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Optimal reactive power dispatch: a bibliometric analysis

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Abstract

Optimal reactive power dispatch (ORPD) plays a significant role in the control and smooth operation of the power system through the enhancement of the network's reliability, security, and economic aspects. This paper presents a bibliometric and visual analysis of ORPD-related research articles extracted from the Web of Science (WoS) database from its inception to October 29, 2019. A total of 263 articles drawn from 166 journals, published between 1989 and 2019, were retrieved and analysed using Excel, HistCite, and VOSviewer visualisation software. The total number of citations for the 263 articles ranges from 0 to 297. The top three journals with the most significant number of ORPD publications were the International Journal of Electrical Power and Energy Systems, Applied Soft Computing, and two journals qualified for the third place, IEEE Transaction on Power Systems and IET Generation Transmission and Distribution. The most active researcher is Provas Kumar Roy, with nine (9) articles from Kalyani Government Engineering College. The most trending/cited researcher is Yi Jia Cao, with 129 Total Local Citation Scores from Hunan University, Changsha. In terms of contribution by countries, India, China, Iran, and the United States were the most significant contributors with 27.8%, 20.9%, 11.8%, and 8% of the total articles, respectively. The top 5 most frequently used substantive keywords to identify the trending topic and research direction were Particle Swarm Optimisation, Genetic Algorithm, Gravitational Search Algorithm, Linear Programming, Evolutional Algorithm, and Hybrid Algorithm. This study provides a detailed outline and reveals the future research directions for both experienced and novice ORPD researchers to identify research topics, questions, and collaboration partners.

Keywords: Optimal reactive power dispatch, Bibliometric analysis, Web of science, HistCite, VOSviewer

Introduction

The economic stability of any nation has a direct link with the amount of energy it generates and consumes. Therefore based on this, there is a need for stable, sustainable, sufficient as well as reliable electrical power system network. The power grid consists of three main stages, namely generation, transmission and distribution, which delivers the power to both industrial and residential consumers. The power network needs to be robust to accommodate all the dynamic factors associated with the system [1, 2].

Usually, network losses in a power system vary between 5 and 10% of the total generation, which translates to millions of dollars per annum [3]. Due to the rapid voltage fluctuations caused by the variation in consumer demands, there is need to device a suitable means of maintaining a stable load bus voltage, apparent power through the lines, as well as the reactive generator power [4]. Consequently, loss minimisation, as well as voltage balancing, needs to be adequately addressed in any power system network [5–7]. The two can be controlled by regulating and monitoring the magnitude of the bus voltages, transformer tap settings and capacitive reactive power injection while adhering to the units and system constraints [8, 9].

Previously, ORPD problems were solved using conventional optimisation strategies, such as linear programming [10, 11], nonlinear programming, quadratic programming [12], Newton Rapson method, gradient-based algorithm and interior point method [13]. However, they were found to be inefficient in solving the nonlinear functions as well as discrete variables [14, 15], hence resulting in inaccurate solutions. Due to their disadvantages, coupled with the rapid advancement in computer technology, stochastic optimisation techniques for solving power system problems emerged. Heuristic and metaheuristic population-based strategies with stochastic transition rules, Genetic Algorithm (GA) [16, 17], Improved GA [18], Real Parameter GA [19], Adaptive GA [17], Evolutionary Strategy (ES) [20], Hybrid Evolutionary Programming [21], Particle Swarm Optimisation (PSO) [22], Hybrid PSO [23], Bacterial Foraging Optimisation (BFO) [24], Self-Adaptive Differential Evolution (SADE) [25, 26], Artificial Bee Colony (ABC) [27], Harmony Search Algorithm (HSA) [28], improved and modified HSA [29, 30], Tabu Search (TS), Gravitational Search Algorithm (GSA) [31, 32], Grey Wolf Optimisation (GWO) [33], Hybrid Firefly Algorithm (HFA) [34], Teaching–Learning-Based Optimisation algorithm (TLBO) [35], and many more were successfully applied to obtain ORPD solutions.

Bibliometric studies follow a systematic set of the procedure to quantify and analyse popular scientific articles on a specific research field/area or topic of interest [36, 37]. The outcome produced research foci and a summary of the developmental trends of the research field and the future research direction [38, 39]. The bibliometric evaluation examines bibliometric features and information such as publications, citations, as well as research study results [40–43]. It permits researchers to recognise research activities framework, qualities and patterns. The evaluation process correlates the study activities into a consistent trend of a research domain as it includes scientific research works of various contexts such as publications, institutions, authors, organisation countries and citations. It is an approach that reports on a thorough analysis of the growth of researchers [44, 45]. Example of such technique was utilised by [46, 47] to determine the intellectual development in information security and computer technology. Bibliography study has the following advantages:

1. Writers can show the importance of their research.
2. Academic researchers can forecast future study as well as substantial influence on any specific topic.
3. Institutions can review publication efficiency and gauge the quality of their impact.

Based on the author's knowledge, there has been no bibliometric study carried out on ORPD research field. Most of the publications focused on reviewed articles and application of optimisers to achieve optimal and reliable operation of the power system network. Hence, this paper undertakes a new twist by presenting a bibliometric analysis on ORPD published articles that are index in the Web of Science database. The steps involved in conducting the bibliometric study are shown in Fig. 1. Systematic and chronological distribution of ORPD publications, the most active ORPD scientific journals, and principal key authors, organisations/institutions along with their citations, co-citations and collaborations were visualised using Histcites and VOSviewer tools. The research outcome provides valuable insights into the current and future research trends to ORPD researchers. The whole paper is structured into

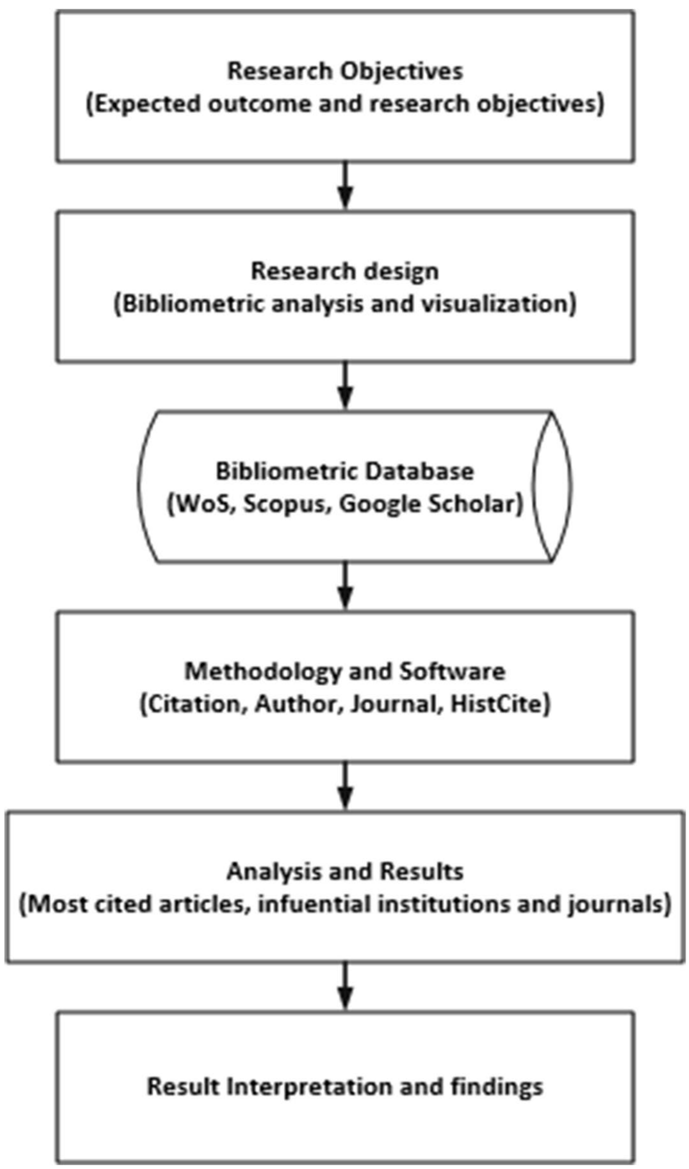

Fig. 1 Bibliometric flowchart

four (4) sections. "Introduction" section is the introduction section, followed by the methodology in "Methods" section. "Results and discussion" section presents the results and discussion, while "Conclusion" section draws the research conclusions.

