

Portable and Customizable Solar Panel Cleaner Design

Aep Saepul Uyun^{1,*}, *Muhammad Ivan Setiawan*², *Bangun Novianto*¹, *Fitriani Fitriani*¹, *Riki Firmandha Ibrahim*¹, *Andy Tirta*¹, *Muhammad Syukri Nur*¹, *Didik Sugiyanto*², *Roy Hendroko Setyobudi*¹, and *Juris Burlakovs*³

¹Graduate School of Renewable Energy, Darma Persada University, Jl. Taman Malaka Selatan No.22, Special Region of Jakarta 13450, Indonesia

²Department of Mechanical Engineering, Darma Persada University, Jakarta 13450, Indonesia

³The Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Wybickiego 7, 31-261 Kraków, Poland

Abstract. The purpose of this research is to design a solar panel cleaning tool that is easy to operate and can adjust the size of the installed solar panels. There are several factors that can affect the performance of solar panels, namely the placement of solar panels that cause accumulation of dust, bird droppings and water (salt) stains. The traditional cleaning system is still done manually. Manual cleaning has several disadvantages such as panel damage, risk of worker accidents, movement difficulties, poor maintenance, and others. Therefore, a solar panel cleaning tool is needed on the market that can help optimize solar panel performance and is easy to operate. The method used in this research is to design a prototype solar panel cleaner that can be operated easily and can be adjusted according to the size of the installed solar panel. The result of this research is a prototype of a solar panel cleaning tool with a total mass of 6 kg and easy to operate with a microcontroller system. Effectively this equipment shows the function of the cleaning tool to do its job, namely cleaning dust. Furthermore, this research needs to analyze the techno-economics of addition batteries to facilitate operation.

Keywords: Brush, customisable, lead screw, photovoltaic.

1 Introduction

Solar energy is a renewable energy that is abundantly available throughout Indonesia, especially since the country is located on the equator [1]. This energy takes the form of rays and waves. Solar energy can be converted into electricity using solar photovoltaics [2], and solar thermal power [3], or into heat energy with a solar thermal collector [4], or both electric and thermal with a hybrid photovoltaic and thermal (PVT) collector [5].

Solar power plants (PLTS) as an alternative source of electrical energy can be used by people who need electrical energy [6]. The use of electrical energy is usually used to meet

* Corresponding author: aepsuyun@gmail.com

the electricity needs of houses, buildings, street lighting and other equipment that requires electricity [7]. The use of solar energy is a current effort to reduce global carbon emissions which has become a major global environmental, social and economic issue in recent years [8, 9]. Technological advances and optimization in the solar panel production process, have made it possible to lower prices in the field of solar power production. This product also allows the reduction of CO₂ produced without negative economic impacts. Thus, solar power generation can become an important technology in global efforts to minimize the impact of climate change [10].

However, there are several factors that can affect the performance of solar panels, namely the placement of solar panels that cause accumulation of dust, bird droppings and water stains (salt) [11]. It can significantly reduce the efficiency of solar panels. Solar panel module efficiency is reduced by 10 % to 25 % due to losses in the inverter, cables and module fouling (dust and debris) [12].

Dust remains a significant challenge for the solar industry at both the operation and maintenance level, as dust accumulation on panels can significantly reduce the power output of the panels [13]. There is a strong alignment between areas of optimal solar insolation and the presence of climax conditions that cause dust deposition on solar panels [14]. As such, dust deposition is a critical challenge that will impact the economic viability of solar power in many areas if deposition is not reduced [15].

It has been observed that power generation losses due to dust accumulation can exceed 40 %, and daily losses due to dust deposition in the atmosphere can exceed 6 %. Annual losses in electricity production due to dust deposition can be up to 10 % [16]. Despite the urgency of the problem as indicated by the emerging literature, and much research focused on measuring the impact of dust in reducing solar power generation, there has been little work in place to assess the impact of emerging dust mitigation technologies [17].

The traditional cleaning system is still done manually. Manual cleaning has several disadvantages such as panel damage, risk of worker accidents, movement difficulties due to limited space and distance, poor maintenance, and others. Several other challenges such as energy consumption, pressure on the solar panel cleaning robot, slip on the robot, and autonomous operation need to be identified as the main challenges in the research and development of solar panel cleaning tools [18].

2 Solar panel cleaner

Studies on the design and mechanism of a solar panel cleaning robot have been carried out before. The air-dense two phase flow control equation for the dust adsorption process, the mechanical behavior of the dust particles and the relationship between the pressure distribution and the velocity of the dust particles are theoretically analyzed for Computational Fluid Dynamics (CFD) simulations [19]. The new design and implementation of the portable PV cleaning robotic system has proven to increase the efficiency of PV mini-grid [20]. Design and development of a solar panel cleaning robot using a rotary brush and water spray to enhance the cleaning system. The results of the study of the movement of the solar panel cleaning robot using a gear motor can operate at a surface level of 0° to 30° and a cleaning system using a rotating brush can clean 80 % of solar panels [21].

