Research on the Development Status of Photovoltaic Panel Cleaning Equipment Based on Patent Analysis

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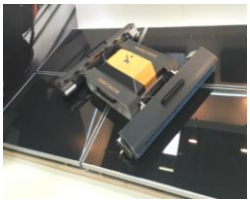
***Abstract*—With the rapid development of the photovoltaic industry, the cleaning equipment that can effectively improve the solar energy utilization rate by cleaning and maintaining photovoltaic panel comes into being. Dozens of enterprises at home and abroad have developed related products. Based on patent analysis method, the development trend, key technologies, regional distribution, advanced agencies and technology roadmap of photovoltaic panel cleaning equipment are clarified, to provide intelligence support for further development of related technologies and products by interested companies, universities and research institutes. Research results indicate that photovoltaic panel cleaning equipment related technologies are booming. Japan leads the development of this field. China starts late, but exhibits great R&D enthusiasm towards this field in recent years, and has applied a large number of patents. In terms of equipment type, on-board type cleaning robot is key R&D type. In terms of cleaning scheme, mechanical cleaning, water cleaning, air cleaning and their combination are mainstream. Moreover, there still exists certain technology gaps in the positioning, navigation and safe operation of photovoltaic panel cleaning equipment. Thus, countermeasures and suggestions are presented for the enterprises to further develop photovoltaic panel cleaning equipment related technologies.**

Keywords-photovoltaic panel; on-board cleaning robot; stand alone cleaning robot; cleaning truck; aircraft; patent analysis

I. INTRODUCTION

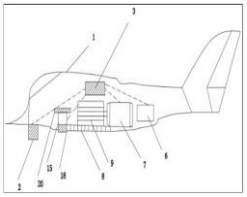
With the tightening of global energy situation, photovoltaic power generation, as a sustainable alternative to energy, has entered a period of rapid development since the second half of the 1990s. In the research of photovoltaic power generation system, improving power generation efficiency and service life are vital goals. An important factor affecting the photoelectric conversion rate of photovoltaic panels is the influence of the natural environment, especially the deposition of dust, ash and other micro-particles widely existing in the environment. Light receiving rate of photovoltaic panels can be improved by regular cleaning and maintenance of photovoltaic panels, thus enhancing the utilization rate of solar energy and then yielding huge economic benefits. As a result, photovoltaic panel cleaning equipment comes into being, and dozens of domestic and foreign companies have developed related products [1-8].

(a)On-board type cleaning robot



(b)Stand alone type cleaning robot

(c)Cleaning truck



(d)Cleaning aircraft

Figure 1. Different types of photovoltaic panel cleaning equipment

The traditional cleaning method of photovoltaic panels is manual high-pressure water gun cleaning, which has high requirements on water resources, meanwhile wastes manpower, and has a low cleaning efficiency as well as poor cleaning consistency. Therefore, it is the main development trend of photovoltaic panel dust removal research to replace manual cleaning work with special cleaning equipment. As shown in Figure 1, there are the following types of photovoltaic panel cleaning equipment on the market or under study. (1) On-board type cleaning robot. The cleaning mechanism is set on the main frame. The main frame moves on the guide rail through the walking mechanism to make the photovoltaic cleaning machine stick to the surface of the photovoltaic panel and move to complete the cleaning work. (2) Stand alone type cleaning robot. Stand alone type cleaning robot is an intelligent robot running independently. It relies on its own electrode to drive each motion mechanism without guide rail and relies on feedback and guidance of a variety of sensors to walk on the photovoltaic panel array according to the established route to complete continuous cleaning of dust and stains. (3) Cleaning truck. In contrast to on-board type cleaning robot and stand alone type cleaning robot which both move and operate on the photovoltaic panel, the moving mechanism of the cleaning truck, such as wheels or tracks, are in contact with the ground. The vehicle body is connected with the mechanical arm that equipped with a cleaning mechanism, such as roller

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brush. The cleaning mechanism is driven to move on the photovoltaic panel through the movement of the vehicle body and the adjustment of the mechanical arm, so as to complete the cleaning work. In addition, there are aircraft cleaning type, fixed nozzle cleaning type, electrostatic cleaning type and other types.

Based on the patent analysis method, the development status of photovoltaic panel cleaning equipment were investigated from the aspects of development trend, key technologies, regional distribution and advantageous institutions, so as to provide information support for related government departments, companies, universities and research institutes to further develop related industries and technologies.

II. Data Sources

In this study, patents were retrieved and collected on Derwent patent database with keywords, IPC classification and CPC classification as searching routes, and with time scope from 1962 to Sep. 2018. A total of 2,678 patent families and 3,638 patents related to photovoltaic panel cleaning equipment technology were obtained. Patent analysis tools such as Derwent Data Analyzer and Derwent Innovation of Clarivate Analytics and PatentStrategy of LexisNexis were comprehensively used.

