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Bibliometric Review of MPPT Algorithms for Wind Energy Conversion Systems

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ABSTRACT

The existing conventional fuels are going up in prices and going down in availability. This has boosted the demand for the renewable resources like wind energy. Wind energy being abundantly available is becoming very popular as it is a freely available pollution free green energy. Some technical aspects like the tracking of maximum power from the wind energy conversion systems has a very high impact on the efficiency of the wind energy conversion systems. Several algorithms have been implemented for tracking the maximum power point of the wind energy conversion systems. The main objective of this paper is to study the extent of the available research works in the domain of maximum power point tracking for wind energy conversion systems. The bibliometric analysis done in this study is primarily based on the data extracted from the Scopus database, Mendeley and Research Gate. Open-source software Gephi was used in the study for drawing clusters. GPS visualizer is used for the geographical analysis in this study. From the bibliometric review, it can be inferred that major publications are from journals, conference and articles from Indian publications and followed by Chinese publications. This study is done starting from the year 2010 to 2020. It spans over a decade. The subject areas of Engineering followed by Energy, Computer Science and Mathematics have the maximum contribution in this domain.

Keywords: Maximum power point Tracking (MPPT), Wind Energy Conversion Systems (WECS), Renewable Energy Sources, Wind Energy, Wind Turbines, Energy Conversion, DC-DC Converters.

1. INTRODUCTION

The availability and increase in the prices of conventional fuels has triggered and boosted up the demand and ever-increasing need of renewable energy. Having a glance at the rate at which the existing fuel resources are being consumed there is a dire need to replace the conventional resources of energy. Wind energy is the most abundantly available resource of renewable energy. It is becoming a very popular renewable resource since it is abundantly available, pollution free green energy which is cost effective and needs less maintenance. The global capacity and annual additions in the installed wind energy systems globally is growing and gaining a lot of popularity in the domain of renewable energy markets globally and in India. Immense popularity is gained by the wind energy systems.

Despite this immense popularity of wind energy conversion systems (WECS) some technical aspects are still there which need improvement and needs more focus, such as the extraction of energy from these systems and wind generators employed for WECS, making these systems more efficient and extraction of maximum power are some of the areas of concerns. The WECS can be stand-alone systems or grid connected. The small-scale standalone systems appear to be an attractive option for remote areas where they can be more affordable. The wind energy conversion system (WECS) employs wind turbines for the converting energy contained in the wind into electrical and mechanical energy. Wind generators (WG) that are preferred for WECS are SEIG or PMSG. WG of PMSG type are used available in the direct drive type which are without gear box WG. SEIG WG also has advantages like ruggedness, lesser cost and protection from overload condition. The output power fetched by a WECS needs to be extracted used effectively. The main objective behind using the WECS is to extract maximum possible energy and make an effective and efficient use of this extracted power. Although lot of literature is available for tracking the maximum power from WECS further work needs to be done for the improvement and efficiency enhancement while extracting maximum power.

Dynamic variations contained naturally in wind velocity needs a controller that can track maximum power point (MPP) which is located near the operating region and find the optimum speed of the generator for that particular instant which will give us maximum energy. An overview and survey of the literature available in the domain of maximum power point tracking (MPPT) for WECS is presented starting from 2010 till date.

There is an immense evolution and development in the area of maximum power point tracking in WECS. The authors (Agarwal *et al.*, 2010) presented a novel method of tracking the MPPT by a two stage method. In the first stage the pitch angle β was used and in the second stage the P&O method was employed. This method does not require additional sensors and the time taken to track the MPP is also very less.

Problems in the hill climb search (HCS) algorithm are addressed by (Kazmi *et al.*, 2011). There is a trade-off between speed and efficiency which has been addressed. A novel technique of detecting the peak is used which helps in the improvement during fluctuating wind speeds. Self-tuning MPPT is proposed that improves the efficiency.

An adaptive MPPT based on Fuzzy logic is proposed by (Azzouz, Elshafei and Emara, 2011). This technique does not need any kind of sensors for measurement of the wind speed. This technique is based on the HCS algorithm but the settling time is quite fast as it is a fuzzy based MPPT. The use of the PI- like fuzzy based current controller instead of the commonly used PI current controller. This method is more reliable for the high variations in the speeds of the wind and also provides better power extraction capability.

Particle swarm optimization (PSO) based MPPT algorithm is used and the duty cycle of the converter is varied to extract maximum power in the method proposed by (Abdullah *et al.*, 2012). By using this technique neither system parameter knowledge nor sensors are required. This method is found to be superior as compared to the other conventional available algorithms.

The authors (Cheng and Zhu, 2014) have presented a detailed and comprehensive review of the types of WECS, MPPT methods for WECS with variable speed and the upcoming potential technologies in WECS. They have discussed and compared the WECS based on parameters like weight, cost, reliability, efficiency and size. Four MPPT techniques are compared and discussed the improvement measures in these techniques. They have highlighted the use of BDFIGs that can replace DFIGs since it can provide improvement in the reliability of the system.

An intelligent MPPT for variable speed WECS employing online Q learning algorithm employs ANNs for the task of function approximation for providing action values based on the inputs which are the electrical power and rotor speed of the generator. By employing this method, higher memory requirement is eliminated. The other benefit of this method is the lesser computational cost when compared to traditional Q learning method. WT characteristics knowledge or the need of WSR is eliminated by using this method. DFIG based WECS is used for simulation and the emulation was carried out using PMSG WECS (Wei *et al.*, 2014).

According to (Killi and Samanta, 2015) CP&O algorithm suffers from the problem of drift. The P&O algorithm for Solar PV system is modified by using an extra current checking and validated mathematically. SEPIC converter with direct duty ratio is employed for this purpose. This method is free from drift and has enhanced efficiency along with better tracking efficiency.

A method for MPP tracking which is based on RBF NN that depends on optimal TSR and rapidly adjusts the torque with the randomly varying condition of the wind. Torque control and pitch control combination is used. The stability of this system was tested under the stochastic conditions between LWR and HWR. This method provides superior tracking time and improved efficiency. The main drawback is it is not a generic method (Li *et al.*, 2015).

MPPT method which was based on fuzzy controller to remove the problems in the P&O algorithm provides significant improvement in the power coefficient obtained using this method and reduction in the tracking speed and power fluctuations (Mozafarpoor-Khoshrodi and Shahgholian, 2016).

