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Dust cleaning robots (DCR) for BIPV and BAPV solar power plants-A conceptual framework and research challenges

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Abstract

This paper proposes a conceptual framework to design and develop robots for addressing the soiling or the dust cleaning issue on the building integrated photovoltaics (BIPV) and building applied photovoltaics (BAPV). BIPV and BAPV turn the present and future buildings (high rise or low rise) into power stations with the introduction of photovoltaics either in the façade (90° wall) or roof (flat or pitched) configuration. But one of the significant challenges that influence the energy performance is the dust accumulation. This is a serious issue in the places where air pollution is very high. Addressing this would be very difficult for the human workforce, and the complexity and tediousness would increase depending on the size of the BIPV and BAPV array or the height of the building. Currently, there are few dust cleaning robots which could offer services in addressing the soiling issues in conventional photovoltaic installations. The existing dust cleaning robots (DCR) could not offer a better feasible solution in BIPV and BAPV as they offered in traditional PV systems that were installed in an open area. Hence for addressing dust cleaning issue, some novel conceptual schemas related to robot developments were proposed in this paper considering the installation configuration of PV systems for building applications. Here, DCR's for three configuration of PV installation with building applications namely BIPV/BAPV façade, BIPV/BAPV horizontal roof, and BIPV/BAPV pitched roof are dealt. The proposed conceptual robots were briefly described with the schematic views highlighting operation, energy consumptions, and slipping issue etc. Scope for the development and various research challenges that are to be considered during the design stage are highlighted along with the discussion.

Keywords: Robots in solar power; dust cleaning robots (DCR); dust cleaning in BIPV/BAPV; dust effects in PV; conceptual robots in PV; BIPV as flat roof; BIPV as façade; BIPV pitched roof.

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1. Introduction

Photovoltaics (PV) is the emerging technologies in the energy sector that converts the suns radiant energy, i.e., solar irradiance directly to the electricity. Here, the PV cells absorb the energy presents in the photons released from the sun into useful energy. PV technology has transformed the energy sector giving keen attention to generate clean power and scope for the world to move towards the sustainable practices in energy[1, 2]. This gave the scope for achieving rapid industrial progress in the photovoltaic industry in the preceding times and is still on the trending scales with the technological advancements. If we see the progress of PV industry, starting from the development of laboratory scale models, experimental scale models, and the present real-time operating power plants, one can experience a great happening in the technology improvements[3]. These PV technologies have emerged and became an integral part of many other sectors in solving the energy demand problems at the load centers itself thereby avoiding the need for long transmission and distribution. PV technologies were also evolved on the commercial scales creating the large-scale utilities or multi-megawatt power plants. In the present times, we can see the massive and widespread utility solar power plants built on open areas, rural and urban buildings, water surface. In recent years, the advancements in PV technologies were seen concerning the modern infrastructure creating a new type of PV technologies named as building integrated photovoltaics (BIPV) and building applied photovoltaics (BAPV). The BIPV and BAPV power plants can be installed in different configurations on to the buildings either in the form of façade and roof as shown in Fig. 1.

Fig. 1. (a) BIPV façade; (b) BIPV horizontal roof; (c) BIPV in single sloped pitched roof; (d) BIPV in double sloped pitched roof.

BIPV has many favorable factors and huge market potentials in urban infrastructure in recent years[4]. Irrespective of the installed capacity either in small or large scale BIPV/BAPV, the output power delivered from the modules is highly sensitive to the weather parameters and system configuration. Apart from the weather parameters, another more sensitive parameter that affects the output performance is the dust accumulation[5]. This is well explained in the subsection 1.1. Whether the cleaning process (traditional and robotic) used in open rack PV systems would help in the BIPV/BAPV performance or not were discussed in subsection 1.2. Based on the drawbacks and difficulties faced with the use of traditional and existing robotic cleaning methods in BIPV/BAPV, the objective of this paper is framed, and a novel DCR's were proposed mainly for the BIPV and BAPV systems based on the three installed approaches, refer to subsection 1.3.