III. Basic Status of World Patent Applications for Photovoltaic Panel Cleaning Equipment

A. *Distribution of Patent Applications in Terms of Types of Photovoltaic Panel Cleaning Equipment*

As shown in Figure 2, according to the patent indexing, among the 2,678 patent families for photovoltaic panel cleaning equipment, the on-board type cleaning robot occupies the vast majority, accounting for 65%. The cleaning truck, stand alone type cleaning robot and cleaning aircraft account for 10%, 6% and 1% respectively, and the rest are other types of cleaning equipment.

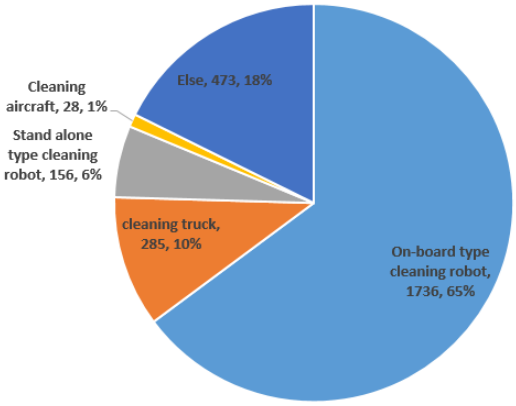

Figure 2. Distribution of patent applications in terms of types of photovoltaic panel cleaning equipment

B. *Annual Patent Application Trend*

Figure 3 shows the annual patent application trend of the photovoltaic panel cleaning equipment from 1983 to 2018. According to the trend, the technical development of photovoltaic panel cleaning equipment can be divided into three stages.

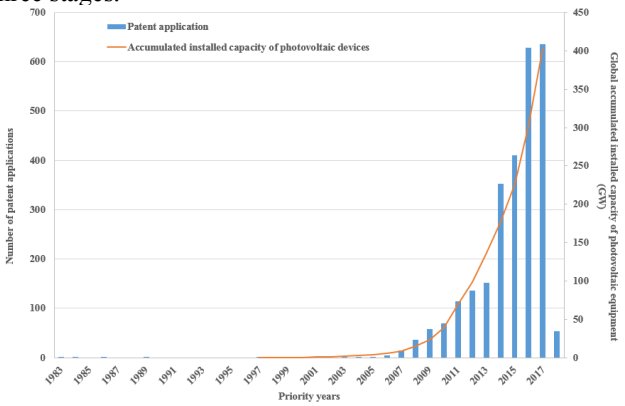

Figure 3. Annual distribution of patent applications for photovoltaic panel cleaning equipment

Stage 1 is ferment stage of photovoltaic panel cleaning equipment technology with time ranging from 1983 to 2006. In this stage, photovoltaic devices installed capacity was small, thus the corresponding patent applications exhibited small number and low growth rate. No more than 5 patents were applied every year. Main technology source countries were Germany and Japan. The first Chinese patent was filed in 2006 by Nankai University. In general, there were no outstanding research and development (R&D) institutions. The research of photovoltaic panel cleaning equipment mainly focused on the on-board type cleaning robot and fixed nozzle type cleaning equipment. The cleaning methods were mainly mechanical cleaning type and mechanical cleaning + water cleaning type.

Stage 2 is take-off stage of photovoltaic panel cleaning equipment technology with time ranging from 2007 to 2013. In this stage, as the photovoltaic devices installed capacity increased significantly, the demand for the cleaning and maintenance of photovoltaic panels also increased correspondingly. Therefore, patent applications related to photovoltaic panel cleaning equipment exhibited an obvious growth. The filed number of patents was 15 in 2007. In contrast, this number soared to 152 in 2013. Many countries began to carry out R&D of photovoltaic panel cleaning equipment. China and South Korea were obviously ahead of other countries in terms of number of patent applications in this stage. The total number of patent applicants was 467. The main applicants were Hileben Co. of South Korea, Hon Hai Precision Industry of China, State Grid Corporation of China (SGCC) and Sinfonia Technology Co., Ltd of Japan. Various types of photovoltaic panel cleaning equipment began to emerge, such as on-board type cleaning robot, cleaning truck, stand alone type cleaning robot and cleaning aircraft. The number of cleaning schemes increased from 5 in Stage 1 to 27 in Stage 2. The main cleaning schemes were still mechanical type and mechanical plus water cleaning type, but new cleaning schemes such as mechanical cleaning+ water cleaning+ air cleaning type, mechanical cleaning + dust collection type, and air cleaning + dust

collection + electrostatic precipitation type appeared. There were some outstanding R&D achievements in this stage. Miraikikai Inc., a Japanese company, developed a robot to clean dust off photovoltaic panels with Kagawa University as co-operator. The robot did not need water, and could perform cleaning work independently after it was placed on the photovoltaic panel. It could work continuously for two hours with a full charge, which was very suitable for the cleaning needs in arid areas [9]. Sinfonia Technology Co., Ltd of Japan developed Resola, a photovoltaic panel cleaning robot for large-scale photovoltaic power stations. The robot used its own water storage tank to spray water while cleaning with a cleaning brush and a scraper. At the same time, a variety of sensors and cameras were installed. By interacting with the information obtained from the sensors, the robot could independently select the cleaning path and clean 100mm^2 area of photovoltaic panel per hour [10].