(Kumar and Chatterjee, 2016) have provided a comprehensive and detailed review of the available methods for MPPT for WECS. TSR, OT and PSF have the advantage of faster tracking but suffer from high cost due to additional sensors for measurement. HCS, INC and ORB have advantages like they are very simple to implement, low cost as they are sensor less but the response time is slow. The authors address the need to set guidelines for selection or the methodology to determine the best MPPT for a given installation.

A hybrid MPPT technique which is a combination of computational behaviour of HCS- PSF-TSR and employs a buck-boost featured primary inductor converter (SEPIC) for extraction of maximum power from the complete wind speed profile range. This method provides improved performance but suffers from complexity and larger memory requirement (Hussain and Mishra, 2016).

An adaptive MPPT based on PLS for a standalone WECS is developed by (Hui, Bakhshai and Jain, 2016). The algorithm makes use of the derived slope relationship that correlates the measured power and speed with TSR. This technique adapts to the aging, robust to atmospheric changes but suffers due to high implementation complexity and greater memory requirement than the already available methods.

A comparison of four different methods for MPPT is done by (Liu, Locment and Sechilariu, 2017). Out of the four methods fixed step perturb and observe, variable step P&O, Newton Raphson based observe and perturb and indirect look up table and Fuzzy logic-based method. The indirect technique gives best performance among all the methods compared. The main drawbacks are increased implementation complexity and cost. In an improved OTC based MPPT which is based on ETR, the torque is optimised based on relationship between ETR and wind conditions. The tracking time and cost are reduced by using this technique with an improved performance of the WECS (Yin *et al.*, 2017).

MPPT using torque control method for WECS in which feedforward coefficient is used to obtain rapid response to the changing wind speed. It mainly focuses on increasing the power capture. The major drawback of this method is that higher power fluctuations are obtained (Cui, Song and Li, 2017). WTE in the laboratory environment is presented to emulate the real time behaviour of the WECS. MATLAB /Simulink model of the fixed pitch variable speed WECS and hardware implementation is done. Real time data acquisition is used for improvement of the accuracy of the system (Sewwandi *et al.*, 2017).

(Kumar *et al.*, 2018) has given a comprehensive review of the available MPPT algorithm for WECS. The authors have compared many available MPPT algorithms in the literature and concluded that MEPT has the best efficiency followed by MMPT, TSR, OTC, PSF respectively. HCS and ORB provide slow response. The merits and demerits of all the algorithms has been discussed in this work. Variable step HCS for a PV system provides improvement in the accuracy and tracking speed. There are some drawbacks observed between the response time and power oscillation (Popescu, 2018).

OPP MPPT for WECS can overcome the issues like requiring pre-requisites like system parameter knowledge and non-unique optimum curve. The combination of PSO and ORB was used. This algorithm does not need any sensors and enhanced efficiency was obtained along with good tracking ability(Abdullah *et al.*, 2018).

(Kumar *et al.*, 2018) have given a comprehensive review of the available algorithms in the literature wherein they have given the classification and discussed about the merits and demerits of the available methods for MPPT. MPPT algorithms can be largely classified as based on speed sensor and speed sensor less. Speed sensor based MPPT are TSR, PFS while those which do not require speed sensors are HCS, ORB and OTC. A lot of improvements and modifications were done in the HCS or P&O method as it has simplicity in implementation and cheap as it needs no special speed sensors. This method suffers from drawbacks like drift in which the algorithm misleads in the wrong direction from the MPP. The tracking time is also high. To overcome these drawbacks many methods were introduced among them are variable step P&O, AVSPO, hybrid methods using observe and perturb clubbed with other methods together, NN based and FLC based methods were also developed.

A new technique of variable step P&O based on MRC (Model predictive reference control. MRC control is superior to PI control and helps mitigate the drawbacks of PI control thereby providing reduction in the oscillations near MPP and also provides high tracking efficiency. This technique is useful for large WTs that provide maximum power in 1.5 MW. The WECS used is DFIG based

WECS (Ali et al., 2019).

(Asri *et al.*, 2019) proposed an adaptive fuzzy logic controller based on PI (AFLC-PI) for direct drive. Here hybrid scheme is devised in which FLC is clubbed with a PI controller. Mitigations in the system variations obtained along with promising outcomes. The main drawback of the FLC is it has higher computational burden during implementation. The number of inputs increase the rule base dimensions A boost Vienna rectifier with an EBP- NN algorithm is used for tracking the MPPT of the WECS. BPNN has drawbacks like large training time and while defining the rules good knowledge of the system parameters (Reddy and Ramasamy, 2019).

A novel control strategy based on RBFNN for MPPT in WECS is given (Kumar *et al.*, 2019). Information of turbine power characteristics as well as sensors are not required thereby reducing the cost of the system. Maximum power is tracked with help of duty cycle. The MPPT algorithm is based on the duty cycle control for extracting the maximum power. This method provides advantages like high efficiency and fast and reliable MPP tracking when compared to the other methods like BPNN and FLC and P&O.

BA-ELM prediction model for MPPT which works in three stages, first predicts the short-term wind velocity by optimizing weights for ELM by employing the BAT algorithm. Second stage helps in adapting to the forecasted values for calculating reference optimal speed. Anemometer is used for measuring the current wind velocity as an input to BA- ELM. In the third stage a combination of the optimal control technique and the state feedback control is implemented in the WECS to track the MPPT and achieve greater efficiency. The main issue with this method is the need of anemometer which reduces accuracy and increases the cost (Zhang, Zhang and Liu, 2019).

A new optimal control of WECS using DFIG to maximize the electrical and mechanical power, uses the algorithm based on the combination of PSF, soft stalling and PSO controllers provide improved efficiency over the entire range of the turbine (Sompracha, Jayaweera and Tricoli, 2019). The problem of high variations in the speed of the wind is still a challenge that needs to be worked upon.

A novel NMPC (nonlinear model predictive control) which uses discrete prediction model with large time step provides a great reduction in the implementation complexity and computational burden which is a major drawback of NMPC methods conventionally used (Song et al., 2020).

2. PRELIMINARY DATA FOR ANALYSIS

There are several popular databases like Scopus, Mendeley, Web of Science, Research Gate, Science Direct Google Scholar and many more. The Scopus data base was used for the bibliometric analysis in this paper. The data accessed on 23rd December from the Scopus database has been used for doing the bibliometric analysis. The various keywords used for extracting data are listed in table 1 below.

2.1 List of keywords

The important keywords that were used for searching “MPPT algorithms for WECS” were Maximum power point tracking (MPPT), Wind energy Conversion System (WECS). The remaining keywords are listed in table 1.