1.1. Problem Statement: Considering Dust Accumulation on BIPV and BAPV

In photovoltaic systems and its applications, the optimum energy performance is determined by various factors, and mostly depending on the weather parameters of the particular installation site. Studies indicate that overall energy lost in the PV systems would be around 20 to 40% on an average making the PV systems to have about 60-80% performance ratio[6,7]. Dust contributes a significant amount of percentage of the energy lost and the need for addressing it is essential. Dust accumulation on the photovoltaic modules could vary from the location to location, and this is due to the rising patterns of dry wind and moisture content present in the particular site. Fig. 2. shows the dust accumulation scenarios of PV, BIPV, and BAPV. In practical, it is clear that dust is a derived parameter of the wind. We can see the occurrence of dust events where the light weighted dust particles are carried out by the dry winds, dust storms, vehicular movements, pedestrian walking, and many other activities. The level dust occurrence is defiantly depending on the intensity of the activity mentioned above and local weather conditions. The raised dust will accommodate as a thin layer on the surface of the photovoltaic module installed in various configurations. Depending on the installed configurations, dust occurrence activity, and its intensity, the thickness of the layer increases finally resulting in a serious issue that is affecting the performance of PV. This is a serious issue in the countries surrounded by deserts or having the loose sedimented soils[2,3,5,8,9]. In the photovoltaic systems installed over the open area on the ground or low-rise building rooftops, this problem can be addressed easily.

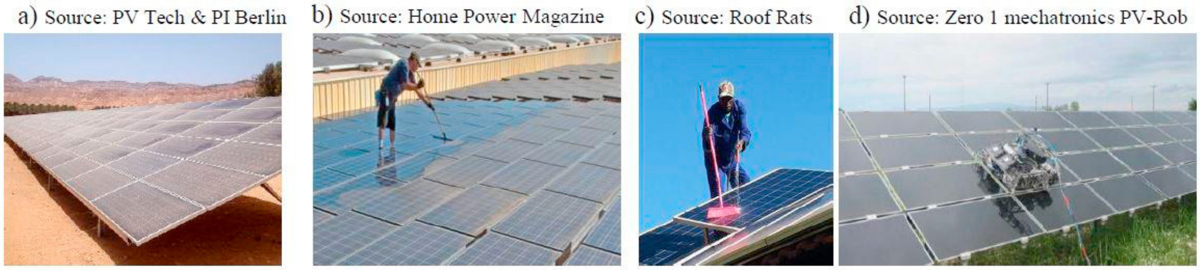

Fig. 2. (a) Dust on PV; (b) brush cleaning; (c) cleaning in BAPV; (d) robotic cleaning in open rack PV.

Table 1. Few of the existing dust cleaning robots (DCR).

Name of the DCR	Features	Visual at Work Place
E4-Water Free DCR[10] (Source: Ecoppia Empowering Solar)	It operates with water free concept while cleaning the soiling on the PV array. It helps in cleaning on an average of 99% soiling. Cleaning wipes are made with Microfibers Airflow can be controlled over the photovoltaic module surface A special feature is a gravity ensured downward movement of collected soiling from the PV array.	
E4-Energy Independent DCR[10] (Source: Ecoppia Empowering Solar)	Dust cleaning based on energy independent A complete and fixed cleaning solution setup acting as an onboard cleaner Enable a nominal energy consumption from the batteries during the cleaning process.	
SMR-640AD model[11] (Source: Miraikikai Inc.)	Completely portable and ease of handling Operated with the help of battery cartridge made with Li-ion. The possibility of changing direction as per the PV array alignment. Contributes to 80% reductions in the cost of solar PV array of the cleaning.	
PV-ROB[12] (Source: Zero one mechatronics)	A novel design by Zero one mechatronics incorporates cleaning process with air and water as mediums. Works on AC supply and also with multipurpose functionality. Enable counting of the photovoltaic module during the cleaning process. PV array edge detection is possible. Capable of cleaning tilted PV arrays (up to 65°)	