Methods

Data sources

There are two well-known databases in Engineering, namely Web of Science (WoS) and Scopus. WoS is selected for this research due to its reputation. Secondly, due to the non-compatibility of the HisCites software with the Scopus database, a search using the phrases "Optimal reactive power dispatch", "Optimum reactive power transfer", "Optimum reactive power dispatch" and "Optimal reactive power transfer" was conducted on September 29, 2019, out of which 263 research-related articles were identified. Due to the limited number of available data, all document categories such as research articles, book chapters, proceedings and reviews were considered. All the data collation was done on the same day to avoid bias.

Data extraction

To ensure that the extracted data are error-free from irrelevant articles so that all selections are purely ORPD-related articles, the initial search result has to be manually refined three times by two independent authors. Each of the article titles was scrutinised to ensure it is genuinely an ORPD article. During the extraction, information such as accession number, citations, publication types, countries/regions, journals, were selected to be included in the extracted data.

Data visualisation and analysis

Excel, HistCites and VOSviewer were the tools used in this study. Microsoft Excel was used in both visualisation and analysis of the data. HistCites is a software used for statistical data analysis. The software is capable of identifying the key research fields. It creates individual authors historiography and equally specifies highly cited papers by providing visual results and the exact timeline of the published research articles. The software is capable of analysing publication records, citation statistics for countries and institutions. While VOSviewer is a visualisation tool that generates maps/chart with bubbles representing an author, article, city or keyword, the bubble size signifies the frequency of occurrence and the colour indicates an individual cluster. Firmly related bubbles are positioned close to each other, and the connection lines are thicker, hence signifying strong bond.

Results and discussion

A total of 263 articles were pulled out of the web of science database. It comprises 130 research articles, 126 proceedings papers, three (3) reviews, three (3) book chapters and one (1) editorial material. The Total Global Citation Scores (TGCS) and Total Local Citation Scores (TLCS) of the articles range from 0 to 297 and 0 to 67, respectively. The average total of GCS and LCS citations for the entire data is 14.6 (3837/263) and 4.1(1083/263), respectively. About 23.2% of the articles ($n = 61$) receives five (5) or more local citation (TLCS) from articles within the collection. While 38% of the

Table 1 List of articles ranked according to the highest TGCS and TLCS

S/n	Author	LCS	GCS
	Ranking based on TGCS		
1	Zhao B et al., A multiagent-based particle swarm optimisation approach for optimal reactive power dispatch, 2005	67	297
2	Wu Qh et al., Power-system optimal reactive power dispatch using evolutionary programming, 1995	49	169
3	Wu QH et al., Optimal reactive power dispatch using an adaptive genetic algorithm, 1998	49	146
4	Dai CH et al. Seeker Optimisation Algorithm for Optimal Reactive Power, 2009	39	140
5	Abou El et al. Differential evolution algorithm for optimal reactive power, 2011	0	109
	Ranking based on LCS		
1	Zhao B et al., A multi-agent-based particle swarm optimisation approach for optimal reactive power dispatch, 2005	67	297
2	Wu Qh et al., Power-system optimal reactive power dispatch using evolutionary programming, 1995	49	169
3	Wu QH et al., Optimal reactive power dispatch using an adaptive genetic algorithm, 1998	49	146
4	Subbaraj P et al., Optimal reactive power dispatch using self-adaptive real coded genetic algorithm, 2009	41	102
5	Duman S et al., Optimal reactive power dispatch using a	40	94

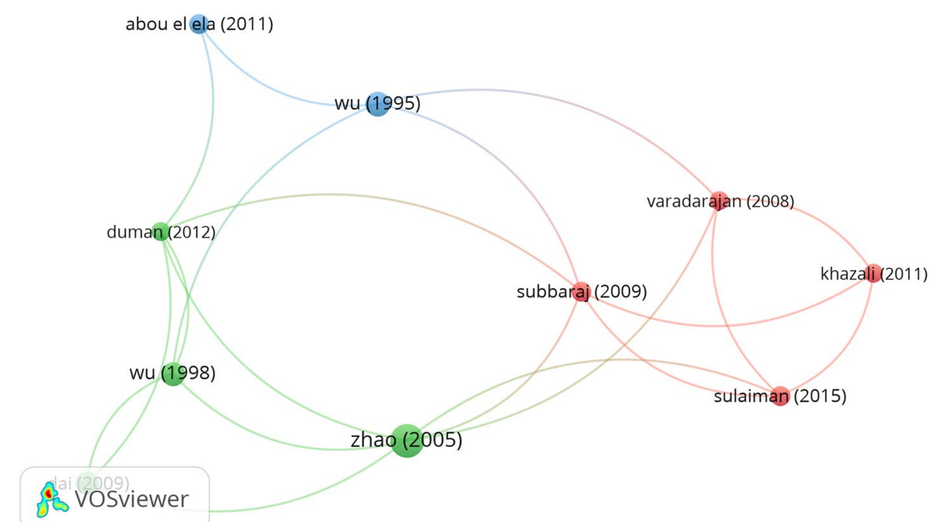

Fig. 2 Top 10 articles with the highest citations

articles ($n = 100$) receives five (5) or more global citation (TGCS) from the entire articles in the web of science database. An article published in IEEE Transactions on Power Systems ($n = 17$, IF2018, 6.807) by Bo Zhao et al. of Zhejiang University, China in 2005, has the highest number of TGCS and TLCS citations of 297 and 67, respectively. Table 1 presents an extract of the top 5 research articles with the highest TGCS and TLCS. Figure 2 shows the citation visualisation network of the top 10 ORPD articles. The network is categorised into 3 clusters under how closely related the research content is with each other, and each circle signifies a journal whose size depends on the amount of citation it receives. This is used as the measure of the impact an article makes in the entire research field. The lines are the citation connection between the articles.

Yearly publication output

The articles selected were published between 1989 and 2019, with the exclusion of 1990, 1991, 2000 and 2001 as there was no record of any publication in those years. Figure 3 shows the number of publications and citations done per year. The left axis contains the number of published articles which is represented by the continuous red line. Based on our data, interest in ORPD started around let 80's and gradually researchers start to pick up interest, with unsteady fluctuations in the research outputs in the mid-'90s and early 2000s. The highest number of publication occurred in 2016, where 34 articles were published. Since then, research outputs has been falling rapidly, signifying a decline in research interest. Similarly, the right vertical axis represents the number of citations per year. Citation directly depends on the publication outputs and the volume of already existing literature in the research field. This is why in the early '80 s, when there were no publications to refer to, the citations were zero. However, as the number of relevant articles increased in the database, both local and global citations started to rise. The highest number of TLCS and TGCS occurred in 2014 and 2011, respectively, hence indicating a rise in ORPD research interest in those years.

ORPD research distribution by countries/regions

The ORPD researchers are spread across 38 countries that cut across all the seven (7) continents. Figure 4 is a pie chart depicting the percentage of article contribution from countries having five (5) articles and above. The percentage of countries with four (4) articles and below is summed up together and tagged as "Others". India, China and Iran topped the list with 24%, 18% and 10%, respectively, signifying the raise in ORPD research interest in the Asian continent. The 4th country is the USA with 7%, and the 5th is a tie between the UK and Algeria with 4%, while the 6th is Germany with 3%. The rest are Turkey, Malaysia and six others who had approximately 2% each. There is an

