Bibliometric Analysis of Smart Grid Research from 2012 to 2017

Tomus Alonso Quintero[1], Guillermo Eliecer Valencia[2]*, Alfonso Rodriguez[3]

[1]**Research Assistant in Mechanical Engineering/ Faculty of Engineering/Universidad Del Atlántico, Colombia.**
[2]**Research Assistant in Research Group on Efficient Energy Management- Kaí / Faculty of Engineering/Universidad Del Atlántico, Colombia.**
[3]**Assistant Professor in Mechanical Engineering Program/ Faculty of Engineering/ Universidad Del Atlántico, Colombia.**

Abstract : A bibliometric analysis of the research published on the subject of smart grids for a period from 2012 to 2017 was carried out, and the use of metadata obtained from Web Of Science was taken for this analysis. Our search identified a total of 1998 publications related to smart grids in the period studied. We analyzed patterns of publication output, major journals, productivity of countries and institutions, collaboration between countries and an analysis of keywords by author. The annual number of publications on smart grid research increased from 61 in 2012 to 1998 in 2017. The magazine that had the most productivity in this period was the IEEE transactions on Smart grid. The United States was the country that contributed the most publications on a global level to the research topic during the period under study. The most productive institution was the Nanyang Technology University with a total of 1.9% of publications, followed by University Waterloo with 1.4%, and Zhejiang University 1.4%, are part of the top 3. In the collaboration network is you can see that the United States is the country that had the most collaboration with the others in the network, since I occupy the center of it. In the keywords of the authors, it is evident that the most used word was Smart that was in a total of 1988 publications that represent 99.5%.
Keywords : Smart Grid, Bibliometric, Investigation, Research output, analysis.

1. Introduction

The term Smart Grid is used for a type of advanced electricity distribution network, which, given that the sense of electricity is bi-directional, allows for the analysis of the energy generation and distribution infrastructure in cities, as well as evaluating the impact that these have on the rational use of energy[1]-[3]. Smart grid technologies are self-sufficient systems that find solutions for a system, reducing the workforce and directing electricity in a sustainable, reliable and quality manner for distribution. Communications networks and their cost accessibility are an ideal tool, providing a possibility to distribute energy with sensors and actuators

connected through the communications network that manage a diffusion of services as a whole[4]-[6]. A smart grid has the ability to control appliances in consumers' homes to enable energy savings, reduce costs and increase reliability[7]. The smart grid is composed of control commands that link security, detection and readings between power generation, transmission and end users[8]. New energy storage technologies offer significant opportunities to improve network efficiency and performance[9]. For the analysis of the transitory performance of the energy distribution network (PDN), analytical models and robust numerical solutions have been proposed that study the transitory behavior of the PDN, such as the application of a homogeneous Markov chain in continuous time that has allowed the performance of this type of technology to be improved[10]. Smart Grid projects are being promoted globally to support green growth and have gained wide consumer acceptance. In Europe, the European Commission monitored the smart grid projects implemented by European countries; in addition, it proposed guidelines for the cost-benefit analysis and deployment of smart metering, investigating the complexity characteristics of smart grids and assessing the size of such projects[11].

Similarly, in Europe a detailed description of the progress made in the field of demand management, demand response programs, distributed generation, technical aspects of their progress and the main advantages expected to be received through the implementation of these programs was provided[12]. There is a high expectation on the part of the smart grid to provide sustainable energy services using a two-way flow of data and energy, facilitated by an advanced information, communication and control infrastructure. An important element of this smart grid is the consumers who also produce and share the surplus energy with the grid and other users[13]. With regard to the economic and environmental aspects of the transition from the current electricity grid to an intelligent network integrated in sensors, technical studies and developments have been developed to monitor the stability of the system, integrate distributed energy and program energy consumption for domestic users[14], which is favored by consumer acceptance as one of the factors that make the smart grid business effective[15]. Smart grids are among the most important evolutionary developments in energy management systems because they enable integrated systems, including decentralized energy systems, the use of large-scale renewables and major improvements in demand management[16]. A study of the new policies needed to understand how smart grids that benefit technologies and markets are managed[17], where to increase the reliability of many of today's electricity systems, it is necessary to address the challenges of new technologies such as wind energy, integrating the use of smart grid systems for greater efficiency in distribution[18]. In recent years, a wide range of architectures, technologies and applications have been developed and used for Smart Grid, thanks to the world's significant improvements in hardware, software and network technologies[19]. As a result, a comprehensive review of progress in smart grid control was developed, highlighting several robust and adaptive strategies with a detailed description of smart grid and overload control[20]. In addition, one study investigated how to mitigate non-technical losses due to power theft and inaccurate meter readings.