Stage 3 is rapid development stage of photovoltaic panel cleaning equipment technology with time ranging from 2014 to now. Along with the rapid increase in the installed capacity of photovoltaic devices, the number of patent applications related to photovoltaic panel cleaning equipment technology also grew rapidly, with 629 applications in 2016 and 635 incomplete applications in 2017. Due to the 18 months open period in patent applications, the data of patent applications in 2017 and 2018 were still incomplete. China filed much more patents than other countries. The number of patent applicants has increased significantly to more than 1,000. The main applicants were Suzhou Haofeng Environmental Protection Technology Co. Ltd., China Datang Corporation, SGCC, Hangzhou Shunhai Photovoltaic Tech Co Ltd., etc. The research mainstream of photovoltaic panel cleaning equipment was still the on-board type cleaning robot. The cleaning schemes has been expanded from 27 types in the previous stage to a total of 40 types, in which mechanical cleaning type and mechanical cleaning + water cleaning type were still main schemes. There were also some outstanding R&D achievements in this stage. In April 2014, an Israeli company developed Ecoppia, a photovoltaic panel cleaning robot. The cleaning brush of the robot used ultrafine fiber, and relied on solar energy as the power source. It rotated on the surface of the photovoltaic panel to remove dust. Meanwhile, it also adopted air blowing method to remove dust. It was reported that the cleaning efficiency of Ecoppia reached 99%. Ecoppia was expected to introduce remote manipulation management to monitor the cleaning process in real time [11-12]. In July 2014, Qingdao Yuchen Intelligent Robot Co. Ltd. announced the development of a non-hydrated photovoltaic module cleaning robot. The robot used crawler to walk, and detected the working status of the cleaning part in real time through various sensors and controllers, and then adjusted its position in time to adapt to uneven road surface and uneven photovoltaic panel.

IV. Development Status of Photovoltaic Panel Cleaning Equipment Related Technologies

A. Key Technologies

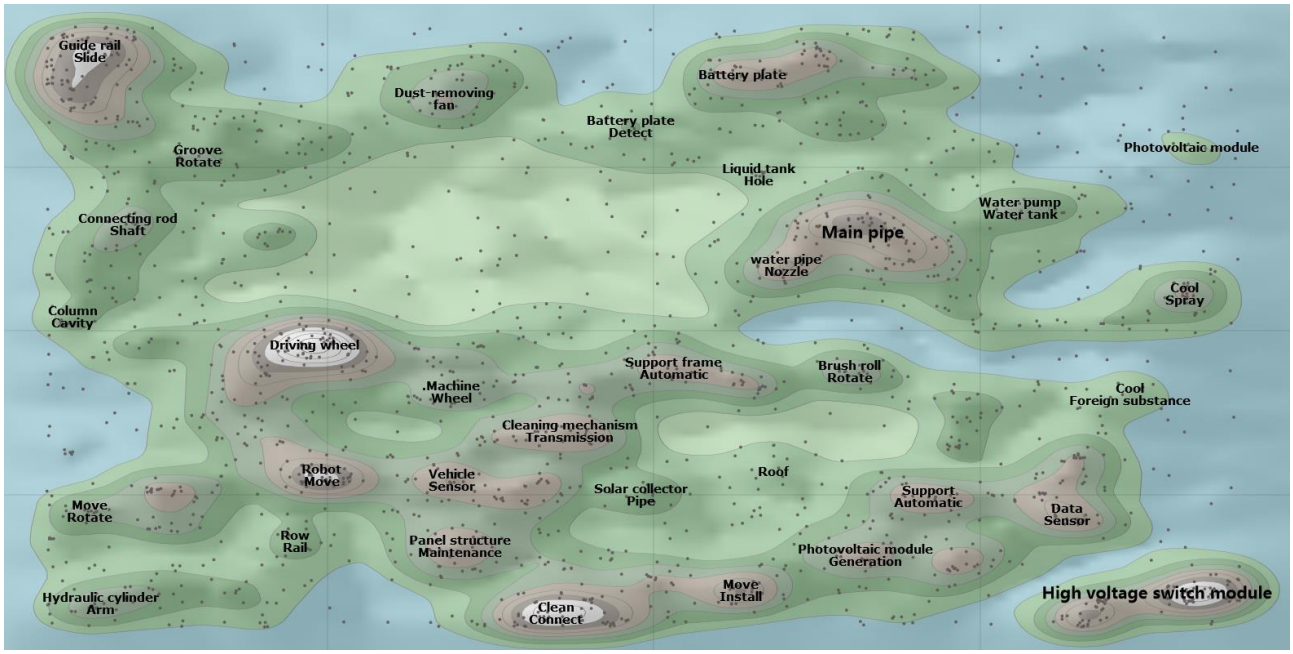

Figure 4. Patent topographic map of photovoltaic panel cleaning equipment

Figure 4 is a topographic map of photovoltaic panel cleaning equipment field. It can be found that on-board type cleaning robot with guide rails, cleaning truck related to hydraulic cylinder and mechanical arm, mechanical cleaning related to brush and scraper, water cleaning associated with pipe and nozzle, gas cleaning related to fan and high voltage switch module related to electrostatic precipitation are the research focuses of this field.