In Fig. 2. (a) to Fig. 2. (d) dust scenarios were shown for rooftop solar PV, building equipped PV, and open rack ground coverage solar PV. Fig. 2. (b) and Fig. 2. (c) shows the dust cleaning method adopted with the use of hand brush and flushing water. However, studies are underway to predict the possible decrease in the efficiency of PV/BIPV/BAPV systems. Also, one must study the thickness levels of the dust that could account a significant decline in efficiency. In this context, it is very much needed to have the dust accumulation scenarios and well-structured cleaning mechanisms.

1.2. Could Existing Cleaning Methods Solve this Problem? Yes or No

Existing cleaning methods could not solve the dust cleaning process in BIPV/BAPV arrays installed over the high-rise buildings. But could solve the dust cleaning process on the small-scale buildings equipped with BIPV's and BAPV's. Existing methods include the hand brush cleaning, see Fig. 2. (b) and Fig. 2. (c), human-assisted vacuum cleaners, wiper brush, automated robotic cleaning see in Fig. 2. (d) etc. The cleaning process with these existing facilities will become easy and convenient in the case of traditional PV systems[13-15]. Table 1 shows the study on few existing dust cleaning robots that are capable of cleaning the conventional PV[10-12]. Among the discussed ones, PV-ROB said to operate and initiate the cleaning process even at inclined surfaces of the PV module (i.e., at 65°)[12]. But in the case of BIPV/BAPV (typically installed at 90°), this is more difficult as the workforce has to needs to climb the high-rise building façade and its roof, and similarly it is quite difficult to carry out the cleaning process with the vacuum cleaners and human-assisted robots. This suggests us to have suitable dust cleaning systems especially for the BIPV's and BAPV's installed over the high-rise buildings.

1.3. Objective

It is identified to have the new DCR's for the dust cleaning process based on the clear understanding of problem statement and the brief study of the existing methods. The objective of this work is to propose the conceptual DCR's based on the installation configuration of BIPV and BAPV and identify the research challenges in developing them. The installation configuration of BIPV and BAPV can be seen in the form of façade, flat roof, and single sloped roof, and double-sloped roof shown in Fig. 1. (a) to Fig. 1. (d).

2. Novel Dust Cleaning Robot Concepts: A View from BIPV and BAPV

From the installation view of BIPV and BAPV, the most commonly seen configurations are façade, horizontal roof, and pitched or sloped roof. Considering these three configurations, the conceptual dust cleaning robots (DCR's) were proposed, and they are described in the subsequent sections below. In most of the urban and rural buildings, the sloped or pitched roof can be seen in the form of single sloped roof or double-sloped roof. Hence these cases are also considered.

2.1. DCR for Façade

Façade in a building can be a wall which is in 90° most of the times. In the case of photovoltaic building applications, the BAPV and BIPV modules can be integrated to the walls installing exactly perpendicular to the horizontal surface[16]. In Fig. 3. A small building is shown with BIPV modules installed in the façade configuration. In such cases to address the dust cleaning issue, we propose a novel DCR that could climb the building wall across the surface of BIPV/BAPV array.

The functioning and the process of cleaning adopted by the proposed DCR for BIPV/BAPV façade is schematically represented in Fig. 3. The DCR is installed either on the top edge of the BIPV façade or the bottom edge of the BIPV façade. However, for the easy and quick installation process, the DCR is installed on to the bottom edge of BIPV facade. The DCR is equipped with sensing elements that could sense the dust levels and other moisture conditions etc. If the accumulated dust reaches the certain thickness, then the DCR starts functioning to clean the dust on the BIPV/BAPV array by accelerating into upward direction following the rails on either side. Here mostly air flushed brush cleaning element is used. With the DCR movement from façade bottom edge to top edge half cycle of the cleaning process is done, if satisfied with cleaning perfection, the DCR can be stopped at the top edge of the façade and can be made to operate with downward movement following the same rails when next instant of cleaning arises.

