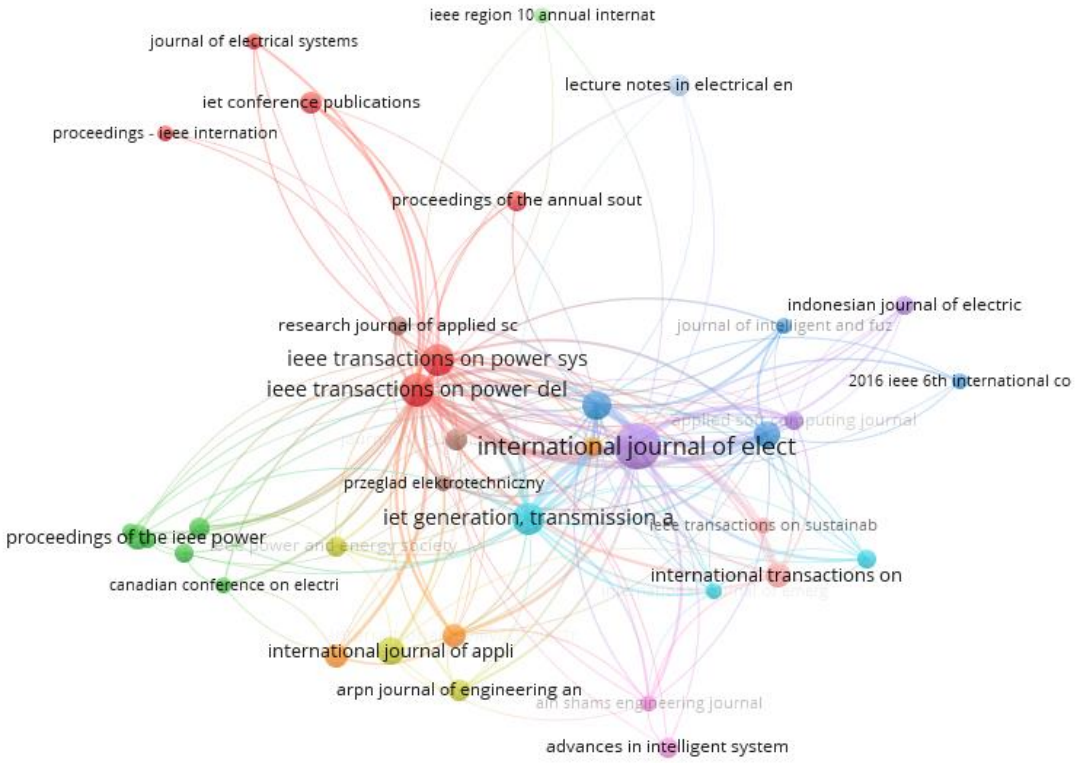

Figure 16: Network Analysis of citation by sources

C) Citation analysis by Authors

Threshold considered here is 5 citations per author. A total of 39 authors met the threshold amongst the total of 1810 authors. El-fergany has maximum link strength of 108 with other authors only for 8 documents with 432 citations. Fig 17 shows the Citation analysis by Authors