B. *Main Cleaning Schemes and Mechanisms*

According to statistics, among 2,678 patent families related to photovoltaic panel cleaning equipment, there are a total of 40 cleaning schemes disclosed. Figure 5 shows the top 15 cleaning schemes in terms of frequency, including mechanical cleaning, mechanical cleaning + water cleaning, water cleaning, mechanical cleaning + water cleaning + air cleaning, mechanical cleaning + dust collection, etc. The low-ranking cleaning schemes include ultrasonic cleaning, water cleaning + coating, dust collection + coating, etc. Figure 6 shows the distribution of the specific cleaning mechanisms used. It can be found that brush, liquid nozzle and scraper are the most commonly used cleaning mechanisms, accounting for 56.1%, 40.1% and 12.0% respectively.

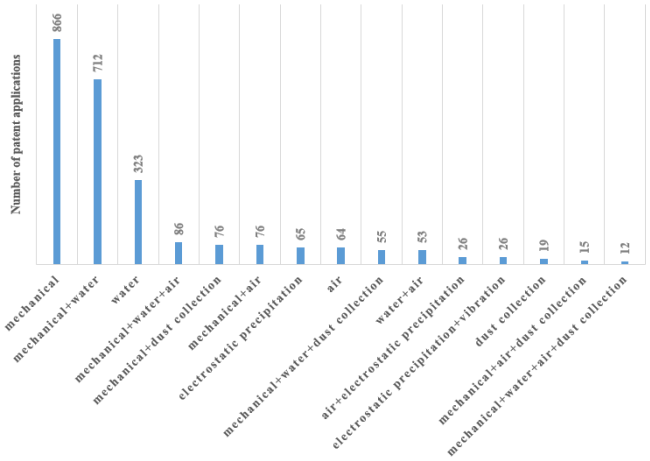

Figure 5. TOP 15 cleaning schemes of photovoltaic panel cleaning equipment

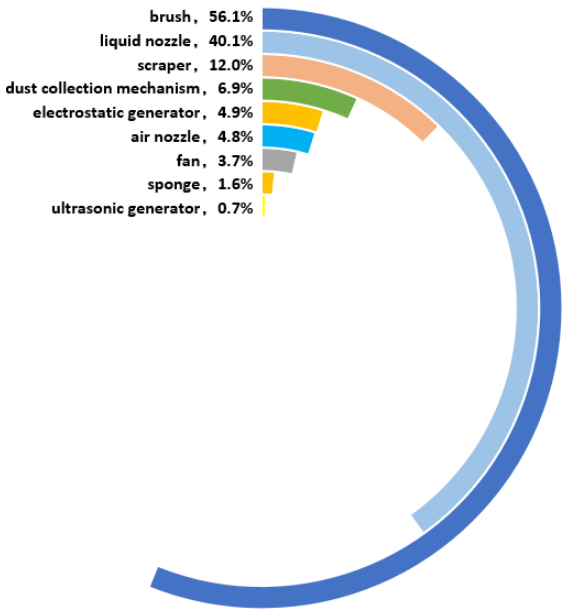

Figure 6. TOP 15 cleaning mechanisms of photovoltaic panel cleaning equipment

V. Patent Regional Competition Status of Photovoltaic Panel Cleaning Equipment

More than 20 countries and districts around the world have applied for patents in the field of photovoltaic panel cleaning equipment. As shown in Figure 7, the top countries and districts of patent applications are China, South Korea, Japan, Germany, and USA in sequence. China accounts for most patent applications (79%), indicating that China is very active in R&D of this field. Secondly, 172 patents are applied by South Korea applicants, accounting for 6%. Japan, Germany and USA rank 3rd to 5th, with 93, 85 and 73 patents filed respectively. The top five countries account for 94% of patent applications.