Table1: List of Keywords

Keywords	Number of Publications
Wind Power	286
Maximum Power Point Trackers	212
Maximum Power Point Tracking	205
Energy Conversion	204
Wind Energy Conversion System	195
Wind Turbines	134
Synchronous Generators	122
Wind	110
Permanent Magnets	108
MPPT	91
Permanent Magnet Synchronous Generator	79
Maximum Power Point Tracking (MPPT)	69
Algorithms	68
Controllers	68
MATLAB	67
Asynchronous Generators	57
DC-DC Converters	57
Electric Machine Control	52
Wind Turbine	51
Electric Inverters	49
PMSG	48
WECS	46

Source: http://www.scopus.com (accessed on 23rd December 2020)

The search was further refined and restricted to the inclusion of the English publications. There are total 367 English publications.

Table 2: Publishing language

Language	Number of publications
English	367
Chinese	7
Spanish	1

Source: http://www.scopus.com (accessed on 23rd December 2020)

Table 3: Publication type

Source type	Number of Publications	Percentage from 375
Conference Proceeding	183	48.8%
Journal	169	45.06%
Book Series	22	0.058%
Book	1	0.002%

Source: http://www.scopus.com (accessed on 23rd December 2020)

Out of the total 375 publications, researchers have 48.8% publications in conference proceedings, 45.06% in journals, 0.058% in book series and 0.002% in books.

2.2 Highlights of primary data

In this study the investigations are done based on keywords that were used to extract 375 publications from the database Scopus. For the domain of MPPT algorithms for WECS the type of documents extracted were conference proceedings, journal articles, book series and books. The time span ranges from 2010 to 2020. Number of publications per year in this domain is depicted in table 4 below.

Table 4: Number of publications per year

Year	Number of publications
2021	7
2020	36
2019	60
2018	44
2017	48
2016	39
2015	34
2014	42
2013	27
2012	24
2011	14

Source: http://www.scopus.com (accessed on 23rd December 2020)

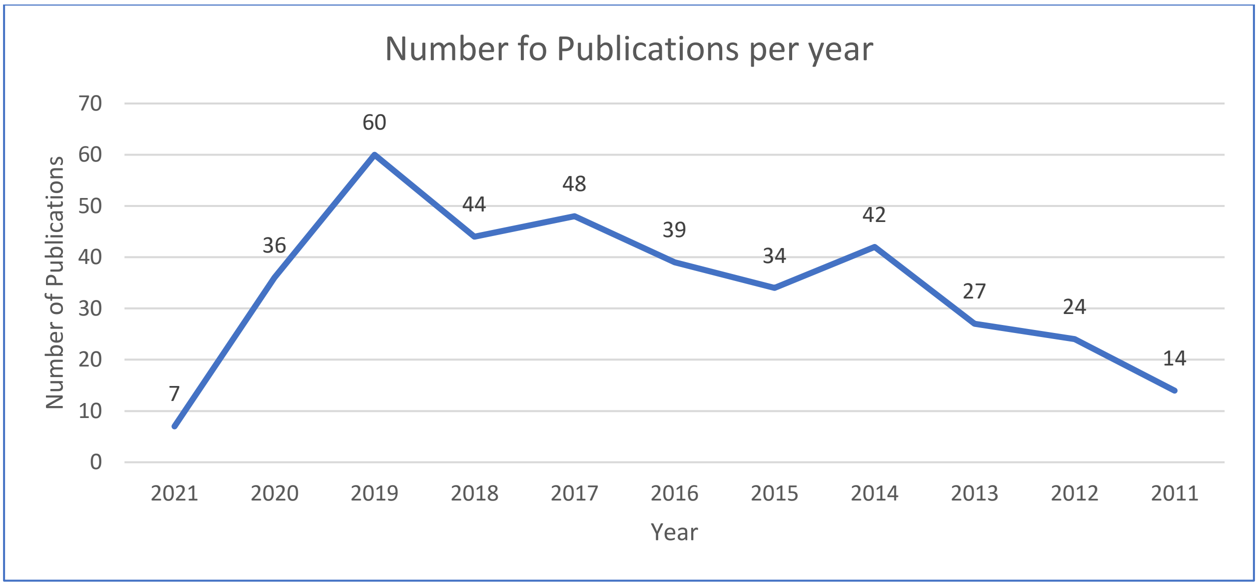

Figure 1: Number of publications per year

2.3 Investigations on data

The bibliometric study clearly reveals the type of research literatures that are available and the distinctness of the available research works by using the geographical distribution and the contributions by different researchers, where the works were published and the statistics of their affiliations.

3 BIBLIOMETRIC ANALYSIS

Following two ways were used for doing the bibliometric analysis

- Analysis based on geographical location
- Statistics based on affiliations, subject area, author statistics, document type and citation analysis.

3.1 Analysis based on geographic location

The geographic regions of awareness of the published works are shown in figure 2. The tool GPS visualizer is used for this purpose from gpsvisualizer.com. The highest number of publications are from the countries like India, Algeria, China, Canada, United states of America, Malaysia and United Kingdom. Top ten countries are depicted in the figure.