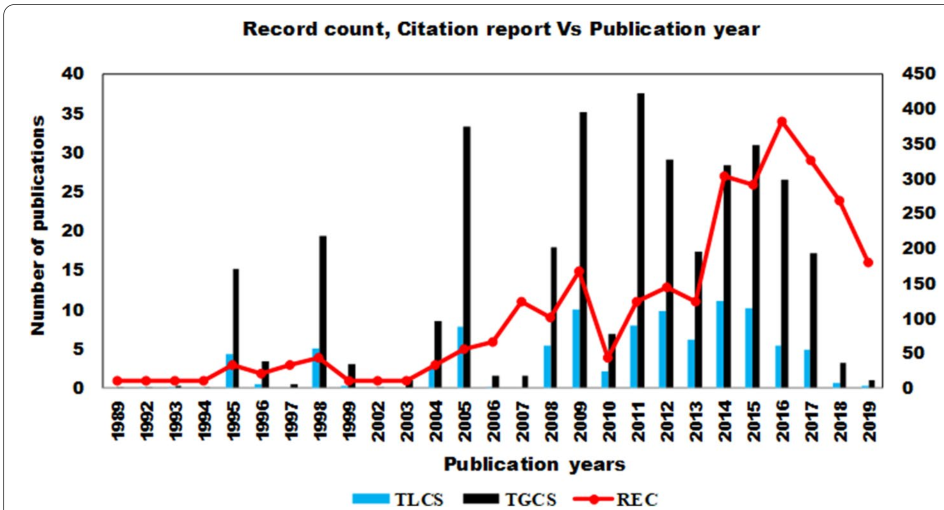

Fig. 3 Number of publications and citations per year

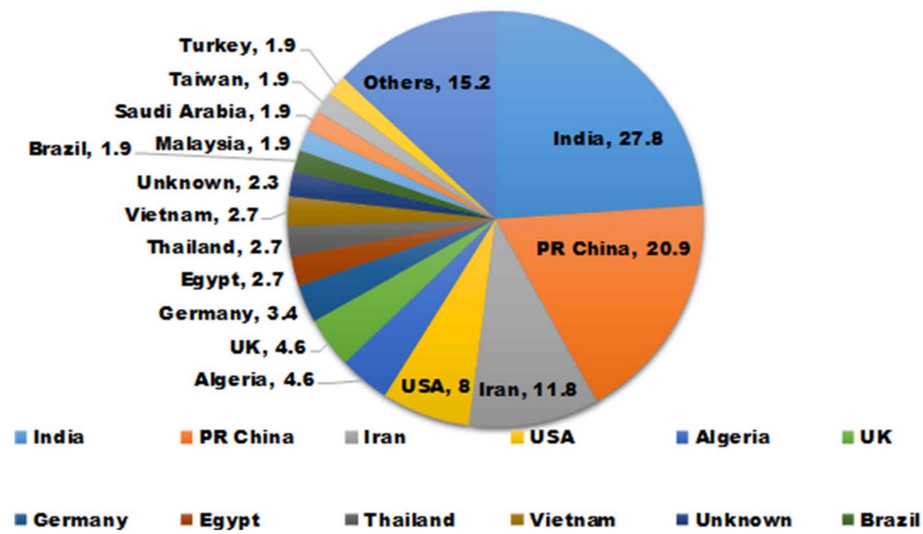

Fig. 4 ORPD articles country-wise contribution

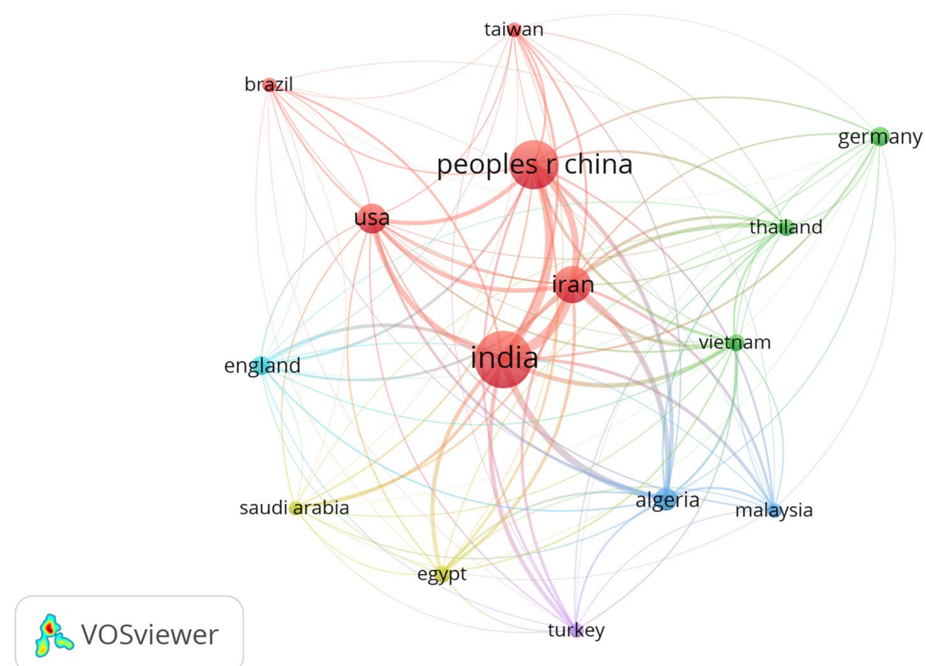

Fig. 5 Network visualisation chart of the 15 top countries

additional 2% in which the contributing country could not be ascertained, hence it is tagged as "Unknown". The remaining 22 countries with 4 or fewer documents amounted to 13% of the total.

Figure 5 shows the network visualisation chart of the top 15 countries. They were classified into three research clusters based on collaborations, co-authorship, citations and co-citations. The size of the circle signifies the level of contribution to the research field.

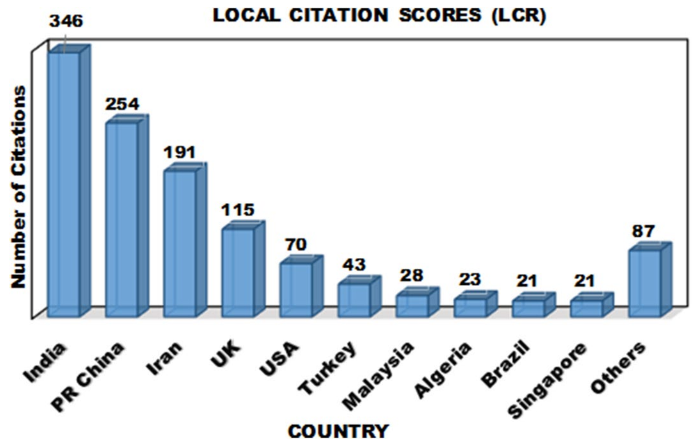

Fig. 6 Total local citation scores

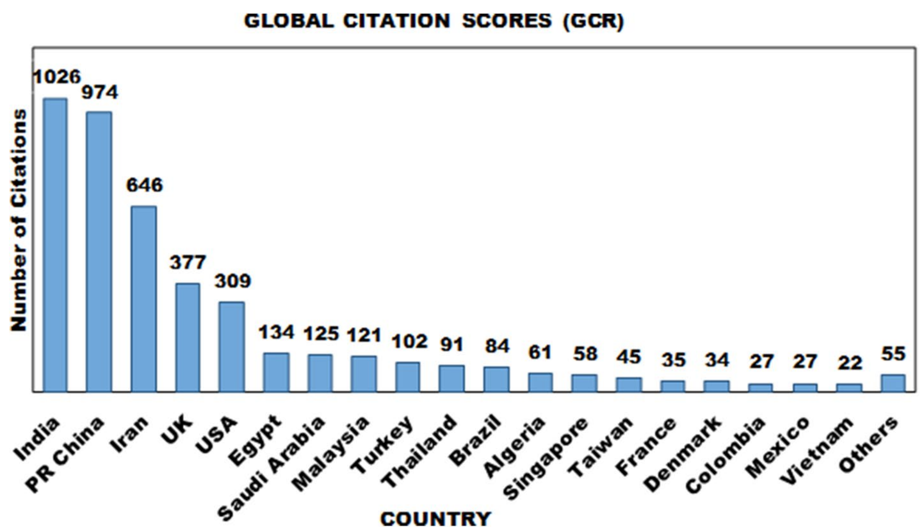

Fig. 7 Total global citation scores

Apart from ranking countries based on the number of published articles, they were equally ranked according to the number of local (TLCS) and global (TGCS) citations they earned. This measure indicates the quality and strength of published research from those countries. Figures 6 and 7 show the chart of countries whose TLCS and TGCS are 20 and above. Interestingly, the top 3 countries with the highest publications in Fig. 4 still occupy the same position in Fig. 6. However, the two countries that previously occupy 4th in publications were displaced by the UK. This further proves that the number of citations earned by researchers or countries depends on the quality of the research and not the number of their publications. All countries having TLCS less than 20 were summed up, and it totalled 87 local citations.

Figure 7 presents the global citation scores. Usually, the number of citation should be higher in TGCS since it is a superset of the TLCS. TGCS is the amount of the total citations earned from the entire web of science database. Nineteen countries had 20 and above citations, whereas the remaining 19 countries with less than 20 citations were classified as others. The top 5 countries in the previous TLCS chart still retain their positions on the TGCS chart, which further signifies the strength and contribution they are making in the ORPD research field.