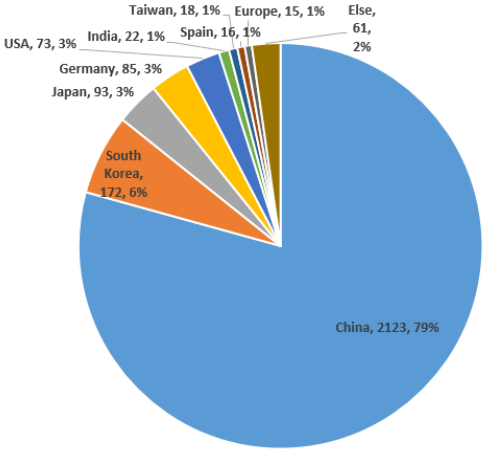

Figure 7. Source countries and districts of photovoltaic panel cleaning equipment related patents

Among the TOP 5 patent source countries, Japan applied for the first related patent in 1983, leading the development of photovoltaic panel cleaning equipment technology. The main applicants of Japan are Sharp, Sinfonia, Shinko Electric, etc. USA lags Japan for more than 10 years, and the main applicants are Alion and Sunpower, etc. South Korea started relatively late, and the main applicants are Hileben, KD Power and Ecosense, etc. China started late in this field too, with the first patent field by Nankai University in 2006. Since 2010, annual number of patent applications has been significantly higher than that of other countries. Main applicants are Suzhou Haofeng Environmental Protection Technology Co. Ltd., SGCC and China Datang Corporation, etc.

VI. Patent Advanced Agencies of Photovoltaic Panel Cleaning Equipment

A. *Ranking of Applicants*

More than 1400 organizations and individuals have applied for photovoltaic panel cleaning equipment related patents worldwide. As shown in Table 1, top 30 applicants are mainly from China, South Korea, Germany, Japan and Israel. In addition to the German Jaeger A and North China Electric Power University, other applicants are companies, indicating that the research work in this field is mainly

applied research and is in the industrialization stage.

TABLE I. PATENT INDEX OF MAIN APPLICANTS OF PHOTOVOLTAIC PANEL CLEANING EQUIPMENT *

No.	Applicant	Patent applications	Active years	Average patent age
1	Suzhou Haofeng, CN	105	1	4.0
2	SGCC, CN	48	8	3.0
3	Datang, CN	43	2	1.0
4	Hangzhou Shunhai, CN	34	3	2.0
5	CECEP, CN	29	6	3.2
6	Hileben, KR	29	8	6.4
7	Tianjin Wenna, CN	29	2	1.6
8	Hefei Zhongke Zhixiang, CN	25	1	2.0
9	CEC Beijing Boshun, CN	24	2	2.0
10	Jaeger A, DE	24	7	5.9
11	Suzhou Radiant, CN	23	2	1.6
12	Zhejiang Guozi, CN	19	2	1.6
13	Shandong Haowo, CN	18	3	1.7
14	Huaneng, CN	17	3	3.2
15	Anhui Tianzhu, CN	16	3	3.3
16	Chongqing Taichu, CN	15	4	3.9
17	Hon Hai Precision, CN	14	4	6.9
18	Beijing Etechwin, CN	13	4	3.2
19	Beijing Shijing, CN	13	1	2.0
20	Henan Senyuan, CN	13	3	2.0
21	Sharp, JP	13	5	4.1
22	North China Electric Power University, CN	13	5	3.4
23	Shenzhen Qianhai Zhengxi, CN	12	2	2.7
24	Sinfonia, JP	11	2	4.7
25	Changzhou Eging, CN	10	2	4.8
26	Chengdu Jiushidu, CN	10	1	3.0
27	Ecoppia, IL	10	6	3.9
28	Helan County Shengda, CN	10	2	2.5
29	Shenzhen Innovpower, CN	10	1	2.0
30	Beijing Xuhairui, CN	9	1	2.0

* CN denotes China, KR denotes South Korea, DE denotes Germany, JP denotes Japan, and IL denotes Israel.

China occupies the leading position in the field of photovoltaic panel cleaning equipment. In TOP 30 applicants, 25 applicants are from China, including Suzhou Haofeng, SGCC, China Datang, Hangzhou Shunhai, CECEP, etc. Among them, SGCC, CECEP and North China Electric Power University have relatively longer active years, and patent applications in recent five years account for more than 69%, indicating these institutions start early and are keeping R&D investment in this field. China Datang, Tianjin Wenna, Hefei Zhongke Zhixiang, CEC Beijing Boshun, and Suzhou Radiant enter this field in recent three years, thus have short active years and small average patent ages. All 105 patents of Suzhou Haofeng were filed in 2014. The patent applications of Hon Hai Precision were concentrated between 2008 and 2013, and no related patents were filed in the past five years, indicating a possible shift in the company's R&D focus.

In addition, among top 30 applicants, Hileben of South Korea, Sharp and Sinfonia of Japan, and Ecoppia of Israel are all keeping the investment in R&D of this field.