Figure 2: Geographic locations of the study of MPPT algorithms for WECS

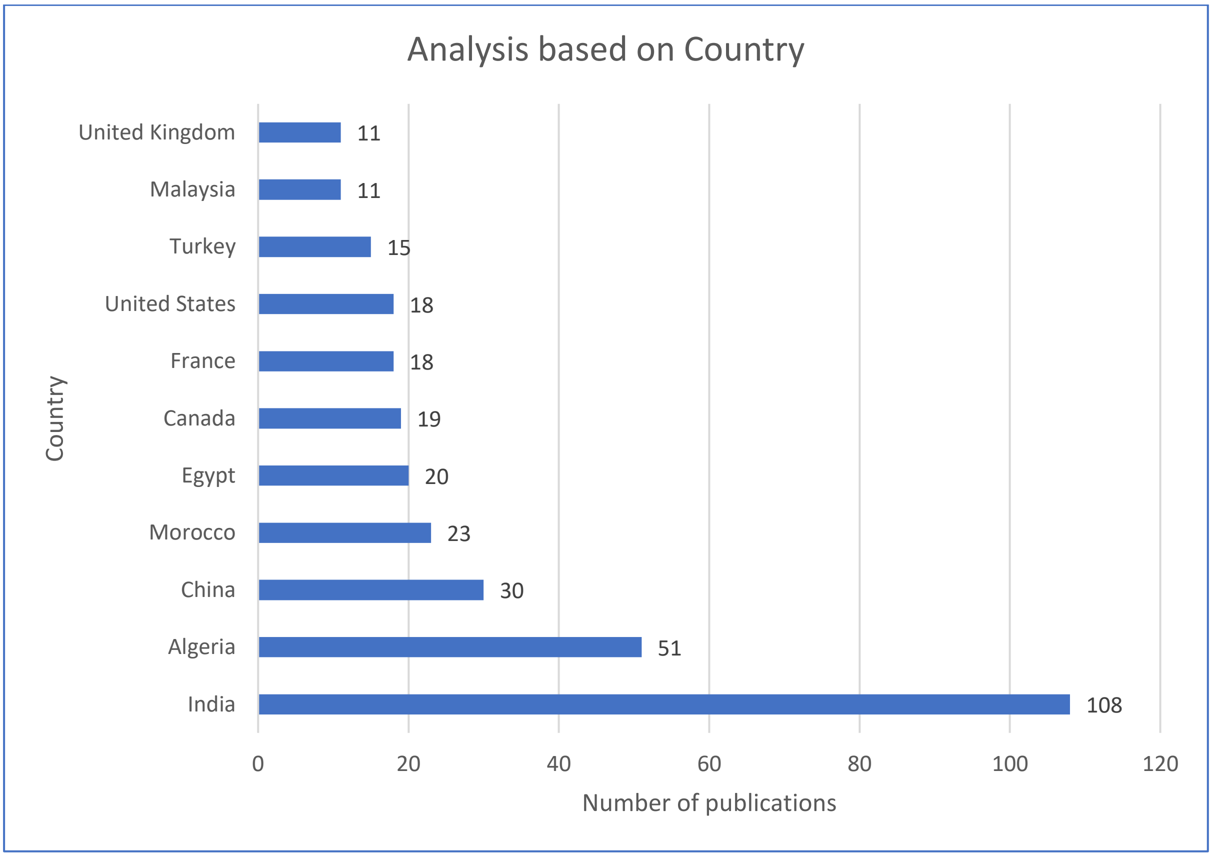

Figure 3: Analysis based on Country/Region
Source: http://www.scopus.com (accessed on 23rd December 2020)

3.2 Analysis for subject area

Figure 4 depicts the analysis that is done based on the subject area. It can be inferred from the analysis that the maximum number of research works published are from the subject areas of Engineering, Energy, Computer Science followed by Mathematics and others in the domain of MPPT algorithms for WECS.

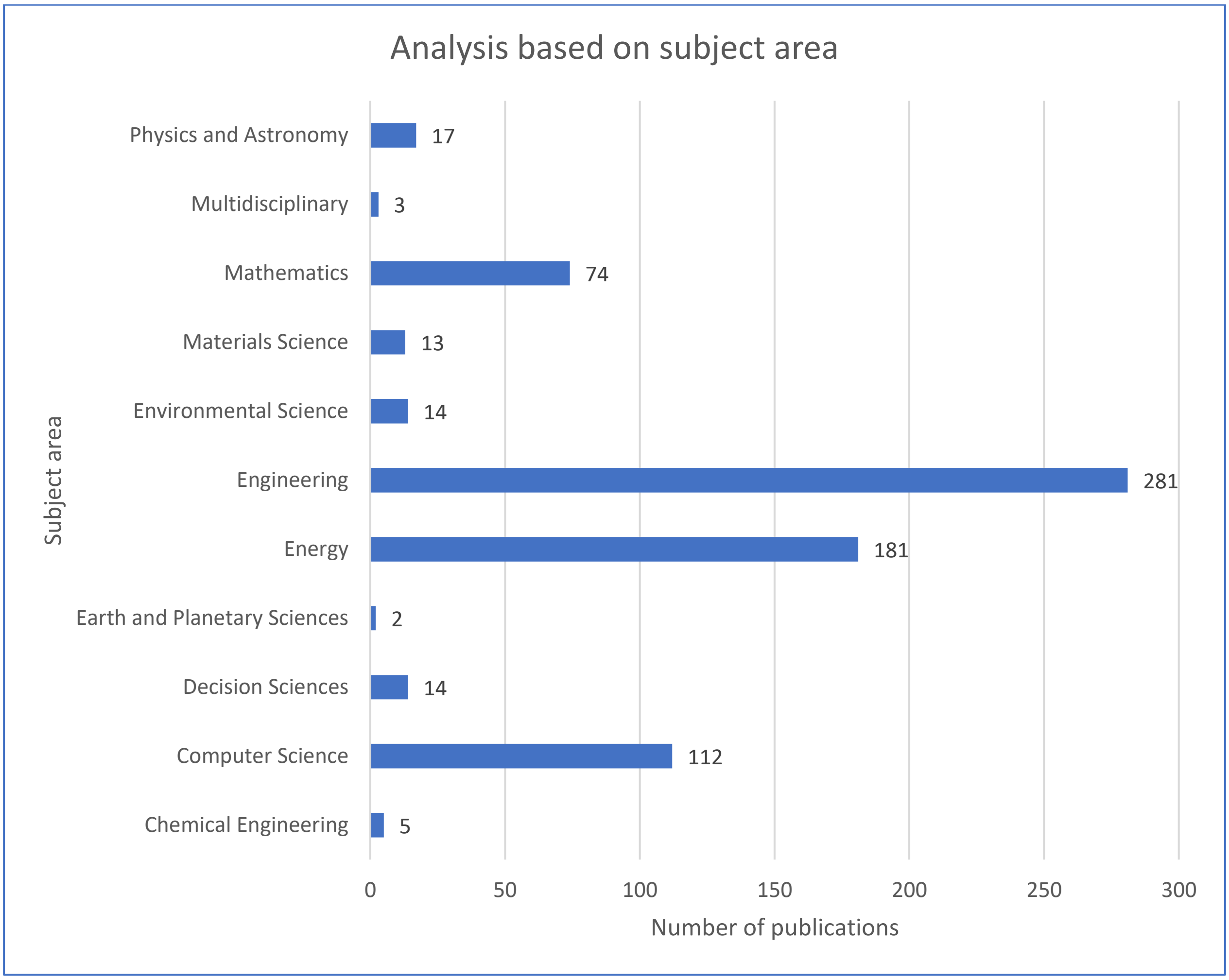

Figure 4: Analysis based on subject area
Source: http://www.scopus.com (accessed on 23rd December 2020)

3.3 Analysis based on Affiliations

In the domain of MPPT algorithms for WECS the contributions by different Universities all around the world is depicted in figure 5. This domain is dominated by the Universities of India, Algeria and China. Top twenty Universities contributing in this domain are shown in figure 5.