ORPD research contributions based on universities and organisations

A total of 258 organisations, universities and institutions contributed to the field of ORDP research for the period considered in this study. The key indicators used to measure the level of research contribution are the number of publications, TLCS and TGCS obtained by each organisation. Table 2 contains a list of 22 institutions and universities having a minimum of four (4) publications. The 22 universities were able to publish 131 ORPD-related articles, representing 49.8% of the total articles published by the 258 institutions/organisations. The most productive organisation is the National Institute of Technology, which is a public institution with 31 branches spread across India.

Figure 8 shows the universities/institutions visualisation chart. There are five (5) research clusters, each represented by a different colour. The clusters were based on the level of collaborations that exist between the organisations. Each cycle represents an institution/university or organisation whose collaboration strength was determined by the distance between the cycles. The line thickness linking the cycles signifies the citation strength. It is worth mentioning that the 258 institutions/organisations are located in 38 countries across the globe. Figure 9 depicts the countries and the interconnection link in terms of collaborations, citations and co-citations. India, China and Iran are the

Table 2 University/institutions with the number of publication greater than or equal to 4 articles (publications ≥ 4)

University/institution	Publications
Natl Inst Technol	12
Dr BC Roy Engn Coll	8
Indian Sch Mines	8
Islamic Azad Univ	8
Univ Duisburg Essen	8
Sharif Univ Technol	7
Iran Univ Sci & Technol	6
Jadavpur Univ	6
S China Univ Technol	6
Unknown	6
Zhejiang Univ	6
Asian Inst Technol	5
Ho Chi Minh City Univ Technol	5
Indian Inst Technol	5
Shiraz Univ Technol	5
South China Univ Technol	5
Thiagarajar Coll Engn	5
Asansol Engn Coll	4
Kalasalingam Univ	4
Kalyani Govt Engn Coll	4
Univ Tabriz	4

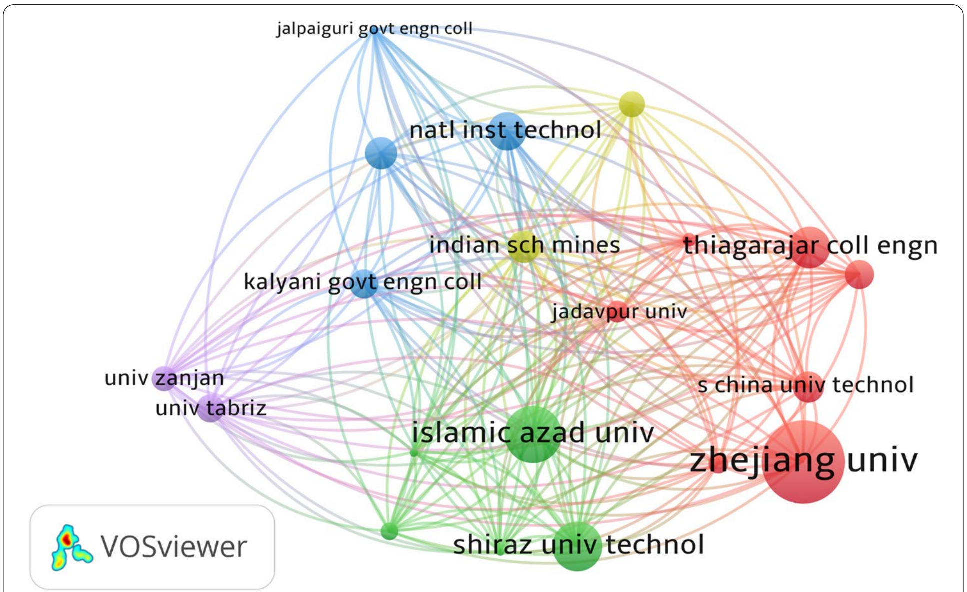

Fig. 8 University/organisational visualisation network chart

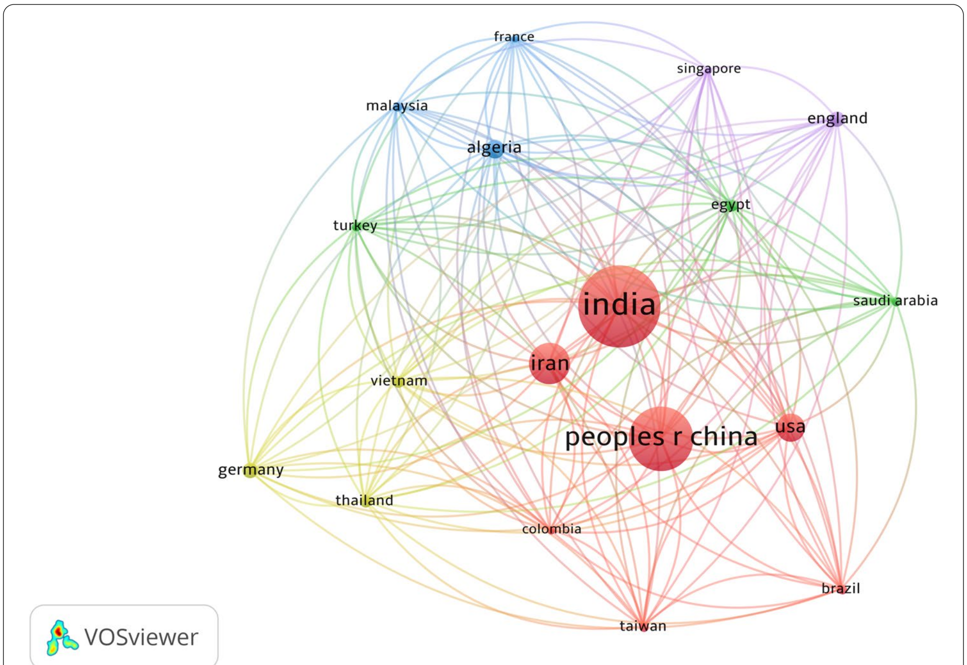

Fig. 9 Collaborating countries visualisation network chart

1st, 2nd and 3rd countries, respectively, with the highest location of ORPD research contributors. The research contributors (universities and organisations) are also ranked according to the number of TLCS and TGCS they earned.

Figures 10 and 11 present the TLCS and TGCS citation charts for the research collaborators. Islamic Azad University (9%), Zhejiang University (7.4%) and Shiraz University (6.9%) make up the top 3 contributors in terms of local citations within the selected