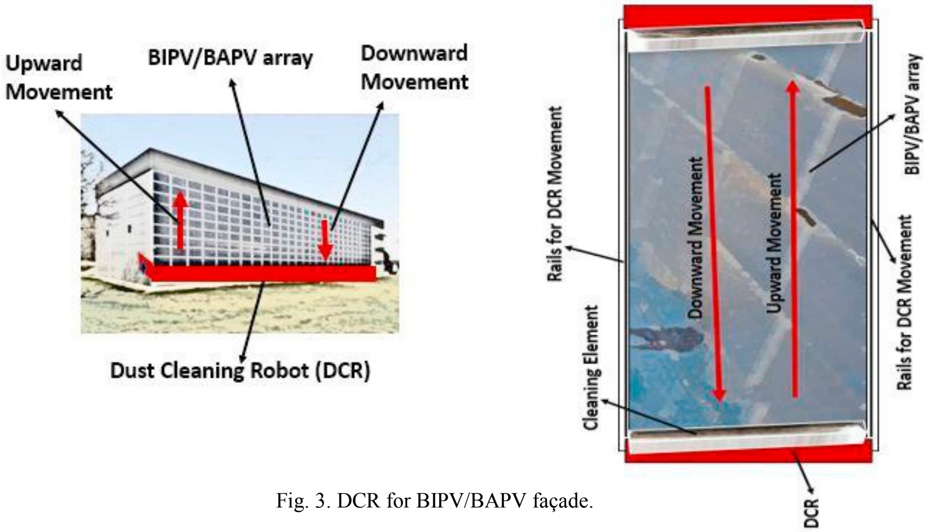

Fig. 3. DCR for BIPV/BAPV façade.

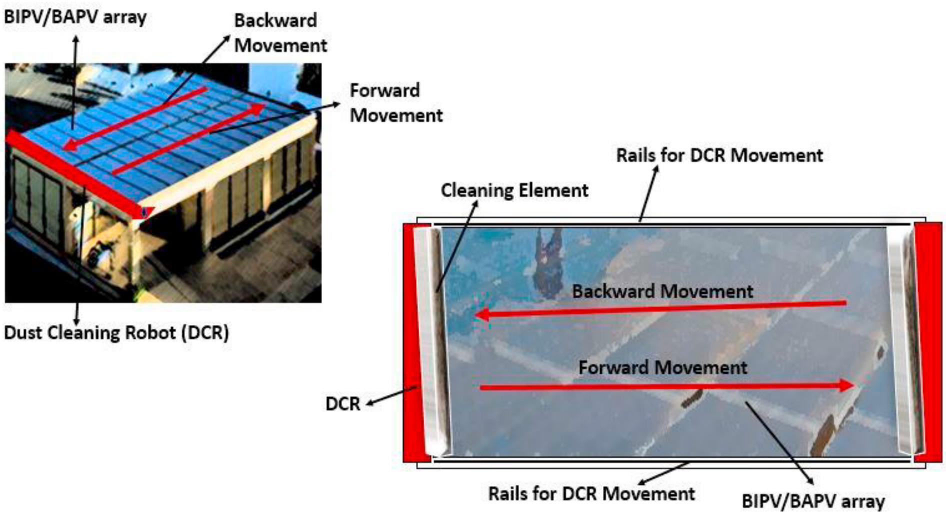

Fig. 4. DCR for horizontal BIPV/BAPV roof.