2.   Data Sources And Methodology

The data were extracted from the Web of Science (WOS) database as metadata and then analyzed using HistCite software. The articles selected for the study were taken between 2012 and 2017, and the search was conducted using keywords such as "Smart grid", "communication net Works" and "Devices", in order to obtain the largest number of documents related to the Smart grid topic.

All the publications obtained through the WOS database of the topic were analyzed by criteria such as year of publication, thematic categories, journals that most frequently published, countries with the highest rate of publication, total global references, geographical distribution of authors, publications with authors from the same country and with international collaboration were quantified, in addition to the publications with the greatest impact that were referenced in other publications.

3.   Results and Discussions

Below are the results obtained for each of the criteria analyzed, based on the number of publications, the journals that have the greatest affinity with the subject matter studied, productivity and international collaboration in terms of bibliometric indicators for both countries and researchers.

3.1 Number of publications

From 2012 to 2017 a total of 1998 publications related to the Smart Grid were presented, obtaining that the publications in the Smart Grid theme increased from 61 publications in 2012 to a total of 1998 in 2017 as shown in Figure. 1, presenting an exponential increase in the number of publications until 2016, being this year the one that presents more publications as a result of the technological and computational advances necessary to achieve results of great impact for society.
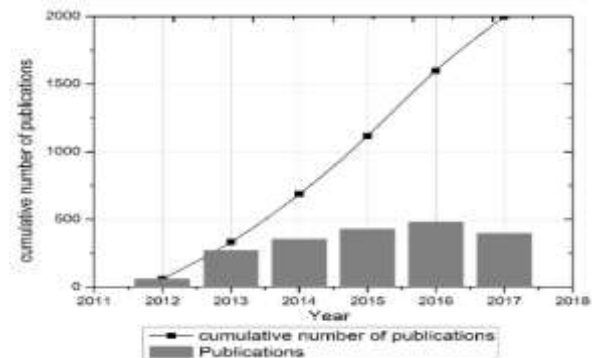

Figure 1. Years of publications vs cumulative number of publications

Table 1. Most commonly used document types in publications.

#	DocumentType	Recs	TLCS	TGCS
1	Article	1726	3158	16004
2	Review	134	440	2387
3	Editorial Material	88	22	111
4	Article; ProceedingsPaper	37	37	210
5	Letter	5	6	14
6	Book Review	4	0	1
7	Correction	2	0	2
8	Article; Book Chapter	1	0	1
9	Meeting Abstract	1	0	1
10	News Item	1	0	0
11	Review; Book Chapter	1	1	11

Table 1 shows that 86% of the publications on this subject correspond to scientific articles (1726), this being the type of document most widely used, followed by revisions comprising 6.7% (134) of total publications, editorial materials with 4.4% (88), conference documents with 1.8% (37), among others. The table also shows the number of local (TLCS) and global (TGCS) citations for each of the types of documents submitted.

Similarly, it was noted that 99.2% of the publications presented from 2012 to 2017 on the subject of Smart Grid were in English (1983), followed by Portuguese (8), Spanish (4) and other languages represented in Table 2, so it is recommended to search for information in this language to ensure results in the search in the databases.

Table 2. Top 7 of the languages used in publications

#	Language	Recs	TLCS	TGCS
1	English	1983	3664	18736
2	Portuguese	8	0	3
3	Spanish	4	0	1
4	Turkish	2	0	0
5	French	1	0	0
6	German	1	0	2
7	Polish	1	0	0