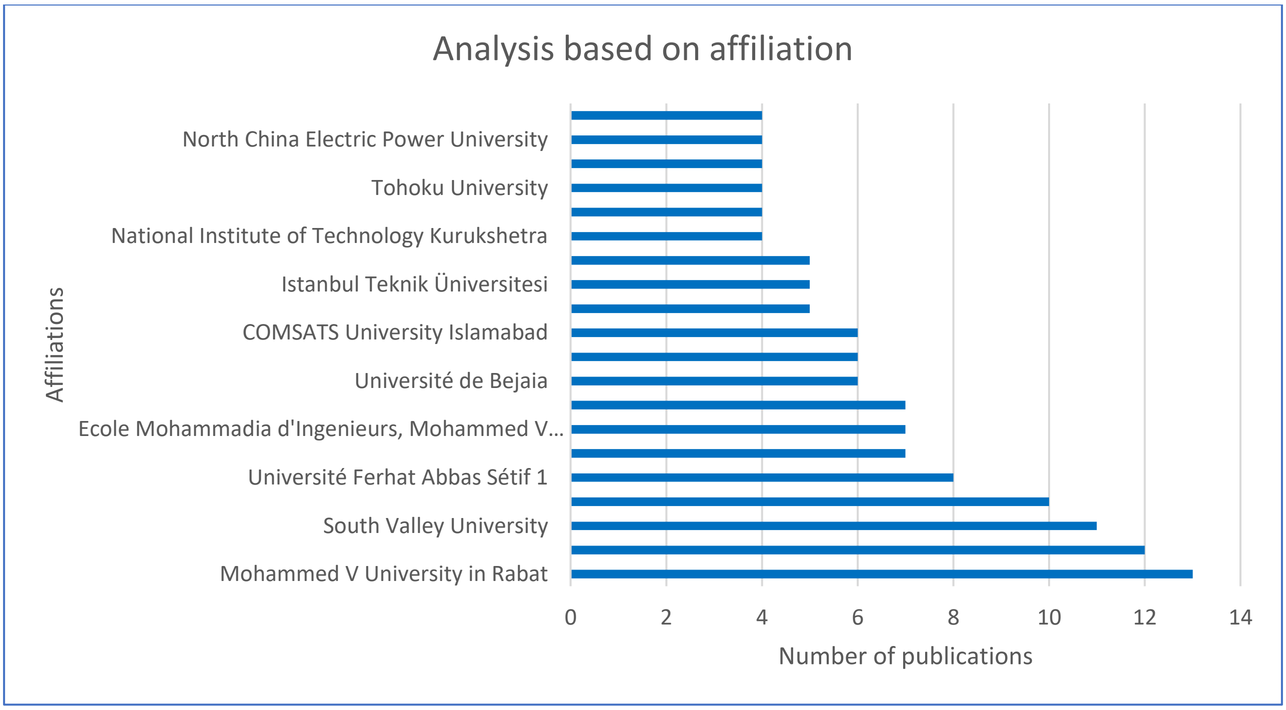

Figure 5: Analysis based on affiliations
Source: http://www.scopus.com (accessed on 23rd December 2020)

3.4 Analysis based on the authors of the research works

Key contributors in the field of MPPT algorithms for WECS are shown in figure 6. Top twenty authors are depicted from the data accessed from the Scopus database.

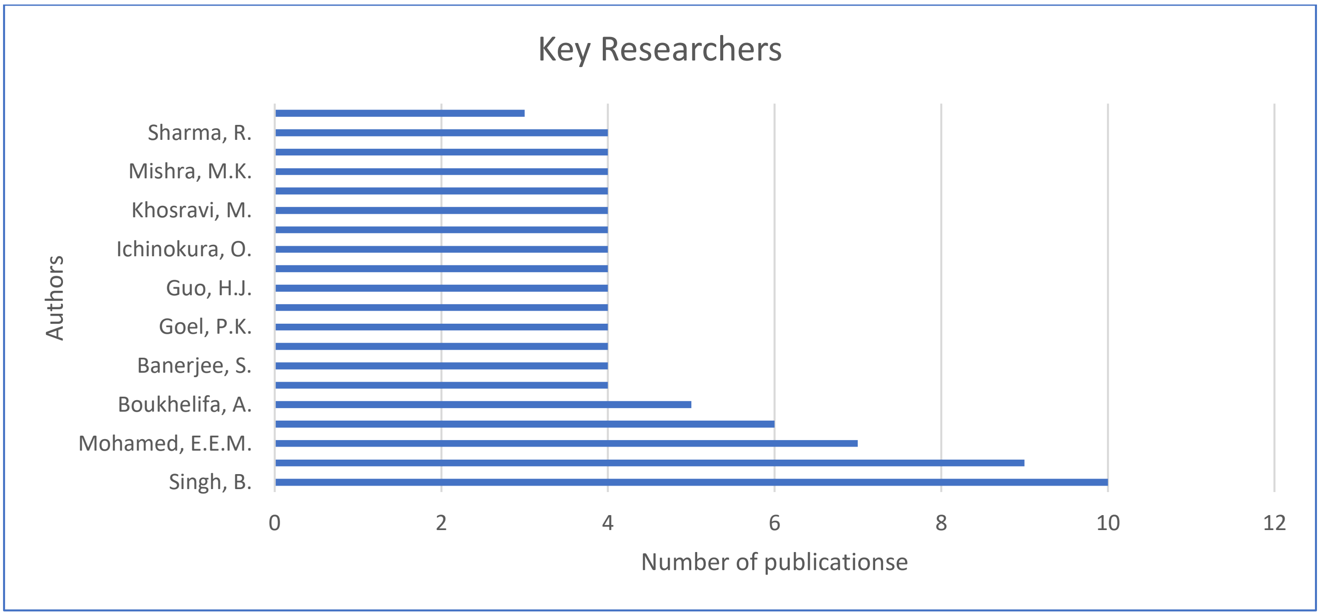

Figure 6: Key researchers
Source: http://www.scopus.com (accessed on 23rd December 2020)

3.5 Analysis based on source type

Figure 7 depicts the publication source type. It is evident that 45% publications are from journals, 49% are from conference proceedings, 45% from journals and 6% are from book series.