2.2. DCR for Horizontal Roof

In a building, a roof which is precisely horizontal to the earth surface can be called as the flat roof which typically maintains 0° position[16]. Such vacant spaces in the building can be equipped with the BAPV or event can be transformed into BIPV roof. In Fig. 4. A small building is shown with BIPV modules installed in the horizontal roof configuration. In such cases to address the dust cleaning issue, we propose a novel DCR that could move forward and backward covering the entire array surface area of the building roof. The functioning and the process of cleaning adopted by the proposed DCR for BIPV/BAPV horizontal roof is schematically represented in Fig. 4. The DCR is installed either on the side edge of the BIPV roof. The DCR is equipped with sensing elements that could sense the dust levels and other moisture conditions etc. If the accumulated dust reaches the certain thickness, then the DCR starts functioning to clean the dirt on the BIPV/BAPV array by accelerating into forward direction following the rails on either side. Here mostly air flushed brush cleaning element is used. With the DCR movement from one side to another side, a half cycle of the cleaning process is done, if satisfied with cleaning perfection, the DCR can be stopped at the top edge of the façade and can be made to operate with backward direction following the same rails when next instant of cleaning arises.

2.3. DCR for Pitched Roof

The pitched roof is commonly seen is most of the nations, apart from façade and horizontal roof in a building. Pitched roof refers to the rise and run ratio that creates a particular angle for the roof[17]. This angle might be different based on the location when the thermal comfort of the building is considered. On this type of roof also, PV systems can be mounted either in the form of BIPV or BAPV. In Fig. 5. A small building is shown with BIPV modules installed on the pitched roof that created tilt angle. In such cases also the possibility of dust accumulation exists. Hence to address the dust cleaning issue, novel DCR for the pitched roof (single and double-sloped roof) is proposed. Here this DCR is meant to climb the building roof at inclined angles. The functioning and the process of cleaning adopted by the proposed DCR for BIPV/BAPV pitched roof is schematically represented in Fig. 5. The DCR is installed either on the top edge or bottom edge. However, for the easy and quick installation process, the DCR is installed on to the bottom edge. The DCR is equipped with sensing elements that could sense the dust levels and other moisture conditions etc. If the accumulated dust reaches the certain thickness, then the DCR starts functioning to clean the dust on the BIPV/BAPV array by accelerating into an upward direction at inclined angles as per the roof pitch following the rails on either side. Here mostly air flushed brush cleaning element is used. With the DCR movement from bottom edge to top edge half cycle of the cleaning process is done, if satisfied with cleaning perfection, the DCR can be stopped at the top edge of the roof and can be made to operate with downward movement following the same rails at inclined angles when next instant of cleaning arises.

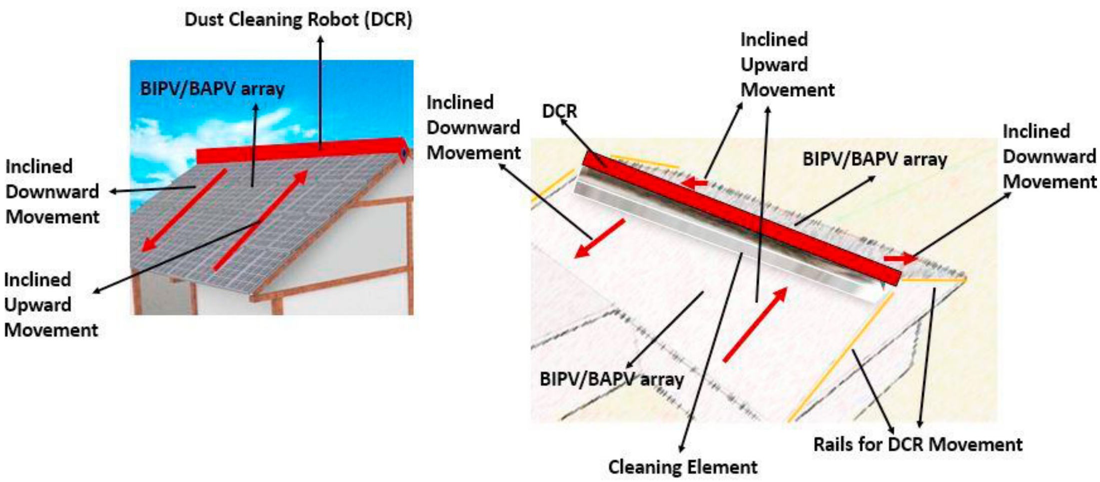

Fig. 5. DCR for single and double sloped BIPV/BAPV pitched roof.