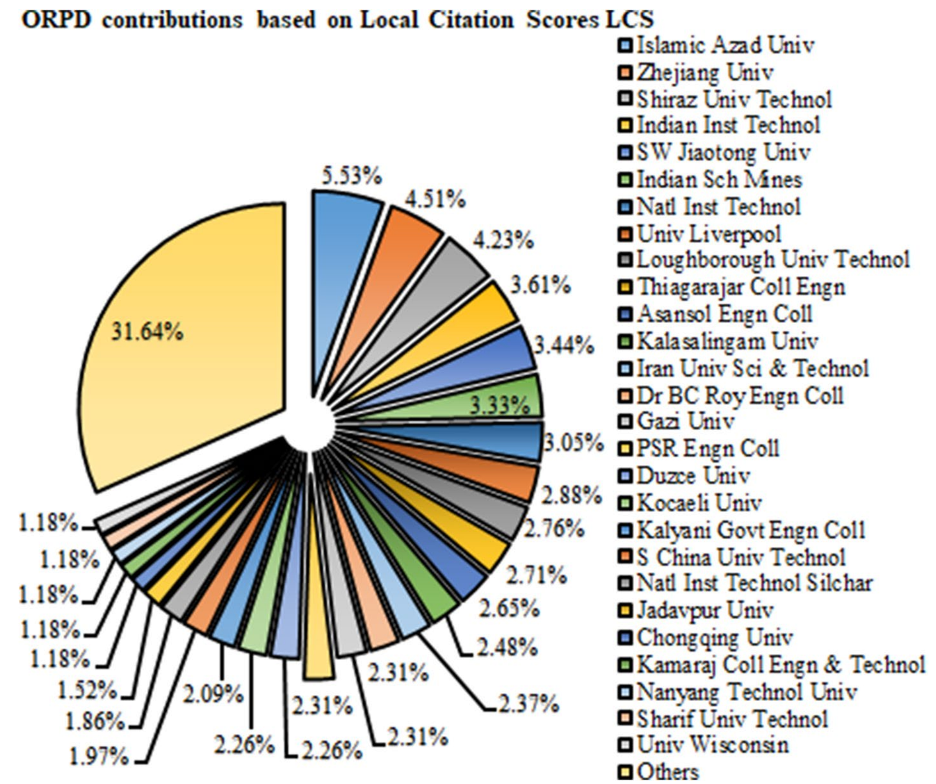

Fig. 10 University/organisational TLCS ranking

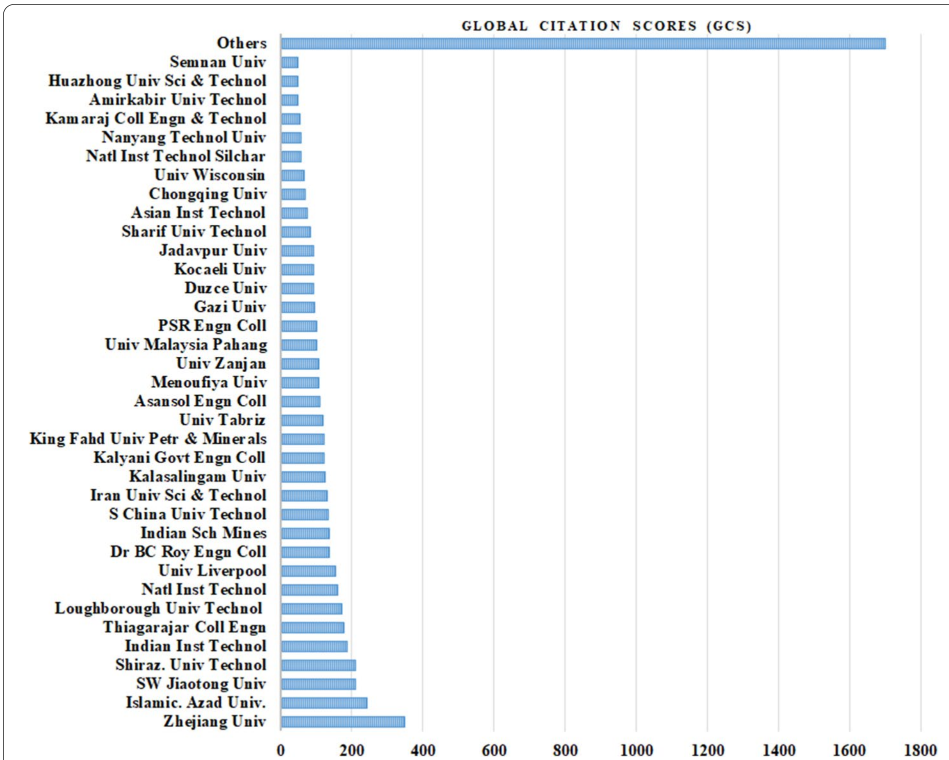

Fig. 11 University/organisational TGCS ranking

data while Zhejiang University (9.1%), Islamic Azad University (6.3%) and SW Jioantong University (5.5%) took 1, 2 and 3 places, respectively, in the global citation (GCS) within the entire web of science database.

Distribution of authors

The entire 263 articles were authored by 571 authors drawn from 258 universities, institutions and organisations across the globe. Similar to the previous section, the primary measure of performance of an author was based on the number of published articles and the number of local (TLCS) and global (GLSC) citation scores earned as well as the geographical location they belong. Therefore, based on the number of articles, Roy PK topped the list with nine (9) articles representing 3.4% of the total records, followed by Cao YJ and Erlich I with eight (8) articles each representing 3%. Then Mukherjee V and Yesuratnam G both having seven (7) articles representing 2.7% of the total. A total of 25 authors have four (4) articles with a combined publication of 125 articles, representing 47.53% of the total publications. The remaining 52.47% was shared among 546 authors.

Figure 12 shows the number of publications of authors with four (4) articles and above. Figure 13 presents the author's visual research clusters and interconnections. The visualisation network contains the list of authors having four (4) and above publications in the extracted data. Each circle represents an author, and closely related authors are positioned near to each other to form a cluster. There are four (4) research clusters in the visualisation network which are classified based on co-authorship, co-citations, collaborations and keywords.

Authors are equally ranked based on the earned TLCS and TGCS. TLCS and TGCS citation signifies the quality and significance of an author/researcher in his research

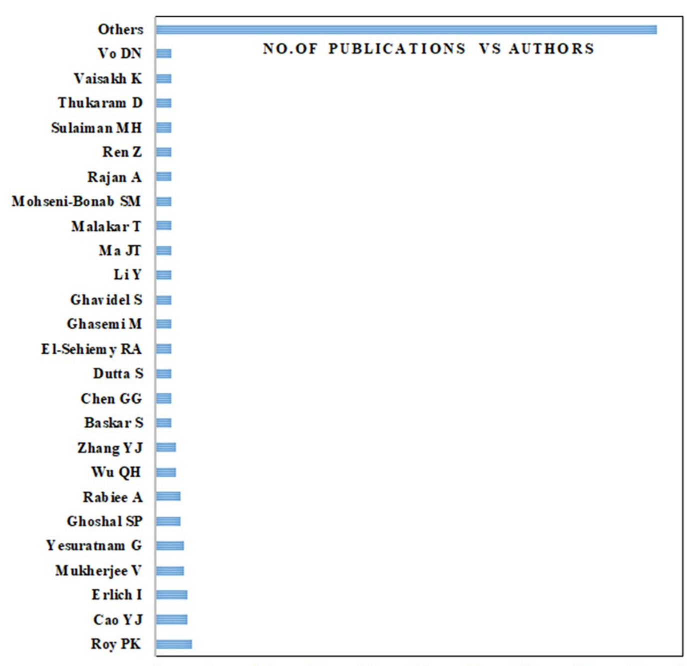

Fig. 12 Number of publications versus author

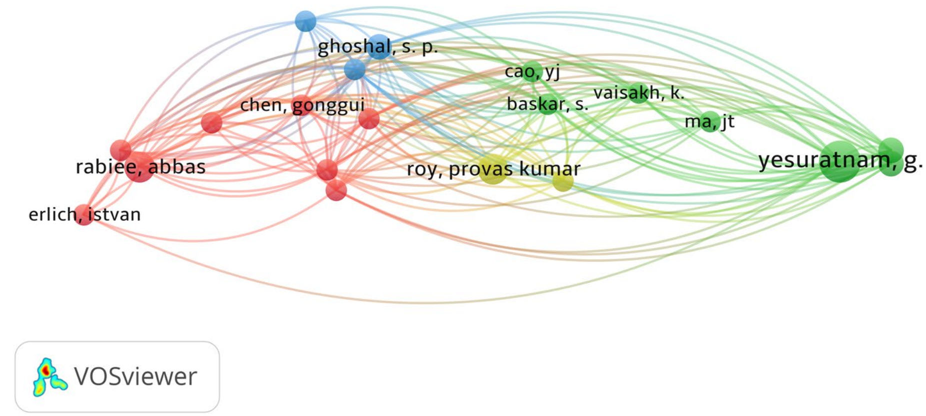

Fig. 13 Author's visualisation network chart

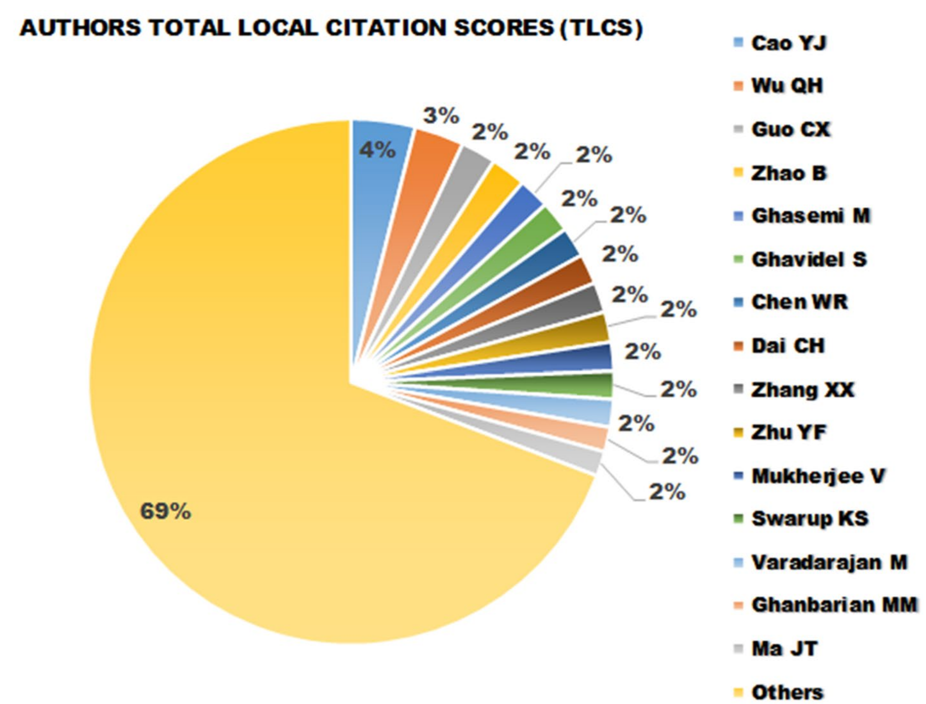

Fig. 14 Author's TLCS ranking

domain. Figures 14 and 15 present the graphical representation of authors TLCS and TGCS.