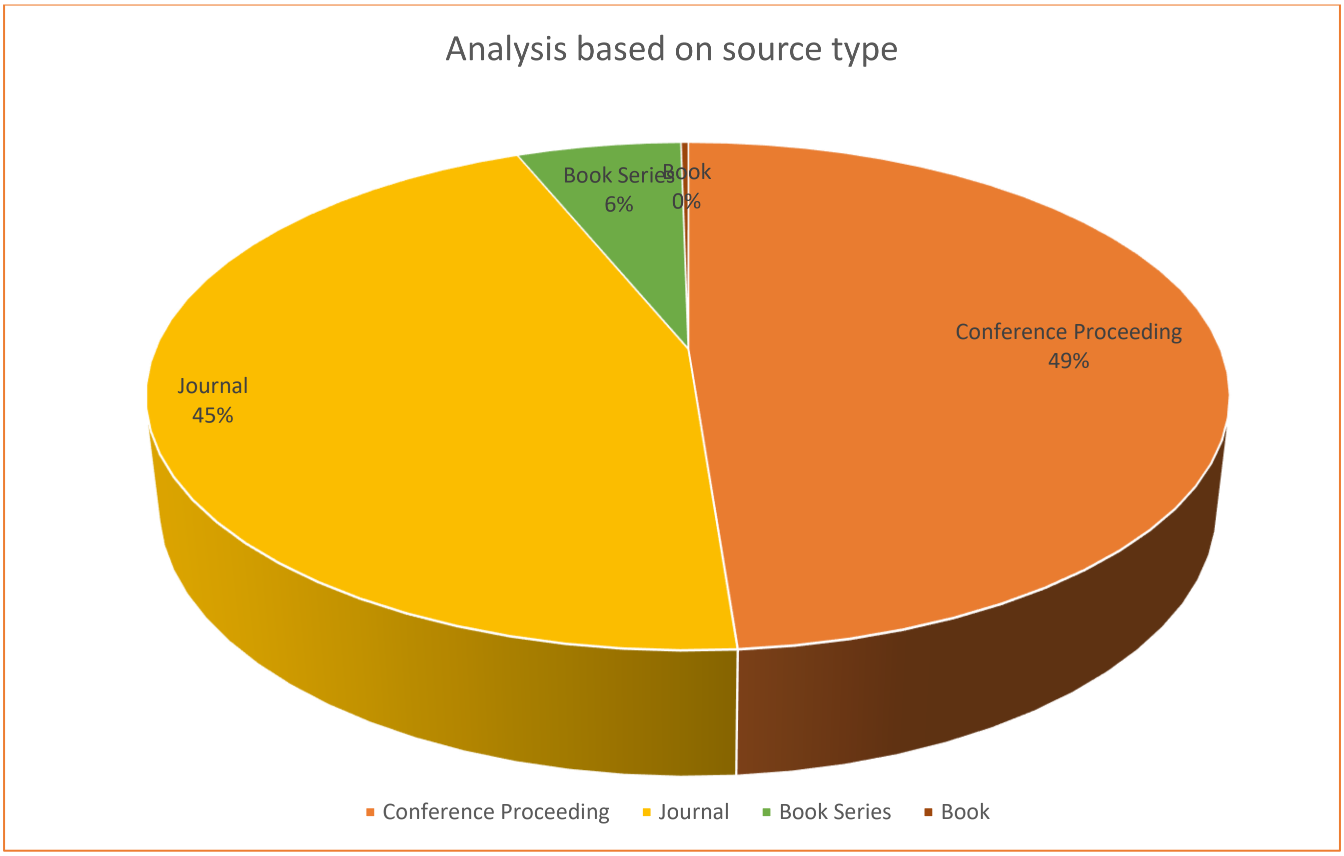

Figure 7: Analysis based on Source type
Source: http://www.scopus.com (accessed on 23rd December 2020)

3.6 Analysis using clusters

The relationship between the various statistical parameters is depicted by using the clusters that are obtained using the tool 'Gephi'. Gephi is an open-source software which is used for clustering of data. Keywords, source type, publication title, year of publication, affiliations, author are represented by nodes and edges. Several combinations of the extracted data from the Scopus database are used for cluster creation, that are shown in figures 8-10. The layout used was Fruchterman Reingold. Figure 8 shows a network based on the affiliations, language and publication type. It has 41 nodes and 36 edges. Figure 9 shows a cluster of keyword and source title. It has 114 nodes and edges. Figure 10 shows a cluster of subject area and year. It has 42 nodes and 33 edges.