3. Discussions

The proposed DCR's are further discussed concerning energy consumption patterns, the stress on the DCR's, and possibility of slipping from its original fixed positions. Table 2 shows the brief about the components and technologies needed for the development of DCR. Proposed three DCR's works on the same principle and has almost similar components, sensing capabilities and effectiveness in cleaning. One major difference is observed in installation and mounting of DCR in the case of façade and pitched roof. Here extra support is needed as the DCR is installed at 90° and inclined angles. Energy consumption patterns of the proposed DCR's in various applicable movements as per the BIPV/BAPV installation configuration were discussed and tabulated in Table 3. It is obvious for the robot to consume excess energy than the normal when it is made to operate in upward movement exactly perpendicular to horizontal or at certain angles. Similarly, Table 4. Shows the possible stress on DCR during this upward movement and a possible slip of DCR during downward movement.

Table 2. Proposed DCR's: components and technologies.

Description of DCR	Components and technologies of DCR's for BIPV and BAPV		
	DCR for facade	DCR for horizontal roof	DCR for a pitched roof
Dust sensing and identification	Sensor elements like dust sensors, moisture sensors, IR sensors etc.	Sensor elements like dust sensors, moisture sensors, IR sensors etc.	Sensor elements like dust sensors, moisture sensors, IR sensors etc.
Technologies behind the autonomous operation	Pattern recognition, artificial intelligence, cloud storage	Pattern recognition, artificial intelligence, cloud storage	Pattern recognition, artificial intelligence, cloud storage
DCR installation and mounting	Rail support, clips, and clamps, extra support fitting to reduce slip	Rail support, clips, and clamps	Rail support, clips, and clamps, extra support fitting to reduce slip
Cleaning method or element	Air flush, brush	Air flush, brush	Air flush, brush

Table 3. Energy consumption patterns for the proposed conceptual DCR's

Proposed DCR	Energy consumption based on DCR movements applicable						
	Upward	Downward	Forward	Backward	Inclined upwards	Inclined downwards	Remarks
DCR for facade	High	Normal	×	×	×	×	In the case of façade, the DCR must climb vertically typically maintaining 90° against the gravitational pull. Hence the chances of extra energy consumptions are possible.
DCR for horizontal roof	×	×	Normal	Normal	×	×	Energy consumption would be normal as rated.
DCR for a pitched roof	×	×	×	×	High	Normal	In the case of the pitched roof, the DCR must climb the BIPV or BAPV roof at inclined elevations. Hence the chance of extra energy consumption is possible.

Table 4. Chances of experiencing stress on the DCR's and slip of the DCR's

Proposed DCR	Stress on DCR and slip of DCR's due to it applicable movement as per the BIPV/BAPV installation configuration						
	Upward	Downward	Forward	Backward	Inclined upwards	Inclined downwards	Reason
DCR for facade	Stress	Slip	×	×	×	×	Stress on DCR is possible due to its weight in the case upward movement typically on a façade installed at 90°. Chances of slip arise during downward movement due to improper mounting of DCR on the façade installed at 90°.
DCR for horizontal roof	×	×	No stress or slip	No stress or slip	×	×	Chances of stress and slip are very less
DCR for a pitched roof	×	×	×	×	Stress	Slip	Stress on DCR is possible due to its weight in the case upward movement typically on the inclined pitched roof. Chances of slip arise during downward movement due to improper mounting of DCR on the inclined pitched roof.

4. Scope and Research Challenges

This section deals with the scope for DCR’s and various research challenges that could be faced in developing DCR’s for BIPV and BAPV.