Authors with 50 local citation scores and above were selected, while those with less are combined and categorised as "Others".

A total of 15 authors satisfied this condition and had a combined TLCS total of 30.8%, while 69.2% went to the remaining 531 authors. Based on the obtained result, Cao YJ has a total of 129 citations, amounting to 3.93% of the total, hence making him be the top author in ORPD research family in the TLCS citations category. The 2nd position is Wu QH with 3.05%, followed by Guo CX and Zhao B in the 3rd place with 2.16% each. The

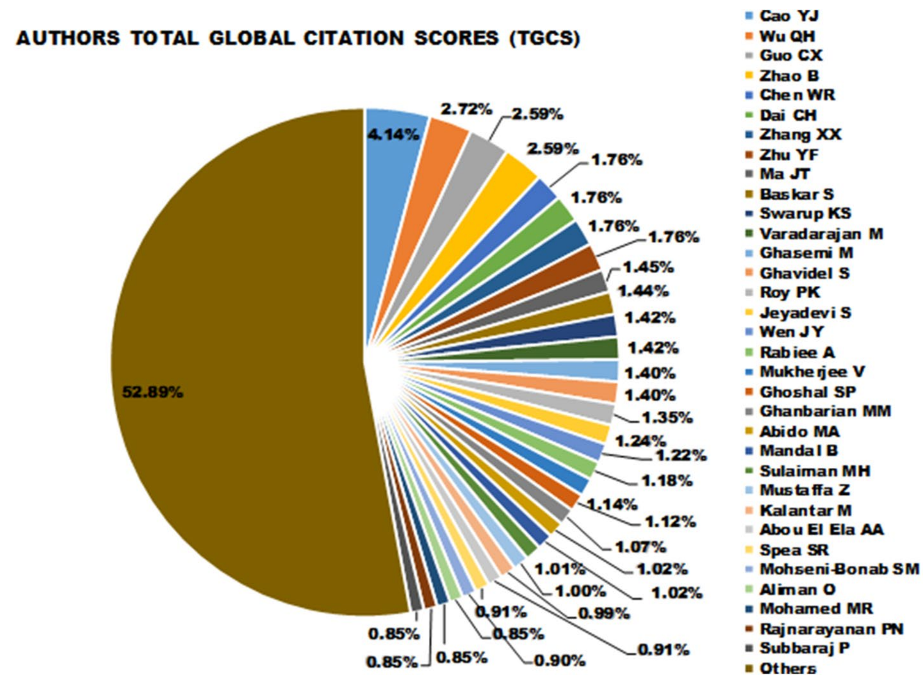

Fig. 15 Author's TGCS ranking

global citation scores (TGCS) measured the author's citation over the entire web of science database, i.e. including citations not part of the ORPD collections.

For the TGCS, authors with 100 and above citations were said to be considered. Based on that, 33 authors were selected, which amounted to 47.11% of the total TGCS citations. The remaining 501 authors shared the remainder of 52.89%. Figure 15 shows the pie chart of the details.

The top authors Cao YJ, Wu QH, Guo CX and Zhao B, occupied the same position as in the previous TLCS chart, with a percentage of 4.14%, 2.72% and 2.59%, respectively. This means that the four authors produce novel and high-quality articles that are equally relevant to other research fields. There are interchanges in other authors' positions, such as the case of the 5th position, which Ghasemi M and Ghavidel S had with 1.98% each, shifted to 13th position in the TGCS citation table.

Journal distribution

All the 263 ORPD articles were published in 168 Web of science index journals. The number of ORPD articles published by each journal ranges from 1 to 23 articles. Figure 16 shows the journal visualisation network, indicating the bibliometric coupling existing between the top 30 journals with each having at least two published ORPD articles. The 30 journals were classified into 6 clusters based on the article content similarities, citations and co-citations between the articles. Each cycle represents an individual journal and the bigger the circle size, the higher the journal productivity and influence in ORPD research field. Table 3 shows the summary of journals that published at least two ORPD-related research article.

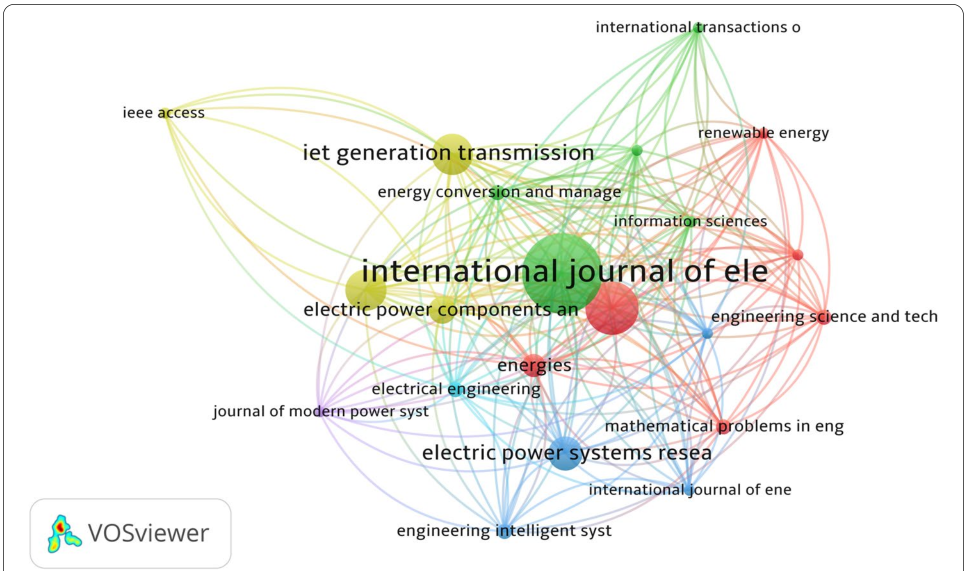

Fig. 16 Journal visualisation network chart'

Table 3 Journal list with ORPD record ≥ 2

Journal	Record	Country/region	Impact factor (2018)	CiteScore (2018)	SJR (2018)
International Journal of Electrical Power &	23	England	4.418	5.79	1.26
Applied Soft Computing	14	Netherlands	4.873	6.27	1.22
IEEE Transactions on Power Systems	10	USA	6.807	6.77	3.14
IET Generation Transmission and Distribution	10	England	3.229	4.25	1.099
Electric Power Systems Research	8	Switzerland	3.022	4.05	1.037
Electric Power Components and Systems	6	USA	0.888	1.48	0.345
Electrical Engineering	3	USA	1.296	1.81	0.26
Energy Conversion and Management	3	England	7.181	7.87	2.730
Engineering Science and Technology-An International Journal-JESTECH	3	Netherland	–	4.85	0.765
Mathematical Problems in Engineering	3	USA	1.179	1.130	0.27
Archives of Electrical Engineering	2	Poland	–	1.09	0.221
Engineering Applications of Artificial Intelligence	2	England	3.526	4.58	0.881
IEEE access	2	USA	4.098	4.96	0.61
Information Sciences	2	USA	5.524	6.90	1.620
International Transactions on Electrical Energy Systems	2	England	1.314	1.71	0.45
Journal of Electrical Systems	2	France	–	0.81	0.2
Journal of Modern Power Systems and Clean Energy	2	China	2.848	4.64	1.031
Renewable Energy	2	England	5.439	4.58	1.89

The top three journals with the highest number of published articles are INT J Elec Power ($n=23$, IF 4.418), Appl Soft Comput ($n=14$, IF 4.873) and IET Gener Transm Dis ($n=10$, IF 3.229), and IEEE T PowerElectr ($n=10$, IF 6.807) that tied together in the third place. The largest cluster consisted of 12 journals, while the smallest contained only one. An additional factor used in the ranking of journals is the amount of TLCS and TGCS earned by each journal. Figure 17 shows the TGCS earned by journals with at least a total of 30 citations in the ORPD-related articles. It seemed Int J Elec Power, IEEE T Power Syst and Electr Pow Syst Res were the top three journals with 25%, 22% and 11%, respectively, while JESTECH took the 14th position with 0.94%. The remaining 154 journals had a total of 11%.