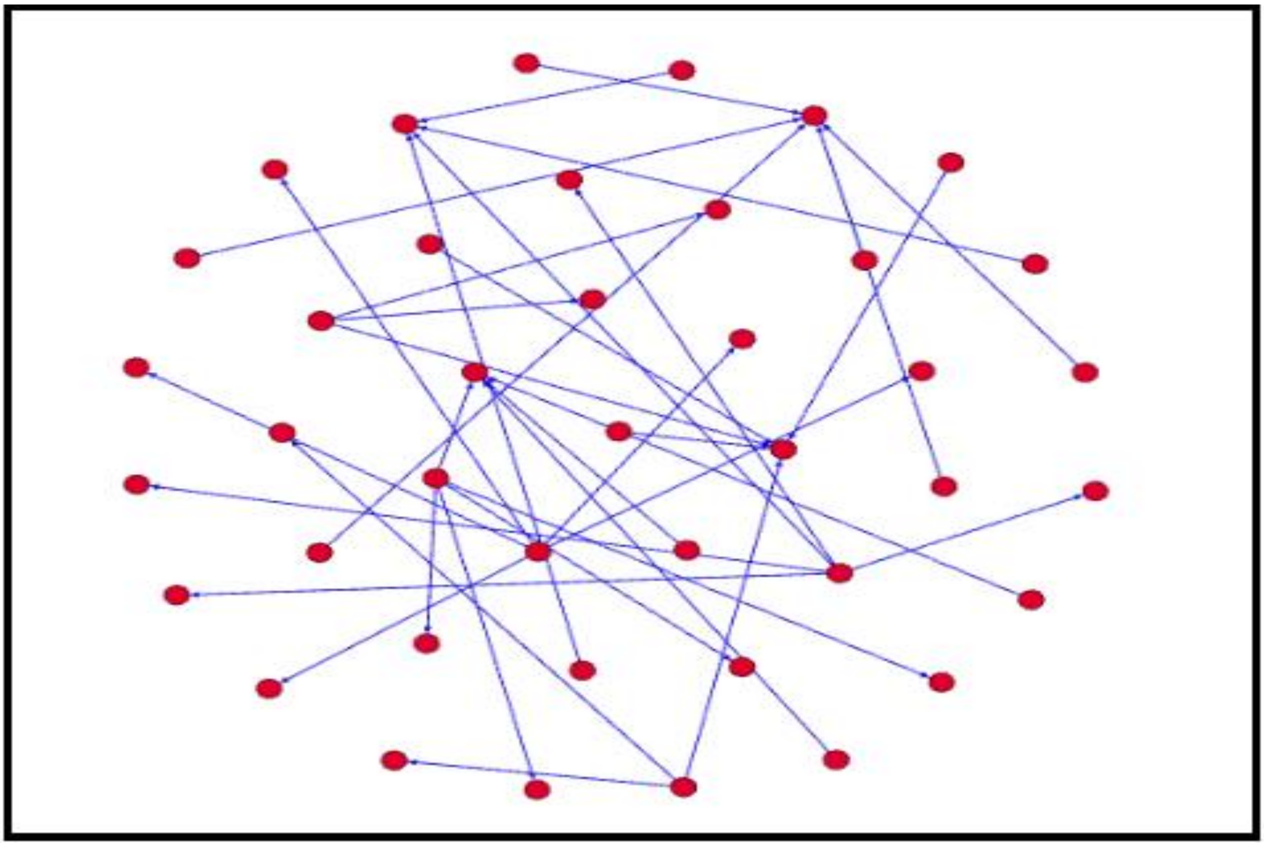

Figure: 8 Cluster of affiliations, language and publication type

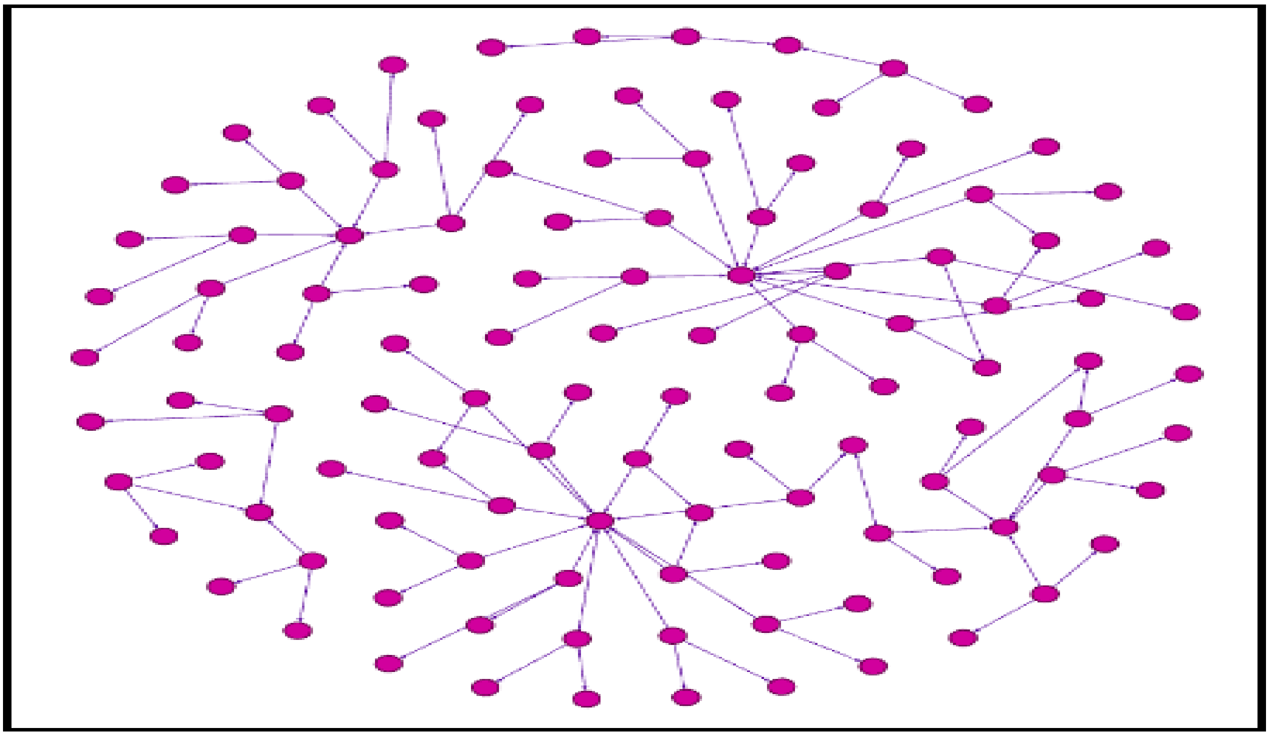

Figure:9 Cluster of keyword and source title

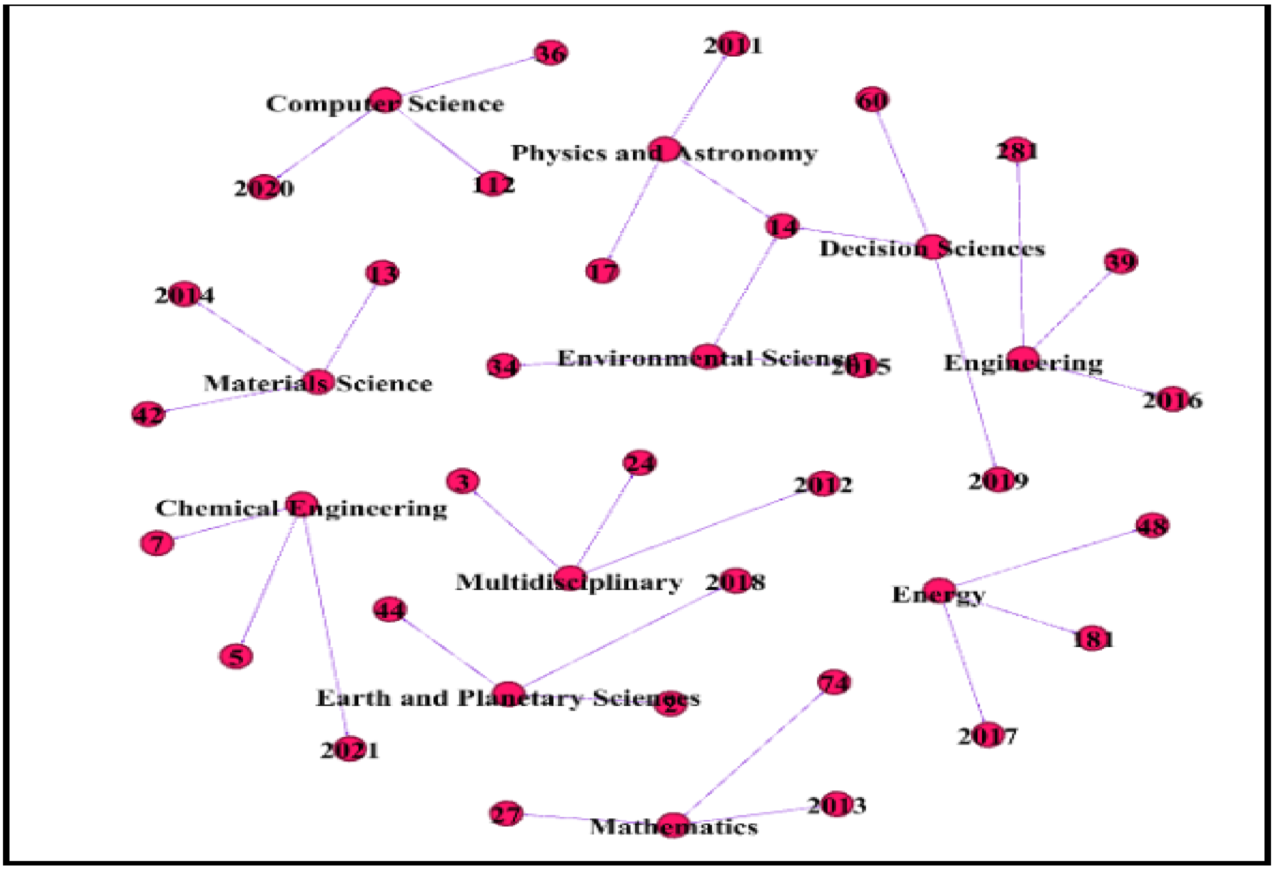

Figure:10 Cluster of Subject area and year

3.7 Analysis based on document source

Figure 11 depicts the analysis based on document source for MPPT algorithms for WECS. It is apparent that the highest number of publications are from the journals of Energies, International journal of Electrical Power and Energy, International journal of Renewable Energy Research, Journal of Electrical Engineering and Renewable Energy.

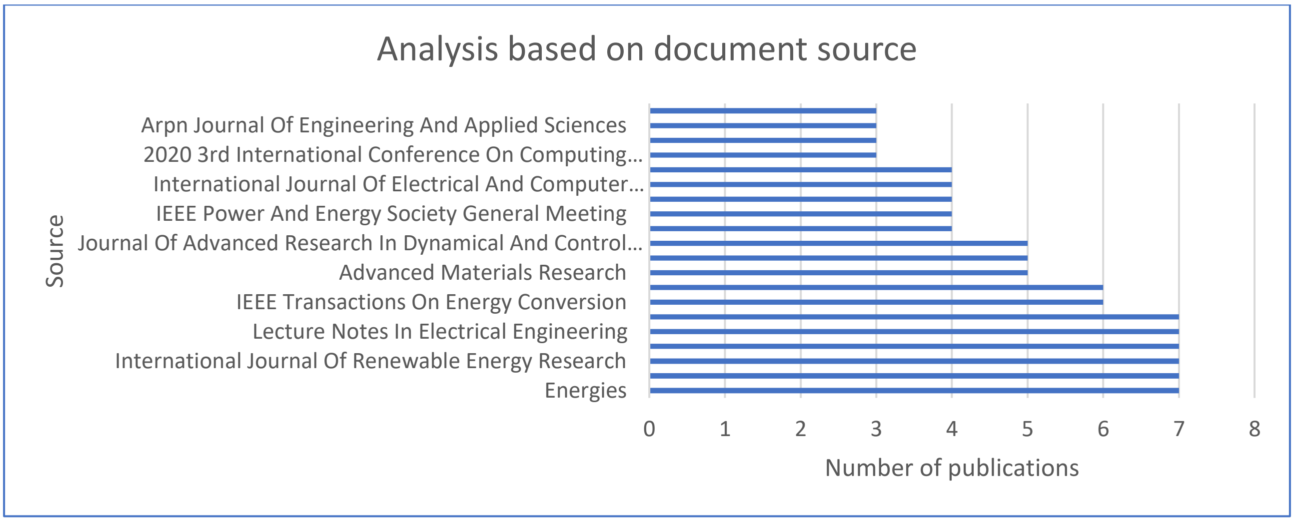

Figure 11. Analysis based on document source
Source: http://www.scopus.com (accessed on 23rd December 2020)

3.8 Analysis based on citations per author

Top ten authors having the maximum number of citations in the domain of MPPT for WECS is depicted in the table 5 below.

Table 5: Citations per author with maximum citations in the area of MPPT algorithms for WECS

Authors	<2016	2016	2017	2018	2019	2020	total
Kazmi S.M.R., Goto H., Guo H.-J., Ichinokura O.	168	30	36	40	33	15	325
Kumar D., Chatterjee K.	0	11	51	43	73	64	246
Tan Y.K., Panda S.K.	72	19	13	16	15	11	146
Dalala Z.M., Zahid Z.U., Yu W., Cho Y., Lai J.-S.	34	17	22	18	24	19	136
Kesraoui M., Korichi N., Belkadi A.	61	14	10	15	19	10	132
Huang C., Li F., Jin Z.	5	22	20	20	27	26	120
Wei C., Zhang Z., Qiao W., Qu L.	0	1	20	27	29	26	106
Kabalci E.	22	15	23	14	22	7	103
Lin W.-M., Hong C.-M.	46	10	10	7	14	10	98
Belmokhtar K., Doumbia M.L., Agbossou K.	8	18	12	19	20	10	88

Source: http://www.scopus.com (accessed on 23rd December 2020)

4. LIMITATIONS OF THIS WORK

The Scopus database was used entirely for extracting data for this study. Combinations of different keywords gave the data presented above in this study. Few journals and research works that are not present in Scopus database could not be included in this study.

5. CONCLUSION

This study is entirely based on the data extracted from the Scopus database. It can be inferred from the bibliometric review of MPPT algorithms for WECS that the highest contribution in this domain as far as research publications are concerned is from the subject areas of Engineering, Energy, Computer Science followed by Mathematics. The bibliometric analysis clearly shows that maximum publications are from conference proceedings, journals, book series followed by books. Major contribution in the published journal articles and conference proceedings is from the countries like India, Algeria, China, USA followed by UK. The researchers in these countries have given a major contribution in research in the domain of MPPT algorithms for WECS which will provide a path for the new researchers for contributing and enhancing the maximum power point tracking capability and thereby enhance the performance of WECS.

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