Table 3. Top 10 of journals related to the amount of paper published

#	Journal	TP	TP R (%)	TC	TC/TP	IF
1	IEEE TRANSACTIONS ON SMART GRID	244	1(12,2)	3526	14,451	717
2	RENEWABLE & SUSTAINABLE ENERGY REVIEWS	80	2(4,0)	1712	21,400	331
3	ENERGIES	59	3(2,9)	350	5,932	54
4	IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS	46	4(2,3)	1214	26,391	267
5	INTERNATIONAL JOURNAL OF ELECTRICAL POWER & ENERGY SYSTEMS	46	5(2,3)	302	6,565	55
6	ELECTRIC POWER SYSTEMS RESEARCH	41	6(2,1)	259	6,317	31
7	IEEE SYSTEMS JOURNAL	37	7(1,8)	354	9,568	113
8	ENERGY	35	8(1,8)	579	16,543	73
9	IEEE ACCESS	34	9(1,7)	74	2,176	13
10	IEEE COMMUNICATIONS MAGAZINE	32	10(1,6)	293	9,156	72

3.2 Principal Journals

The results related to the journals where this content is published allow us to locate the relevant information on this subject. The subject matter has been gaining space and has been included in one of the main themes of different journals, reaching a total of 429 journals that publish research related to this topic between 2012 and 2017. Table 3 shows the 20 journals with the highest volume of articles published on the subject, where it can be seen that the IEEE transaction on Smart grid magazine with 244 articles (12.2%), is the magazine with the highest number of publications made between those years, followed by the Renewable & sustainable Energy revierws with 80 articles (4%) and the Energies magazine with 59 articles (2.9%). Additionally, the table shows the total number of citations and the impact factor as bibliometric indicators to estimate the quality of publications in these journals.

Where TP is the Total of publications, TC is the Total citations, R is the Ranking, and IF is the Impact factor.

3.3 Productivity and international collaboration

The contribution of the different countries was estimated by the location of the institutions of at least one of the authors. Table 4 shows that the country with the highest number of publications in that period was the United States with a total of 537 publications, which represents 26.9% of total publications in the period evaluated, followed by China with a total of 425 (21.3%) and Canada with 170 (8.5%). Similarly, the total number of local and global citations is shown for this one.

Table 4. Top 5 the country related to the amount of paper published

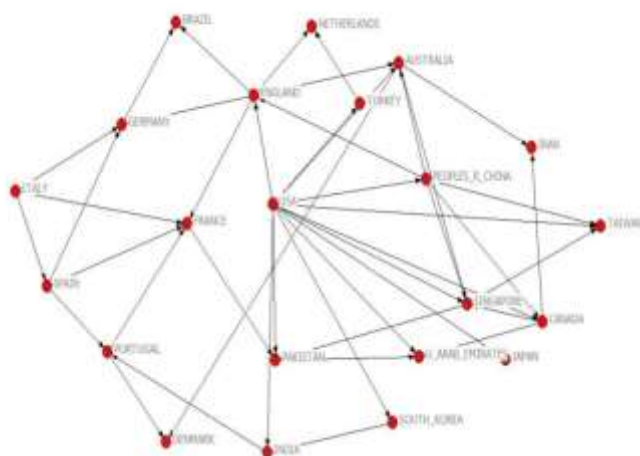| #	Country	2012-2013			2014-2015			2016-2017		
		TP	LCS	GCS	TP	LCS	GCS	TP	LCS	GCS
1	Usa	115	710	3716	205	457	2213	217	98	409
2	Peoples R China	48	264	1125	178	463	1736	197	79	386
3	Canadá	30	152	613	80	237	1162	60	20	129
4	UK	15	96	431	44	94	655	62	25	156
5	South Korea	27	69	255	43	77	343	47	22	118

Figure 2. Collaboration network of the 20 most productive countries

Where TP is the Total Publications, LCS is the Local Citation Score and GCS is the Global Citation Score.

Figure.2 shows the network of collaboration of the 20 most productive countries, developed with the Ucinet program, where each point represents a country and the lines show the collaborations between the countries. As you can see, the United States took the central position of the network, because it was the main partner with respect to the other countries.

On the other hand, table 5 shows the 10 institutions that published the most on the subject during the years of study. Taking into account the institution of at least one author, it can be observed that the most productive institution is Nanyang Technological University, which has a total of 38 publications, representing 1.9% of the total average number of publications, followed by University Waterloo with 28 (1.4%) and Zhejiang University with 28 (1.4%), which are the three institutions with the most publications out of the 20 selected, the table also shows the number of local and global citations for each institution, which gives indications of the quality of these institutions publications.