B. Distribution of Disclosed Equipment Types of Main Applicants

Figure 8 shows the patent applications of TOP 30 patent applicants towards various types of photovoltaic panel cleaning equipment, from which the R&D priority of each applicant can be found out. Suzhou Haofeng focuses on R&D of electrostatic precipitation type cleaning equipment. Hangzhou Shunhai, Tianjing Wenna, Hefei Zhongke Zhixiang, CEC Beijing Boshun, Zhejiang Guozi, Shandong Haowo, Anhui Tianzhu, Sharp, Changzhou Eging, Chengdu Jiushidu, Ecoppia, Shenzhen Innovpower all focus on R&D of on-board type cleaning robot. Suzhou Radiant focused on R&D of stand alone type cleaning robot. Chongqing Taichu, Shenzhen Qianhai Zhengxi and Beijing Xuhairui focus on R&D of cleaning truck. Other applicants have developed a variety of photovoltaic panel cleaning equipment. For example, SGCC files patents towards five types of cleaning equipment, including aircraft type cleaning equipment emerged in recent years.

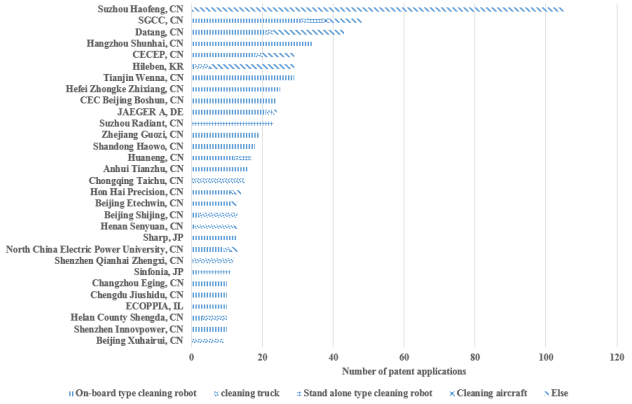

Figure 8. Distribution of disclosed equipment types of TOP 30 applicants

C. Distribution of Disclosed Cleaning Schemes and Mechanism of Main Applicants

The cleaning schemes selected by most patent applicants are mechanical cleaning, water cleaning, mechanical cleaning + water cleaning, and the corresponding cleaning mechanisms are brush, nozzle and scraper. The cleaning schemes adopted by Suzhou Haofeng are electrostatic precipitation, air cleaning + electrostatic precipitation,

electrostatic precipitation + vibration, and the corresponding cleaning mechanisms are electrostatic generator and fan. In the technical scheme disclosed by SGCC, there are mechanical cleaning + dust collection, water cleaning + air cleaning, etc., involving the use of dust collection mechanism and air nozzle.

D. Positioning and Navigation Schemes and Safe Operation Schemes of Main Applicants

Since most patents are related to on-board type cleaning robot with fixed rails, only 20 patents disclose positioning and navigation schemes of photovoltaic panel cleaning equipment, including GPS navigation, optical navigation, laser navigation (laser detector), inertial navigation (accelerometer, gyroscope), metal navigation, electromagnetic navigation, magnetic navigation (tape), acoustic navigation (sonar transceiver), wireless network navigation, and involving edge detection module (ultrasonic sensor, optical pulse sensor, infrared sensor, capacitive sensor, etc.).

Two patents disclose the safe operation scheme of photovoltaic panel cleaning equipment, involving biometric system based on face, fingerprint and other biological characteristics, avoiding unauthorized use of the cleaning robot and unauthorized access of the cleaning robot to the photovoltaic panel array.

E. Patent Application Strategies of Main Applicant

Figure 9 shows the patent application strategies of main applicants. Zhejiang Guozi has mainly applied for cleaning devices, carrying devices and mobile devices used for transferring cleaning devices, navigation systems, control methods and water replenishing vehicles related patents. CEC Beijing Boshun, Hefei Zhongke Zhixiang, Tianjin Wenna and Hangzhou Shunhai are superior in terms of patent layout breadth and depth. For example, CEC Beijing Boshun has applied for cleaning mechanism, mobile mechanism, telescopic mechanism, anti-trip mechanism, correction mechanism, self-locking mechanism, docking rack and other details within the cleaning device related patents. Hefei Zhongke Zhixiang has applied for framework, brush roller, cleaning brush regulating mechanism, brush roller independent grasping mechanism, transmission shaft length regulating mechanism, spindle box mechanism and other details of the cleaning device related patents. Tianjin Wenna has applied for load-bearing track, power output device, temperature compartment of the control system, output cleaning executive system, shell and controller of the cleaning device related patents, and for the lane changing driving mechanism, lane changing trolley mechanism, lane changing connection system and power supply device in the transfer mechanism related patents. Hangzhou Shunhai has applied for scraper mechanism, scraper brake system, retracting and releasing rope device, guide rail mechanism and other details in the cleaning device related patents, and applied for the debugging device, fault detection method and cleaning data push method of the cleaning device related patents.