Co-occurrence of keywords

In order to measure the co-occurrence link within the ORPD articles keywords, 781 keywords were extracted. However, the number was too large to be classified into comprehensible research clusters. Hence, the keywords were further refined manually to remove those words that appeared twice due to spelling alterations and some redundant words. 115 keywords were finally selected. Figure 18 shows how the keywords are interlinked with each other in the ORPD research domain. Six clusters were formed, with the largest cluster having 26 items and the smallest having 12 items. Cluster #1 is the one in red colour. As can be seen, it contains two large circles at its centre and some little scattered ones. The size of a circle signifies the total occurrence and link strength of the keyword in the ORPD research field. The dominant research topic represented by the big

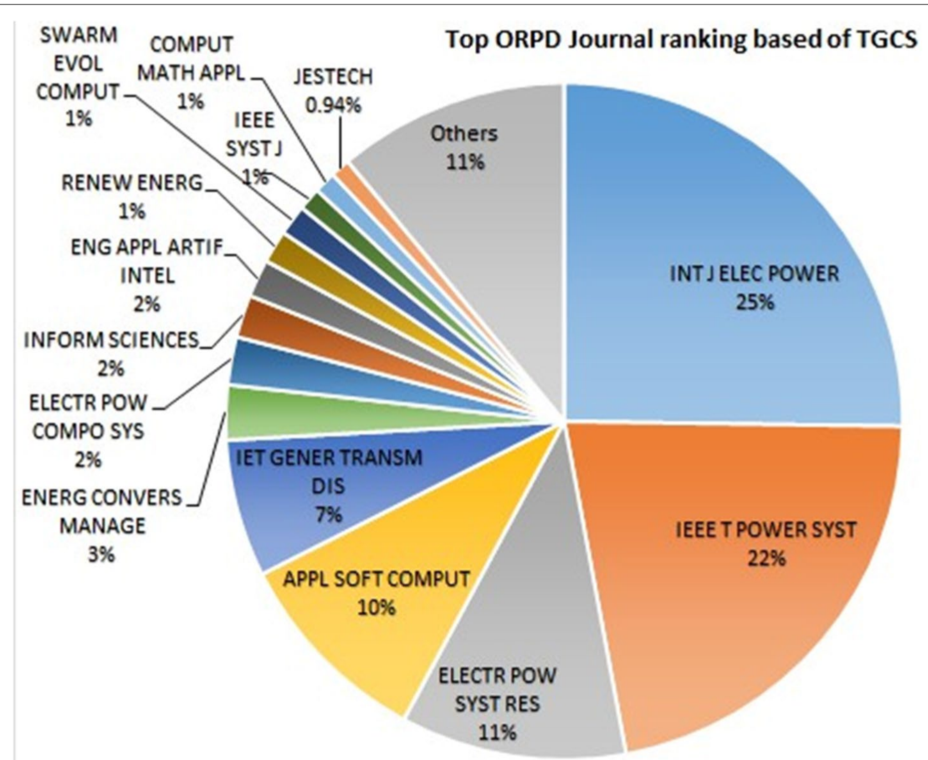

Fig. 17 Journal TGCS ranking

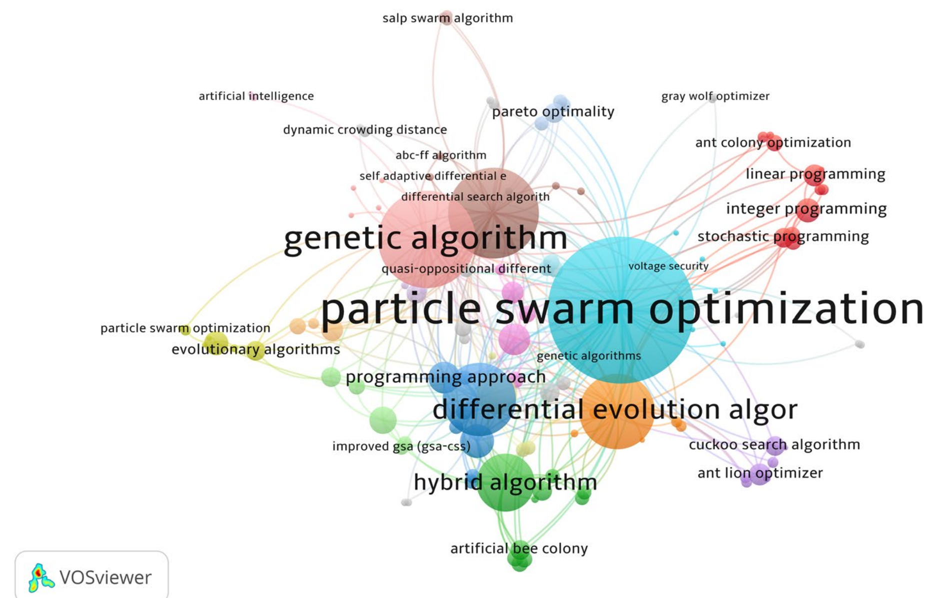

Fig. 18 Journal visualisation network chart

circle is the Genetic Algorithm (GA). GA is a metaheuristic search algorithm inspired by the concept of Darwin's theory of evolution. John Holland first introduced it in 1960, and it used bio-inspired parameters like selection, cross over and mutations to provide an optimal solution to the objective function. GA being among the pioneering optimisers, many articles must have cited it, which perhaps could be the reason for its dominance. Differential Evolution (DE) is equally an evolution-based algorithm with excellent constrained handling capability [48]. Since its inception in 1995 by Storn and Price, it has provided solutions to a lot of constrained based optimisation problems. This feature makes it suitable for ORPD applications [49].

The remaining cluster members are Salp Swarm Algorithm; Chance constrained programming, Symbiotic Organism Search algorithm, Chemical Reaction optimisation (CRO) and Yin-Yang Pair optimisation. Most of which are the trending optimisers and have proven to be effective in handling practical engineering problems.

Cluster #2 is the one with the sky-blue colour, and it has 23 items. The most prominent research topic is Gravitational Search Algorithm (GSA). GSA was introduced in 2009 by Rashedi et al. with the sole purpose of solving optimisation problems. It is a nature-inspired algorithm that was invented based on Newton's gravitational law and the law of motion [50]. The next in the cluster is Bio-geography Base Optimisation (BBO) and was invented by Dan Simon in 2008. Biogeography has a link with the two prominent nineteenth-century scientists, Alfred Wallace and Charles Darwin. Before the 1960 s, biogeography was just a merely descriptive and historical idea, until Robert MacArthur and Edward Wilson collaborate in the early 60s to mathematically model and formulate a theory of Island Biogeography. Their research primary focus was on species migration, emergence of new species and the extinction of a species. The mathematical model of biological genetics and neurons inspired the development of Genetic Algorithms (GAs) and Artificial Neural Network (ANN), so also the biogeography results in the birth of

Biogeography Base Optimisation (BBO). Since then, research interest has been surging due to its effectiveness in solving various academic and industrial engineering problems [51]. Similar to the previously mentioned optimisers, it optimises an objective function through iterative and stochastic means of improving solutions to a specific quality or a fitness function [51].

The remaining optimisers are Imperialist Competitive Algorithm, Frog-Leafing Algorithm, Jaya Optimisation, Oppositional Krill Herd Algorithm, Teaching Learning Algorithm.

They are all optimisation techniques that are often used to solve not only ORPD research but almost all real-life problems.

Cluster #3 is the one with a deep blue colour and contains 20 items in all. The most prominent ORPD research optimiser is Particle Swarm Optimisation (PSO) and was initially introduced by Kennedy et al. [52]. It appears to be the most significant research area in the entire clusters, as it has the most significant circle size and is densely connected to all clusters. PSO is a metaheuristic swarm-based optimiser intended to mimic the motion of a flock of birds or school of fish. Its initial purpose was to simulate social behaviour, but later on, it was observed to have performed excellently in solving optimisation problems [53]. The next most popular research optimiser in cluster 3 is the Cuckoo Search Algorithm (CSA). CSA is also a nature-inspired algorithm developed in 2009 by Xin-she Yaang and Suash Debt [54]. The algorithm was derived from the parasitic breeding behaviour of cuckoo species, whereby it laid eggs in the nest of other species of bird resulting in the host bird abandoning its nest to build another one elsewhere [55]. CSA was found to be suitable for various practical optimisation issues, including ORPD research problem [56]. The remaining optimisers are Ant-Lion Optimizers, Gray Wolf Optimizers, Fractal Search Algorithm, Mixed Bacterial chemotaxis, Symbiotic Organism Search Algorithm, Tabu Search Algorithm. All these algorithms gave an insight to interested ORPD researchers on the types and nature of optimisers used in the research field.