4.1. Scope for DCR’s in BIPV and BAPV

There is a huge scope in developing DCR’s for BIPV and BAPV. As we see, the present market trend for BIPV has been progressive in many countries especially in the developed countries. Many of developing countries which aims to create smart cities are planning to adopt the concepts of BIPV and BAPV in the urban buildings. Also, technologies behind the robotic intelligence are booming. This would make our developments easier and smarter. On the other hand, the performance aspects of the BIPV/BAPV systems are also given huge scope to monitor and maintain the system in a more frequent manner as the dust event prevails.

4.2. Research Challenges

Even though DCR’s have a huge scope, there exist several research challenges in the development. These challenges include either on technological aspects, skill-based workforce, socio-economic elements, etc. Such problems were carefully identified and discussed below:

- The first and foremost challenge would be construction and fabrication materials, as we see these DCR hanging or integrated to BIPV/BAPV installed over some high rise tall buildings. Hence there should be proper weight balance of the robots. This suggests us to have lightweight materials that could be very strong enough to defend extreme weather parameters. Finding the fabrication materials, their processing and constriction could be one of the significant challenges.
- Power management and energy harvesting schemes could be another research challenge. As we see working conditions of the DCR’s, they are integrated with the BIPV/BAPV systems and can operate for specific intervals of time based on dust accumulation intensity. However, the operating time of the DCR’s directly depends on the energy available in the battery but no the dust intensity. Indirectly these DCR’s has to operate extra time if the dust accumulation is more. Hence, allowing the DCR’s to have required power and energy is an essential task. This suggests us to have better energy management schemes, high efficient energy storage technologies, new energy sources, self-energy management control strategies, etc. for the long-lasting operation of the dust cleaning robots equipped for building applications of PV.
- Weight balance and integration issues are the other challenges, where the DCR’s needs to be integrated on to the side edges of the BIPV/BAPV array and allow it to move on the surface of the BIPV/BAPV array across its full area from top to bottom making the brush to be in contact with the module surface. Here, the challenge in integrating DCR’s at specific heights (vertical, horizontal, inclined) would become a difficult challenge.
- As these DCR’s proposed to operate autonomously, they should have sensing capabilities and identify the need for maintenance requirements based on the dust accumulation intensity. Hence there is a significant challenge in developing the sensing, analyzing, and responding commands based on the needs.
- Robotic navigation and autonomous control is another challenge.
- Dust pattern recognition abilities and understanding the level of dust accumulation is to be taken into consideration by introducing the fundamental concepts of artificial intelligence.
- Security issues in the online monitoring and transmission of data related to the dust occurrence events, dust thickness on the array, and dust cleaning events, etc.
- Method of cleaning medium is another critical issue, whether the use of vacuum type of DCR’s, water wash DCR’s, air wash DCR’s, etc. These methods should not pollute the surrounding areas. Hence there is a great need to focus on the dust collecting chambers equipped with DCR’s.
- Other challenges related to the lack of skilled workforce to operate and maintain during the troubleshoots.

- Economic aspects of cleaning process would be another issue, hence need for developing low cost, less complex DCR's is essential.

5. Conclusion

In this study, conceptual DCR's were proposed, and the schematic representation for the possible integration with the BIPV/ BAPV systems were also presented. Discussions on the applicability, scope for DCR were identified here. Various research challenges that could be faced by the developers are also identified and presented. Few challenges like energy consumption, stress on DCR, a slip of DCR, and autonomous operation and recognition of dust accumulation were also identified as the key challenges for the DCR's. Here, we aimed to provide this conceptual framework as in the initial steps, hence this study could be helpful material in developing the small-scale DCR's mainly for the BIPV and BAPV. Future work will be the demonstrative model of the DCR presented in this paper.

References

[1] Jacobson MZ, Delucchi MA. (2011) "Providing all global energy with wind, water, and solar power. Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials." *Energy Policy* **39**: 1154–1169.