Other research implements a low-cost, autonomous robotic device that operates without rails or guides to remove waterless dust and sand from the surface of photovoltaic panels with Arduino as the control system. Experimental laboratory tests have been carried out on a 2 × 4 PV array, the robot is intentionally aligned to the right straight direction of movement for angles up to 30°. Under these conditions, it has been verified continuous operation of the robot capable of carrying out more than 50 consecutive complete turns of a laboratory PV array covering a total surface area of approximately 550 m² without interruption [22]. The

development of cleaning robots is also underway to clean PV modules at Quaid-e-Azam Solar Park (QASP) which are low cost and have a simple design. This mechanism mainly consists of a duct fan, roller brush and fan blower to allow for slip-free movement and optimize cleaning of the glass surface. The results show the efficiency of the mechanism in cleaning the module effectively [23]. Another development for low-cost robots is cleaning photovoltaic surfaces by leveraging mobile applications. The test method (i.e. in dusty conditions), a small amount of powder is sprinkled over a panel under irradiated sunlight. The generated current and efficiency levels are monitored using the Blynk app, which is connected to the PV panel. The results show an increase in system performance where the generated current increases from 0.35 to 0.95 A while the efficiency level is increased from 35 % to 94.95 % after robot cleaning [24].

In another study, a solar panel cleaning model based on the internet of things, called the smart solar photovoltaic cleaning system, is presented by Khadka *et al.* [25]. This research focuses on its implementation in large-scale solar power plants with standard panel configurations. Several technology platforms can be leveraged to deploy autonomous vehicles for cleaning solar panels. The PV power plant is modeled using a virtual robot experiment platform and a Robot Operating System (ROS) is used for the algorithm to control the vehicle [26, 27]. Another study used the Arduino controller system to control the robot's movement during the cleaning process. In addition, it is equipped with two coarse sponges and a water pump system that can be used to clean dust or dirt found on the surface of the PV panels. The results show that the developed solar panel cleaning robot is able to clean the panel effectively and increase the output current and maximum power of the panel by 50 % [28].

3 Methods

Cleaning dust can be done if you know the nature of the dust (chemical properties, size, shape, weight, etc.) and environmental conditions (location-specific factors, environmental features, and weather conditions). Surface type, slope angle, humidity and wind speed also affect the dusting process. A framework for understanding the various factors governing dust deposition/assimilation. Several methods for cleaning PV panels are broadly divided into two methods, namely the method of cleaning with water and cleaning without water [29].

The method used in this research are: first, initial design and parameter analysis based on solar panel dimensions. The initial design was carried out by designing a cleaning system without using water, this was done considering that the installation of solar panels is in a large field where water is not available around the installation site. The dimensional parameters of solar panels are an important factor in making a cleaning system that can adjust dimensions to make it easier to operate. In addition, the selection of materials and components for vertical and horizontal motion is also considered carefully.

Second, designing a control system for automatic control. The control system can be done automatically using Arduino as a microcontroller. The system is made to control the vertical and horizontal motor movement speed. Controlling the motor so that it can stop when it is at the end of the solar panel to avoid damage to the cleaning tool. In addition, the control system will regulate the brush so that it can operate optimally.

Third, 3D design and fabrication. The 3D design was created based on the initial design using the student version of the Autodesk Inventor software. Overall, cleaning equipment is designed and fabricated with equipment that is easy to use, and is available in the laboratory.

4 Results and discussion

4.1 Solar panel cleaning design

The advantage of this solar panel cleaning prototype is that the operation process is very easy, it can be adjusted to the installed solar panel dimensions, and adopts a semi-automatic system. Based on these challenges, the authors choose equipment and materials that are easy to fabricate. The equipment and materials used are shown in Table 1.

Table 1. Initial design parameter materials of the solar panel cleaning design.

Number	Input parameters	Value	Unit
1.	Aluminium profil	3	m
2.	Pillow block	6	pcs
3.	Shaft (as)	330	mm
4.	Gearmotor power	0.0017	kW
5.	Motor rotation (n)	150	rpm*
6.	Gearbox ratio (r)	37.3:1	
7.	The number of the pulley teeth on the motor (zm)	40	th
8.	The number of the pulley teeth on the shaft/as (zr)	29	th
9.	Lead screw	500	mm
10.	Lead screw diameter (d)	8	mm
11.	Wheels	65	mm

Figure 2 shows pictures of prototype solar panel cleaner. The total weight of this prototype is only 6 kg. The main components of the solar panel cleaner prototype are shown in Figure 2.