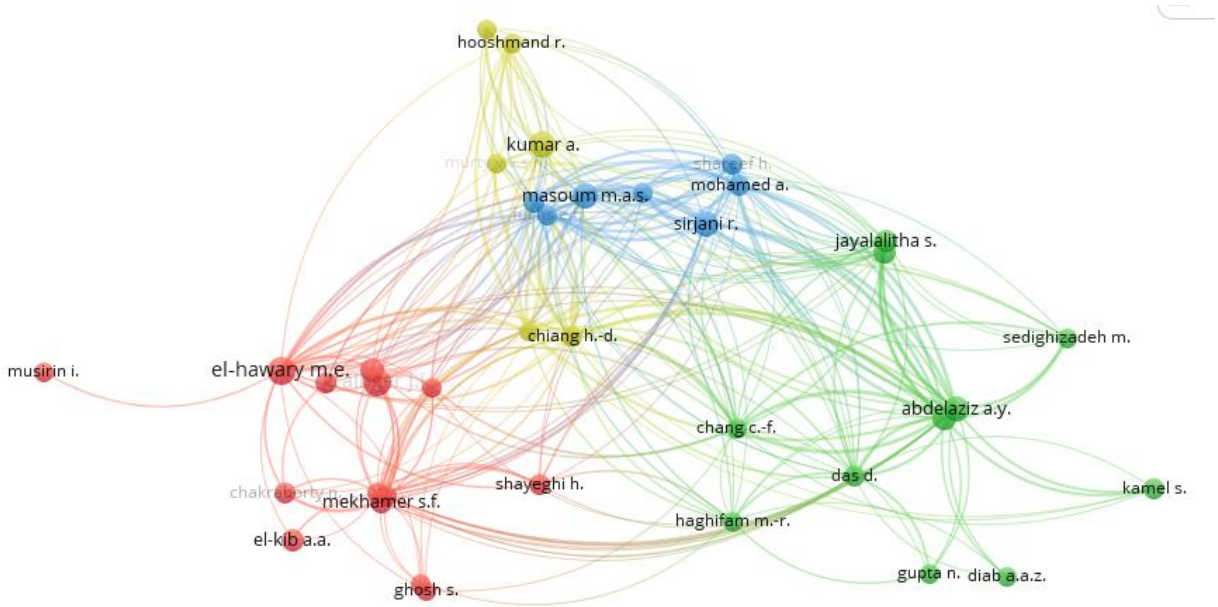

Figure 17: Citation analysis by Authors

D) Citation analysis by organization

There are total of 1384 organizations linked with this database. Threshold value considered in this analysis is 2 citations per organization. Total of 84 organizations met the threshold. Maximum citations are with the Department of Electrical Engineering and Computer Science, University of California,. It has highest link strength of 53 with 2199 citations. Figure 18 shows the Citations by Organizations,

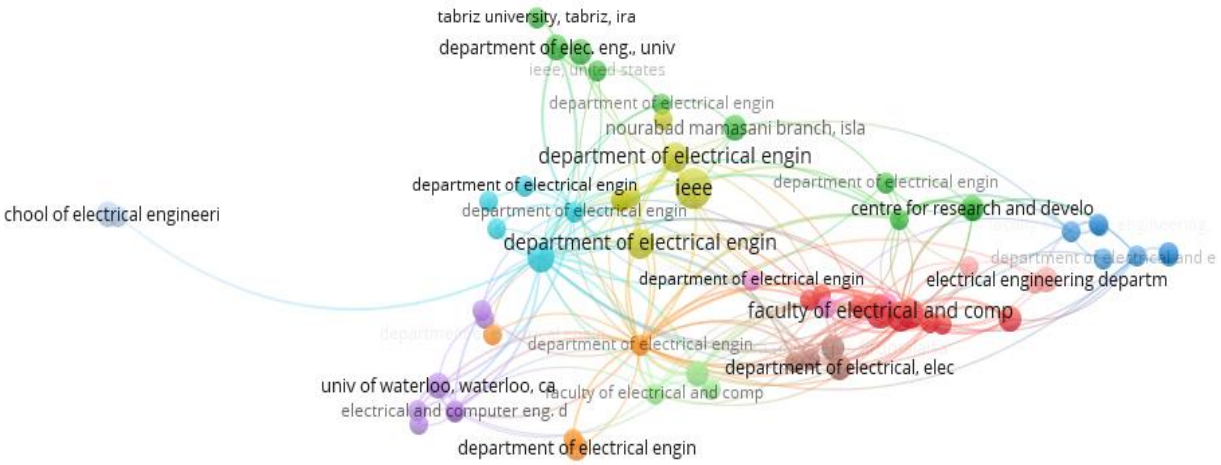

Figure 18: Citations by Organizations,

E) Citation analysis by country

Out of a total of 73 countries present in the database of the current search, 30 met the threshold criteria. Analysis has a threshold of minimum of 5 documents with minimum 5 citations. Fig. 19 shows Citation analysis by country