[2] Mohammad Reza Maghami, Hashim Hizam, Chandima Gomes, Mohd Amran Radzi, Mohammad Ismael Rezadad, Shahrooz Hajighorbani. (2016) "Power loss due to soiling on solar panel: A review." *Renewable and Sustainable Energy Reviews* **59**:1307–1316**.**

[3] Motasem Saidan, Abdul Ghani Albaali, Emil Alasis, John K. Kaldellis. (2016) "Experimental study on the effect of dust deposition on solar photovoltaic panels in desert environment." *Renewable Energy* **92**: 499-505.

[4] Nallapaneni Manoj Kumar, K. Sudhakar, M. Samykano, V. Jayaseelan, (2018) "BIPV Market Growth: SWOT Analysis and Favorable Factors." *2018 4th International Conference on Electrical Energy Systems (ICEES),* 7-9 February 2018, Chennai, India.

[5] Basant Raj Paudyal, Shree Raj Shakya. (2016) "Dust accumulation effects on efficiency of solar PV modules for off grid purpose: A case study of Kathmandu." *Solar Energy* **135**: 103–110.

[6] Kumar, N. M., Kumar, M. R., Rejoice, P. R., and Mathew, M. (2017) "Performance analysis of 100 kWp grid connected Si-poly photovoltaic system using PVsyst simulation tool." *Energy Procedia* **117**:180-189.

[7] Nallapaneni Manoj Kumar, K. Sudhakar & M. Samykano (2017) "Techno-economic analysis of 1 MWp grid connected solar PV plant in Malaysia." *International Journal of Ambient Energy* DOI: 10.1080/01430750.2017.1410226

[8] Julius Tanesab, David Parlevliet, Jonathan Whale, Tania Urmee. (2017) "Seasonal effect of dust on the degradation of PV modules performance deployed in different climate areas." *Renewable Energy* **111**: 105-115.

[9] F. Ju and X. Fu. (2011) "Research on impact of dust on solar photovoltaic(PV) performance." *2011 International Conference on Electrical and Control Engineering*, Yichang, pp. 3601-3606.

[10] Water-free and energy independent cleaning system, Ecoppia - Robotic Solar Cleaning Solution, URL: http://www.ecoppia.com/ (Last Assessed on 04 May 2018)

[11] Solar Cleaning Robots, MIRAI, URL: https://www.miraikikai.jp/english (Last Assessed on 04 May 2018)

[12] PV-Rob, Zero One Mechatronics, URL: https://www.01mechatronics.com/reference/pv-rob (Last Assessed on 04 May 2018)

[13] Mallikarjun G. Hudedmani, Gita Joshi, Umayal R M, Ashwini Revankar. (2017) "A Comparative Study of Dust Cleaning Methods for the Solar PV Panels." *Advanced Journal of Graduate Research* **1(1):** 24-29.

[14] E. M. Al-Qubaisi, M. A. Al-Ameri, A. A. Al-Obaidi, M. F. Rabia, L. El-Chaar and L. A. Lamont. (2012) "Microcontroller based dust cleaning system for a standalone photovoltaic system." *2009 International Conference on Electric Power and Energy Conversion Systems, (EPECS)*, Sharjah, pp. 1-6.

[15] Amit Kumar Mondal & Kamal Bansal. (2015) "A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels." *Advanced Robotics* **29(8)**: 515-524.

[16] Nallapaneni Manoj Kumar, Bhogula Navothna, Manisha Minz. (2017) "Performance Comparison of Building Integrated Multi-Wattage Photovoltaic Generators Mounted Vertically and Horizontally." *2017 IEEE International Conference on Smart Technology for Smart Nation (SmartTechCon)*, 17th–19th August 2017, Bangalore, India, pp. 709-714.

[17] Nallapaneni Manoj Kumar, P. Rajesh Kumar Reddy, Kalakanda Alfred Sunny, and Bhogula Navothana. (2016) "Annual energy prediction of roof mount PV system with crystalline silicon and thin film modules." *Special Section on: Current Research Topics in Power, Nuclear and Fuel Energy, SP-CRTPNFE 2016, International Conference on Recent Trends in Engineering, Science and Technology* **1 (3):** 24-31, Hyderabad, India.