Table 5. Top 10 the country related to the amount of paper published

#	Institution	TP	TP R (%)	TC	TC/TP	IF
1	NanyangTechnolUniv	38	1(1,9)	465	12,24	134
2	Univ Waterloo	28	2(1,4)	446	15,93	105
3	Zhejiang Univ	28	3(1,4)	523	18,68	121
4	IndianInstTechnol	25	4(1,3)	296	11,84	5
5	Univ Ottawa	25	5(1,3)	267	10,68	60
6	North China Elect Power Univ	22	6(1,3)	122	5,55	44
7	TsinghuaUniv	22	7(1,1)	256	11,64	30
8	Hong Kong PolytechUniv	21	8(1,1)	199	9,48	41
9	Univ Tennessee	21	9(1,1)	147	7,00	58
10	IslamicAzadUniv	20	10(1,1)	112	5,60	36

Table 6. Top 5 keywords per author at 2-year intervals

AuthorKeywords	TP	TP R (%)	2012-2013		2014-2015		2016-2017	
			P	R	P	R	P	R
Smart	1988	1(99,5)	330	1	870	1	788	1
Grid	1499	2(75)	256	2	572	2	671	2
Grids	514	3(25,8)	79	3	218	3	217	3
Based	308	4(15,4)	41	5	111	4	156	4
Energy	280	5(14,1)	49	4	101	5	130	5

TP is the total publications, TC is the Total citations, R is the Ranking, and IF Impact factor.

3.4 Keywords of authors

Table 6 shows the keywords that the authors have used in the study period, the table gives the information of total publications for each word, where it can be observed that Smart is the word that the authors used most, with a total of 1988 publications representing 99.5% in the period. Additionally, the table shows for every 2 years an analysis of the number of publications per keyword and the position it occupies with respect to the other words, I feel Smart occupies the first place in each of the intervals of years, so this word should be included in the search equations of this topic in the databases.

TP is Total publications, P is the Publications in the period, R is the Ranking.

4.   Conclusions

A bibliometric analysis of the publication output patterns, the main journals, productivity, international collaboration and distribution of authors on documents related to the topic of Intelligent Networks was carried out between 2012 and 2017, with exponential growth between 2012 and 2016 in the number of publications on the topic.

A total of 1998 publications were presented in the period from 2012 to 2017, which grew over the years, so much so that the average annual growth of publications in the field of smart grids research was close to 500%.

The journals that made the most publications in the period analyzed were The IEEE transactions on Smart grid, renewable & sustainable Energy Review and energies, which also presented the highest indicators of bibliometric citation both locally and globally.

The United States, China and Canada were the countries that presented the best development in terms of publications during the period studied, with the United States standing out as the country with the most articles cited globally, positioning the country at the center of the collaboration network. Finally, at the institutional level, it was observed that Nanyang Technological University, University Waterloo and Zhejiang University are

the institutions that had the best development in publications in that period, which indirectly allows us to locate China in a good world position in the subject.