The way this solar panel cleaning tool works is at the beginning of operation, the brush motor drive will turn on and supply electrical power to the pulley which is channeled to the shaft to drive the cleaning brush, after the cleaning brush rotates, the lead screw motor drive will rotate the lead screw clockwise to lower the cleaning frame until it touches the limit switch. Cleaning frame touches the limit switch installed on the lower base frame, the lead screw motor driver will automatically change the reverse rotation to raise the trousers frame again, until it touches the limit switch mounted on the upper frame base, after the pants frame touches the upper limit switch, the driving motor moves will turn on to move the base frame horizontally, this mechanism will work continuously until the ultrasonic sensor no longer reads the surface on the solar panel. After the ultrasonic sensor does not read the solar panel surface signal, this equipment will automatically stop. That means the cleaning tool has successfully completed cleaning evenly to the PV array system.

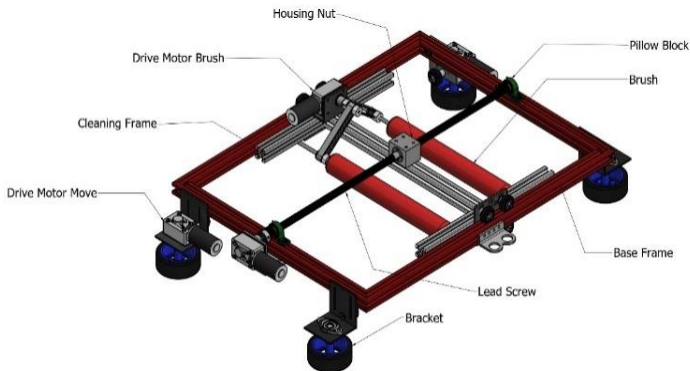


Fig. 1. The solar panel cleaner components.

4.2 System overview

Figure 3 shows a block diagram of a solar panel cleaning tool. Consists of a microcomputer unit, Arduino mega, ultrasonic sensor, limit switch, motor driver, and DC motor. The brain of this project is the microcontroller unit. A microcontroller unit controls the motion of a DC motor based on input from an ultrasonic sensor. It also determines how long the brush should be on during cleaning.

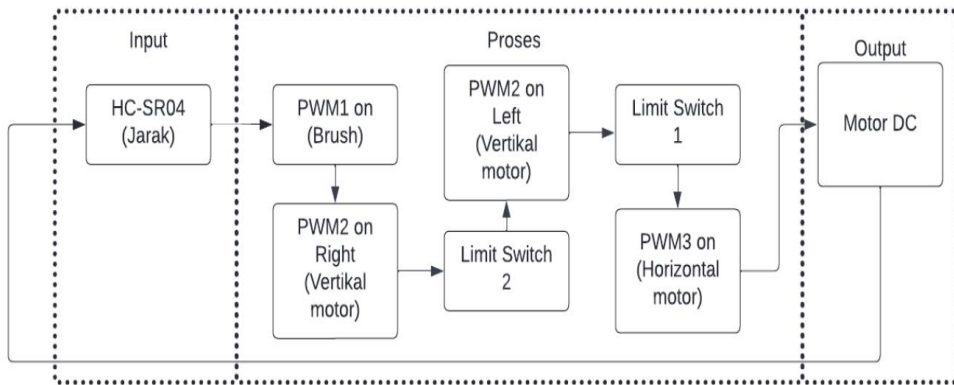


Fig. 2. Block diagram for the designed cleaning solar panel tool.

In this system, the input from the ultrasonic sensor checks the distance between the tool and the surface of the solar panel, if the distance is too far then this tool will not turn on, on the contrary if this tool has been placed in accordance with the standard it will enter the process stage. Next, PWM1 turns on, namely the brush motor which starts to rotate at maximum speed, and continues with 53 PWM2 turns on rotating to the right to bring the brush down until it is hit by the limit switch.

The limit switch functions as an input in the form of a value of 1 or 0 which indicates that 0 limit switch is not depressed and 1 limit switch is depressed, this is the same for the limit switch on the top of the tool. If the brush has reached the bottom and the limit switch is pressed, PWM2 will move in the opposite direction to bring the brush up. Then, the horizontal motor or PWM3 will turn on to move to the right and when horizontal movement will always be checked on the ultrasonic sensor whether the tool is still in the actual position. The last output of this tool is a DC motor that drives the entire device. The list of hardware used to develop the proposed prototype is shown in Table 2.

Table 2. List of hardware.

Number	Component	Description
1.	Arduino mega	To control the overall cleaning process of the tool.
2.	Motor driver BTS 7960	Embedded with arduino mega to connect the DC motor.
3.	Motor DC	To rotate the brush and move the tool.
4.	Ultrasonic	To measure the distance movement of the robot.
5.	Limit switch	Change the position of the terminal contacts to return the motor rotation in the opposite direction.