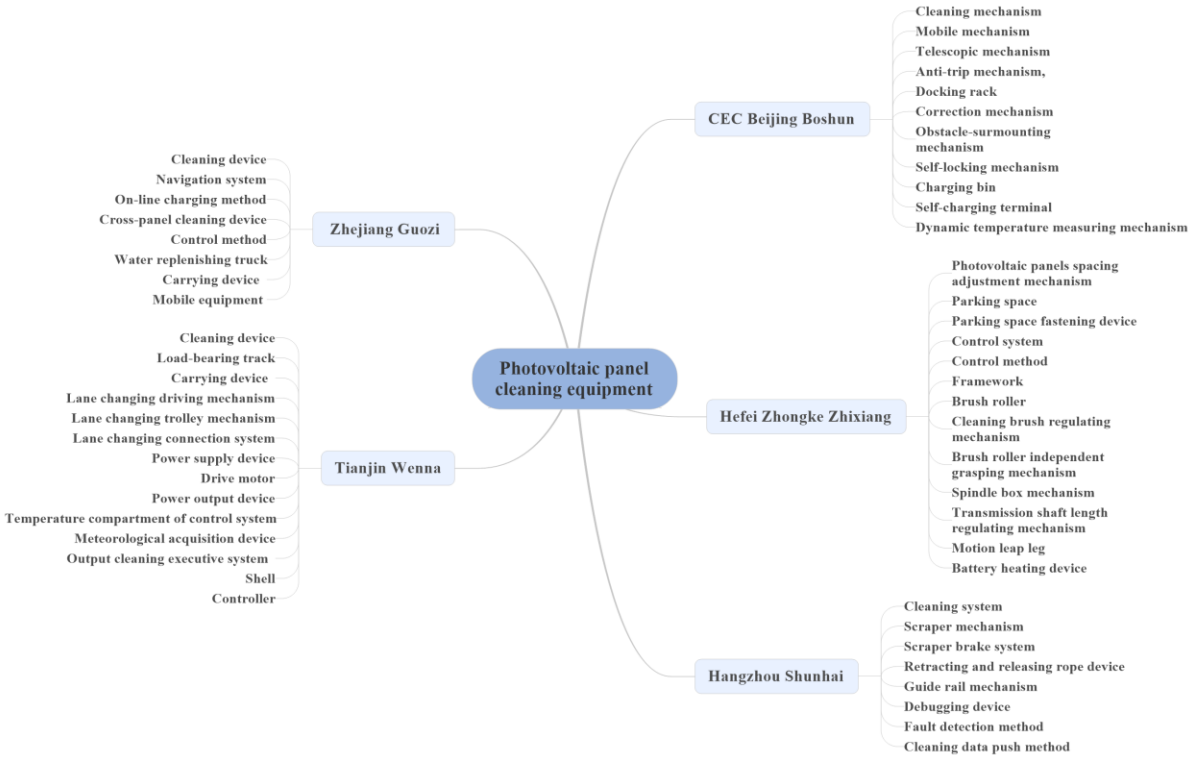

Figure 9. Patent application strategies of main applicants

VII. Technology Roadmap of Photovoltaic Panel Cleaning Equipment

Based on relevant core patents, the technical roadmap of photovoltaic panel cleaning equipment is drawn. As shown in Fig.10, most applicants of these core patents are related institutions in Europe, America and Japan, which shows that these institutions have strong R&D strength in the field of photovoltaic panel cleaning equipment. In addition, the evolution of technology direction is analyzed along the time axis. It can be found that the development of the solar panel cleaning equipment exhibits diversified, systematic and intelligent trend. Specifically, the type of photovoltaic panel cleaning equipment and the type of cleaning scheme tend to diversified. be diversification and cleaning device for cleaning mode diversification, The cleaning device is gradually fitted with a specialized transfer device. A variety of smart components and technologies are introduced, such as intelligent sensors, remote control, and GPS navigation.