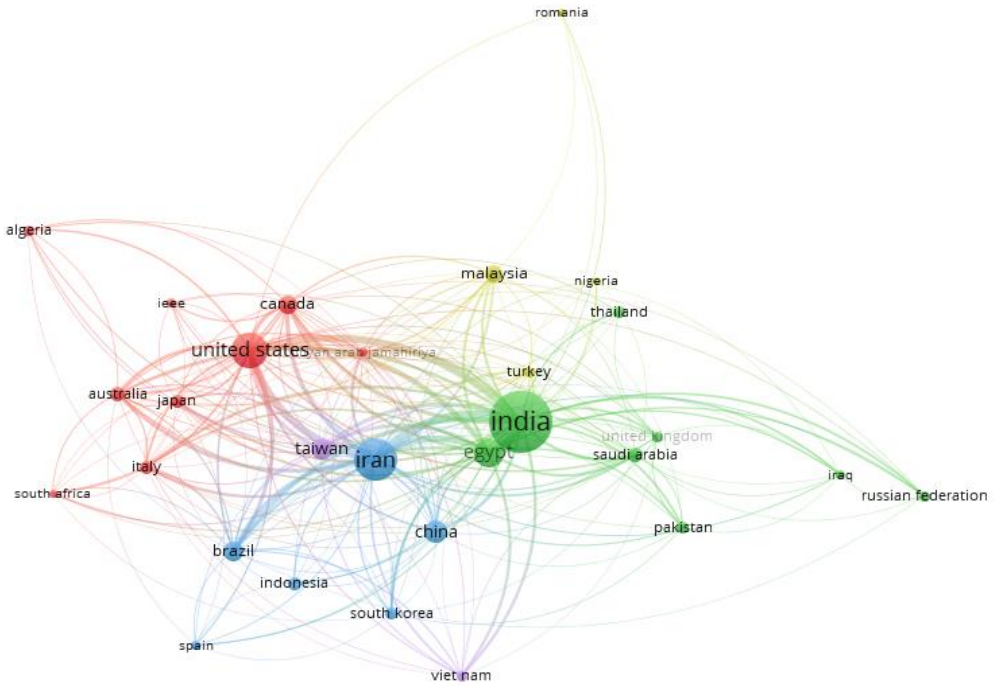

Figure 19. Citation analysis by country

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 909 documents 425 documents met the criteria. Documents with minimum 5 citations are considered. Gampa S. R. is found to have highest Bibliographic coupling strength of 846.

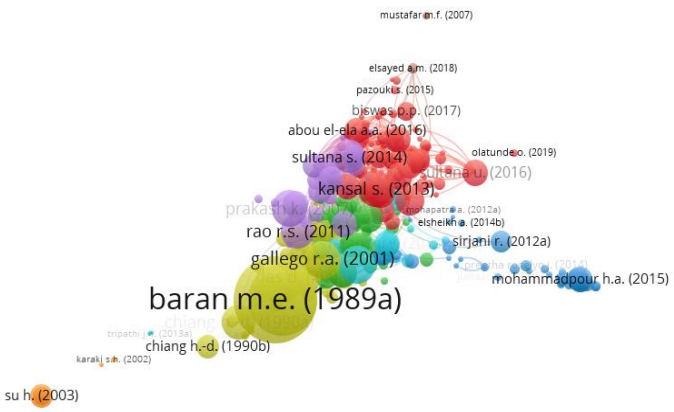

Fig. 20. Bibliographic coupling of Documents

B) Bibliographic coupling of Sources

In this analysis, 69 sources met the threshold amongst a total of 461 sources. Threshold considered here is 3 documents per source. International Journal of Electrical Power and Energy Systems has highest bibliographic coupling strength of 9218 with other sources with 37 documents. Fig 21 shows the Bibliographic coupling by Sources.