Cluster #4 has 19 keywords, and the yellow colour denotes it. The three dominant research phrases in the cluster are Seeker Optimisation Algorithm (SOA), Artificial Bee Colony Algorithm (ABC), and Double Differential evolution Algorithm (DDE) [57]. SOA is an adequately addressed optimiser and was proposed by Dai et al. [57]. It is an algorithm that exploits the human capability of performing a random search by utilising its history and social experience [57]. Whereas, ABC is a bio-inspired optimisation algorithm that harnesses the intelligent foraging behaviour of the honey bee. It is a swarm-based optimiser that utilises social cooperation to achieve its tasks successfully. It was developed in 2005 by Dervis Karaboga and has been widely deployed in the field of optimisation to solve ORPD and other various engineering problems [58]. The immune algorithm, Modified Teaching Learning-Based Optimisation, Global Numeric Optimisation and Learning-based optimisation are some of the major trending research optimisers in the cluster.

Cluster #5 is the one in purple colour and contains 15 research items. The three most dominant are Ant Colony Optimisation (ACO), Linear Programming (LP), and Nonlinear programming. ACO was proposed in 1991 by Marco Dorigo, and it was used to identify the optimal path of a given graph by mimicking the ant food search behaviour.

Biological Ant uses a pheromone to optimise their exploration and exploitation in the search space, while similarly, in the artificial ant, the quality of result and position are recorded for better solutions. ACO has been used on various engineering applications ranging from sequential ordering, project scheduling, protein folding and ORPD [59]. LP is equally called Successive Linear Optimisation, and it is a method used to maximise or minimise a linear objective function based on linear equality or inequality constraints. It was developed in 1939 by Leonid Kantorovich. It is an optimisation tool used in the power system to minimise the running cost of the network [60].

Cluster #6 is the last cluster denoted by green colour and contains the least number of keywords (12). The cluster comprises some famous bio-inspired algorithms like Firefly algorithm, Moth- Flame Optimisation (MFO) and Whale Optimisation Algorithm (WOA). The cluster contains hybrid optimisation, which is a combination of two or more algorithmic features to solve the same set of problem. Firefly algorithm is an optimiser inspired by the flashing characteristics of the firefly and was developed by Xin-She Yang in 2008 [61]. The algorithm differs slightly from PSO, which has caused tremendous criticism from some researchers [62]. MFO is a bio-inspired algorithm that mimics the navigational properties of moths fly. It was first developed in 2015 by Mirjalil. Since then, it has been used by researchers to solve complex engineering optimisation problems [63]. WOA is another bio-inspired optimiser that mimics the hunting behaviour of humpback whales. It was proposed in 2016 by the same inventor of MFO. Since its inception, it has been applied to various engineering and real-life problems like ORPD, Maximum power point tracking, Economic dispatch problem, Breast Cancer diagnosis [64]. Table 4 summarises the optimisers having at least two and above occurrences.

Conclusion

Optimal reactive power dispatch (ORPD) is an essential optimisation aspect in an electrical power system that aids in achieving optimal reliability, security as well as cost-effective operation of the power system network. Its significance is the reason behind the rise in research interest. To generate a summary of the research progress and the future directions, this article has undertaken a bibliometric analysis on ORPD-related publications index in the WoS database covering a period of 30 years (1989–2019). The findings show that 263 articles are published within the period under review, with the highest number of published articles in 2016. However, the annual publications have been declining after 2016, hence reflecting a slight global reduction in ORPD research interest. These articles are published in 166 journals, thereby signifying research diversification. International Journal of Electrical Power and Energy Systems and Applied Soft Computing has the first and second positions, respectively, while IEEE Transaction on Power Systems and IET Generation Transmission and Distribution occupies the third place on the bases of ORPD publications. A total of 571 authors published the 263 articles with Provas, Kumar Roy having the highest number of ORPD articles, while Yi Jia Cao is the author with the highest number of TLCS. ORPD research appears to have broader coverage and active research collaborations among countries like China, USA, England, India, Germany, Algeria, Denmark, Austria, Canada and Morocco. It is interesting to note that the top three countries with the highest research output are from the Asian continent, which is

Table 4 Keywords with occurrence frequency ≥ 2

Keyword	Occurrence	Link strength
Particle Swarm Optimisation	101	749
Genetic Algorithm	65	489
Differential Evolution Algorithm	41	381
Gravitational Search Algorithm	28	248
Linear Programming	7	119
Bio-Geography Based Optimisation	7	76
Artificial Bee Colony	7	31
Cuckoo Search Algorithm	6	34
Ant Colony Optimisation	5	23
Imperialist Competitive Algorithm	4	45
Learning-Based Optimizer	4	42
Ant Lion Optimizer	4	29
NonLinear Programming	3	52
Chaotic Krill Herd Algorithm	3	35
Jaya Search Optimizer	3	22
Tabu Search Optimizer	3	20
Fuzzy Search Algorithm	2	86
Chemical Reaction Optimisation	2	24
Frog Leaping Algorithm	2	19
Pseudo Gradient Search	2	16
Harmony Search Algorithm	2	16
Firefly Search Algorithm	2	15
Symbolic Organism Search Algorithm	2	10

probably due to the enormous energy demand and network stress attributed to their large population. One hundred fifteen (115) keywords were used to visualise the co-occurrence networks, which were then classified into six (6) research clusters. The most dominant and trending research topic in each of the six clusters is PSO, GA, GSA, LP, EA and Hybrid Algorithm.

In a nutshell, this study provides valuable outlines and future directions on ORPD research so that both experienced and novice researchers in the field can quickly identify trending research topics, top authors/supervisors, and universities/organisations/industries from which to seek appropriate funding and collaborations.

Abbreviations

ORPD: Optimal reactive power dispatch; GA: Genetic algorithm; ES: Evolutionary strategy; PSO: Particle swarm optimisation; BFO: Bacterial foraging optimisation; SADE: Self-adaptive differential evolution; ABC: Artificial bee colony; HSA: Harmony search algorithm; GSA: Gravitational search algorithm; GWO: Grey wolf optimisation; HFA: Hybrid firefly algorithm; TLBO: Teaching–learning-based optimisation algorithm; WoS: Web of science; TGCS: Total global citation scores; TLCS: Total local citation scores; IF: Impact factor; SJR: SCImago journal rank; DE: Differential evolution; CRO: Chemical reaction optimisation; BBO: Bio-geography base optimisation; ICA: Imperialist competitive algorithm; FLA: Frog- leafing algorithm; JO: Jaya optimisation; OKHA: Oppositional Krill Herd algorithm; CSA: Cuckoo search algorithm; ALO: Ant-lion optimisers; FSA: Fractal search algorithm; SOA: Seeker optimisation algorithm; DDE: Double differential evolution; ACO: Ant colony optimisation; LP: Linear optimisation; MFO: Moth-flame optimisation; Swarm Evol Comput: Swarm and evolutionary; INT J Elec Power: International journal of electrical power and energy; Appl Soft Comput: Appl soft computing; IET Gener Transm Dis: IET generation, transmission and distribution; IEEE T Power Syst: IEEE transactions on power systems; Comput Math Appl: Computers and mathematics with applications; Renew Energ: Renewable energy an international journal; Eng Appl Artif Intel: Engineering applications of artificial intelligence; Inform Sciences: Information sciences; Electr Pow Compo Sys: Electric power components and systems; Energ Convers Manage: Energy conversion and management; Electr Pow Syst Res: Electric power systems research; JESTECH: Engineering science and technology, an international journal.

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Authors' contributions
IH Shanono, A Muhammad performs the data extraction while MC Tiong cross-checked and refined it to avoid duplication. NRH Abdullah and H Daniyal use HistCite and VOSviewer visualisation software to analyse the data. IH Shanono uses MS Excel to plot some of the graphs. All the authors contributed in result interpretation, drafting and proofreading the manuscript.

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Competing interests
The authors declare that they have no competing interest.

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