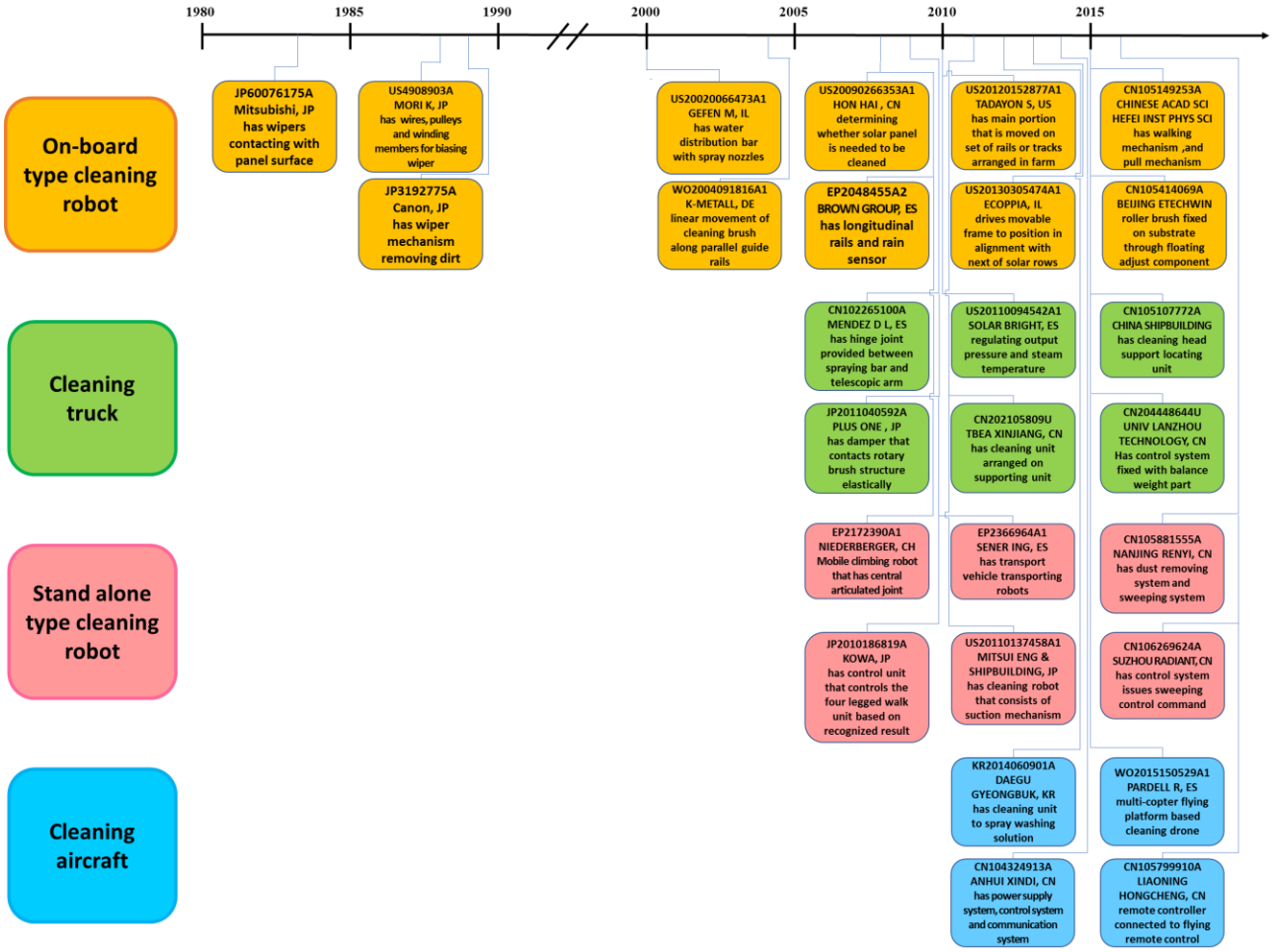

Figure 10. Technology roadmap of different types of photovoltaic panel cleaning equipment

VIII. Conclusions

As can be seen from the above analysis results, with the significant increase in installed capacity of photovoltaic device, photovoltaic panel cleaning equipment field entered the technology take-off period around 2007 with overall significant increase in the number of patent applicants and patents, and it is still in the growth period. Japan leads the field, but China accounts for most patent filings and is more active in R&D. The on-board cleaning robot is the key R&D type of photovoltaic panel cleaning equipment. Mechanical cleaning, mechanical cleaning + water cleaning, water cleaning, mechanical cleaning+ water cleaning + air cleaning, mechanical cleaning + dust collection are mainstream cleaning schemes. There are few disclosed patents about the positioning, navigation and safe operation of photovoltaic panel cleaning equipment, thus there are some technical gaps.

For related companies, the technical innovation of photovoltaic panel cleaning equipment can be promoted from the following aspects. Firstly, from the perspective of improving the cleaning effect and market development, the integrated R&D of various cleaning mechanisms/schemes and the layout R&D of multi-type photovoltaic panel cleaning equipment should be strengthened. Secondly, in consideration of factors like cost, precision and demand, the

integrated R&D of positioning and navigation technology of photovoltaic panel cleaning equipment should be strengthened. Thirdly, the pioneering R&D of the safe operation technology of photovoltaic panel cleaning equipment should be strengthened, introducing advanced technologies such as image recognition, tactile feedback, neural network and high-performance sensors to the safe operation of photovoltaic panel cleaning equipment. Fourthly, the forward-looking R&D of potential new hotspots should be strengthened, especially the applications of intelligent components and technologies like various sensors, remote control, GPS navigation in photovoltaic panel cleaning equipment. Fifthly, the breadth and depth of patent layout should be improved. For example, a series of peripheral patent about the internal mechanism for cleaning device such as dynamic mechanism, transmission mechanism, cleaning mechanism, perception mechanism, etc. can be applied to form patent portfolios to strengthen protection. Moreover, original innovation can also be protected in expansion ways, such as replacement of specific cleaning method and cleaning mechanism.

ACKNOWLEDGMENT

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