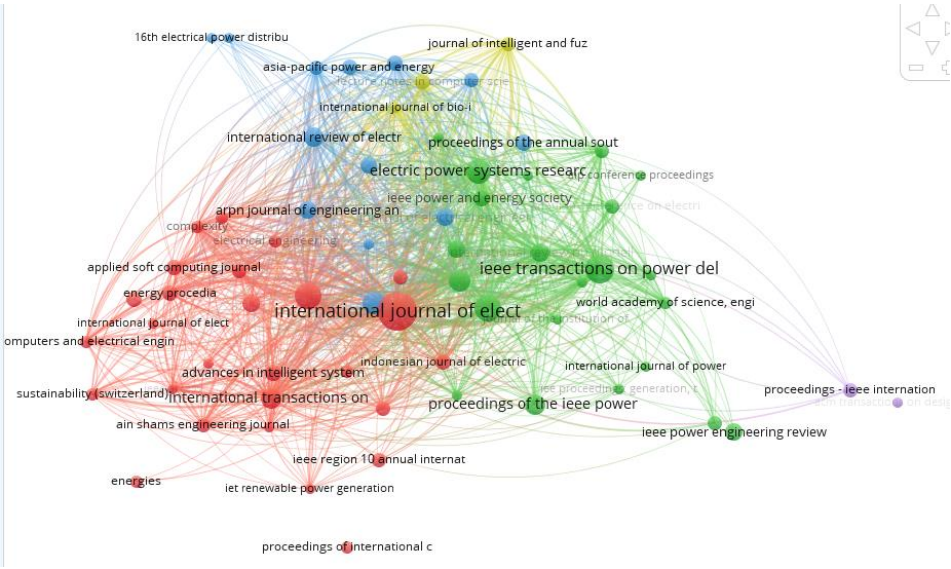

Fig. 21. Bibliographic coupling by Sources

C) Bibliographic coupling of Authors

Considering, 3 documents per author as a minimum threshold value. Out of total 1810 authors, 176 authors met the threshold criteria. Abdelaziz having maximum bibliographic coupling strength of 7058 with 9 documents and 414 citations. Fig 22 shows the Bibliographic coupling by Authors

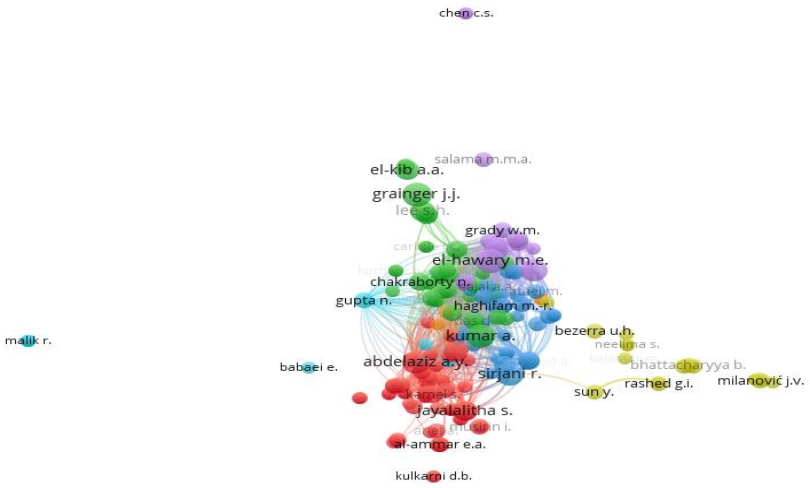

Figure 22. Bibliographic coupling by Authors

4. Conclusions

Bibliometric Survey is carried out on the topic of ‘ Optimal Capacitor Placement’ using Scopus Database. There were 909 documents found. Some of the highlights of observations are presented here. Majority of the published documents are articles followed by conference papers. There are 50.3% Articles and 44.3% Conference papers. India has published 277 documents followed by Iran and USA. Iran has published 135 documents and USA has published 95 documents in this area during 1981-2001. El-Hawary and Grainger have published eleven documents each in the area of OCP which is highest and followed by Abdelaziz with 9 documents. Ain Shams University has published 21 number of documents which is highest followed by Iran University of Science and Technology with 18 documents. National Natural Science Foundation of China and National Science Foundation have sponsored 6 documents which is highest in the category of funding agencies.

VOSviewer is used to carry out the network analysis. El-hawary has total link strength of 26 which is the highest in the co-authorship analysis in terms of authors with 352 citations for 11 documents. The highest citations of 44 by both University of Texas, Austin and University of Colorado, Boulder was observed from the co-authorship analysis in terms of organizations. United States is found to have the highest citations of 4323 and the link strength of 34 with respect to co-authorship analysis in terms of country. This is followed by Iran with link strength of 30. The keyword "Capacitors" is having 4169 link strength with 376 times occurrence in various documents with respect to co-occurrence analysis in terms of all keywords. This can be concluded that the Optimal Capacitor Placement is having lot of potential for research in future also.

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