References

1.   "Smart Grids | ENDESA EDUCA," 2016. .
2.   H. Lund, "Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems approach," *Energy*, vol. 151, pp. 94–102, May 2018.
3.   R. Marah and A. El Hibaoui, "Algorithms for Smart Grid management," *Sustain. Cities Soc.*, vol. 38, pp. 627–635, Apr. 2018.
4.   "Que es una smart grid | Networking and Internet Technologies." .
5.   K. Mahmood, S. A. Chaudhry, H. Naqvi, S. Kumari, X. Li, and A. K. Sangaiah, "An elliptic curve cryptography based lightweight authentication scheme for smart grid communication," *Futur. Gener. Comput. Syst.*, vol. 81, pp. 557–565, Apr. 2018.
6.   S. Aleksic and V. Mujan, "Exergy cost of information and communication equipment for smart metering and smart grids," *Sustain. Energy, Grids Networks*, vol. 14, pp. 1–11, Jun. 2018.
7.   A. S. Malik and M. Bouzguenda, "Effects of smart grid technologies on capacity and energy savings - A case study of Oman," *Energy*, vol. 54, pp. 365–371, Jun. 2013.
8.   R. Narayan Yadav, R. Misra, and S. Bhagat, "Spectrum access in cognitive smart-grid communication system with prioritized traffic," *Ad Hoc Networks*, vol. 65, pp. 38–54, 2017.
9.   K. K. Zame, C. A. Brehm, A. T. Nitica, C. L. Richard, and G. D. Schweitzer, "Smart grid and energy storage: Policy recommendations," *Renewable and Sustainable Energy Reviews*, vol. 82, Pergamon, pp. 1646–1654, Feb-2017.
10.   X. Chang, J. M. Martinez, and K. S. Trivedi, "Transient Performance Analysis of Smart Grid with Dynamic Power Distribution," *Inf. Sci. (Ny).*, vol. 422, pp. 98–109, Jan. 2017.
11.   I. Colak, G. Fulli, S. Sagiroglu, M. Yesilbudak, and C. F. Covrig, "Smart grid projects in Europe: Current status, maturity and future scenarios," *Appl. Energy*, vol. 152, pp. 58–70, 2015.
12.   S. Kakran and S. Chanana, "Smart operations of smart grids integrated with distributed generation: A review," *Renew. Sustain. Energy Rev.*, vol. 81, no. August 2017, pp. 524–535, 2018.
13.   R. Zafar, A. Mahmood, S. Razzaq, W. Ali, U. Naeem, and K. Shehzad, "Prosumer based energy management and sharing in smart grid," *Renew. Sustain. Energy Rev.*, vol. 82, no. July 2017, pp. 1675–1684, 2017.
14.   C. Tu, X. He, Z. Shuai, and F. Jiang, "Big data issues in smart grid – A review," *Renew. Sustain. Energy Rev.*, vol. 79, no. May, pp. 1099–1107, 2017.
15.   C. Park, H. Kim, and T. Yong, "Dynamic characteristics of smart grid technology acceptance," *Energy Procedia*, vol. 128, pp. 187–193, 2017.
16.   Y. Zhang, W. Chen, and W. Gao, "A survey on the development status and challenges of smart grids in main driver countries," *Renewable and Sustainable Energy Reviews*, vol. 79, no. May. Elsevier Ltd, pp. 137–147, 2017.
17.   C. Park and S. Cho, "ScienceDirect Future sign detection in smart grids through text mining," *Energy Procedia*, vol. 128, pp. 79–85, 2017.
18.   G. Köktürk and A. Tokuç, "Vision for wind energy with a smart grid in Izmir," *Renew. Sustain. Energy Rev.*, vol. 73, no. April 2016, pp. 332–345, 2017.
19.   M. Badra and S. Zeadally, "Lightweight and efficient privacy-preserving data aggregation approach for the Smart Grid," *Ad Hoc Networks*, vol. 64, pp. 32–40, 2017.
20.   M. Irfan, J. Iqbal, A. Iqbal, Z. Iqbal, R. A. Riaz, and A. Mehmood, "Opportunities and challenges in control of smart grids – Pakistani perspective," *Renew. Sustain. Energy Rev.*, vol. 71, no. December 2014, pp. 652–674, 2017.
21.   S. C. Yip, K. S. Wong, W. P. Hew, M. T. Gan, R. C. W. Phan, and S. W. Tan, "Detection of energy theft and defective smart meters in smart grids using linear regression," *Int. J. Electr. Power Energy Syst.*, vol. 91, pp. 230–240, 2017.
22.   H. Wang, M. Liu, S. Hong, and Y. Zhuang, "A historical review and bibliometric analysis of GPS research from 1991-2010," *Scientometrics*, vol. 95, no. 1, pp. 35–44, 2013.
23.   L. F. Aguas, Y. C. Escorcia, and G. V. Ochoa, "Bibliometric Analysis of Recent Literature on Energy Generation Under Rankine Cycle," vol. 11, no. 03, pp. 374–382, 2018.
24.   I. S. Yulineth Cardenas, Guillermo Valencia, "Análisis cienciométrico de la investigación de sistemas

fotovoltaicos integrados a edificios desde el año 2000 a 2017," *Rev. Espac.*, vol. 38 (N° 47), pp. 1–12, 2017.

25.   J. M. Merigó and J.-B. Yang, "A bibliometric analysis of operations research and management science," *Omega*, vol. 73, pp. 37–48, Dec. 2016.

✶✶✶✶✶