Based on the results described above, there are at least two important things that need to be discussed further here. First, mechanism of vertical movement to transmit cleaning system with lead screw. Second, portable and customizable solar panel cleaning tool made compared to previous studies.

The timing belt is usually used as a link between the shaft and the pulley on solar panel cleaning tools to move the brush section vertically. However, the timing belt has a weakness, namely the belt cannot be used with a very long shaft distance because slip or deflection will occur on one side of the belt.

Therefore, the vertical mechanism in this study uses a lead screw on the main frame which is supported by a pillow block and connected using a nut housing on a cleaning H frame as shown in Figure 4. In addition, the use of this lead screw makes it easier for the user to adjust the size cleaning tool according to the size of the installed PV because there is no worry that deflection will occur. When compared to the belt, it will be difficult for the user to adjust the size of the cleaning tool to the size of the installed PV.



Fig. 3. The vertical transmission system mechanism uses a lead screw.

The previously made solar panel cleaning equipment is portable, easy to move and operate. Some of the solar panel cleaning equipment that has been made has working properties resembling a robot [21, 22], where the working principle of the drive wheel is relatively moving above the glass of solar panel. The author considers the usability aspect for extreme slopes, because different locations will have different tilt angles of the PV system. In addition, if the choice of wheel material is not correct, it can cause slip due to the load of the cleaning tool, it can also cause the equipment to fall from the solar panel due to gravity from the tilt angle of the solar panel. Therefore, the propulsion system is made using wheels that move on the trajectory of the frame from the solar panel. Apart from being unaffected by extreme tilt, the wheels will also not damage the PV glass which can reduce the efficiency of PV production.

Most solar panel cleaners are designed with predefined dimensions [18, 25], which means that solar panel cleaners can only be used on one size of PV array system, cannot be used if the size of the PV array system is different. Differences in PV array systems usually occur due to differences in PV capacity. In the solar panel cleaning tool that is made, the dimensions of the solar panel cleaning tool can be adjusted to the size of the PV array system.

Customizable itself can be done by removing the elbow bolts on the base frame then the base frame can be adjusted to the size of the installed solar panel as shown in Figure 5. In addition, this equipment also has a shock breaker installed on the horizontal drive wheels to adjust the movement of the wheels. uneven due to joints in the PV array system.

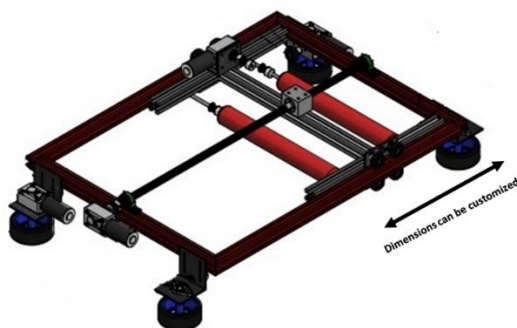


Fig. 4. Customizable size solar panel cleaning tool.

Solar panel cleaning tools can be operated to clean PV arrays installed on rooftops due to the range of available electricity. However, this equipment is still difficult if the PV farming is located in a very large area and far from a power source. Therefore, for future research directions, this research needs to technically and economically analyze the addition of batteries to facilitate operation.

5 Conclusion

In this study, a fully assembled solar panel cleaning tool including programming and cleaning sequences was made using the Arduino platform. It is completely designed to be easy to operate and can adjust the installed solar panels very easily. The experimental results show the function of the cleaning tool to do its job, namely cleaning dust.

References

1. R.A. Wahyuono, M.M. Julian, *Revisiting renewable energy map in indonesia: seasonal hydro and solar energy potential for rural off-grid electrification (provincial level)*. The 3rd International Conference on Electrical Systems, Technology and Information (Bali, Indonesia, 2017). MATEC Web of Conferences **164**,01040: 1–11 (2018) <https://doi.org/10.1051/mateconf/201816401040>
2. M.B. Hayat, D. Ali, K.C. Monyake, L. Alagha, N. Ahmed, *Int. J. Energy Res.*, **43**,3: 1049–1067 (2018) <https://doi.org/10.1002/er.4252>
3. N.R. Avezova, A.E. Khaitmukhamedov, A.Y. Usmanov, B.B. Boliyev, *Appl. Sol. Energy*, **53**: 72–77 (2017) <https://doi.org/10.3103/S0003701X17010030>
4. K.R. Kumar, N.V.V.K. Chaitanya, N.S. Kumar, *J. Clean Prod.*, **282**: 125296 (2021) <https://doi.org/10.1016/j.jclepro.2020.125296>
5. E. Yandri, *MethodsX*, **6**: 2620–2635 (2019) <https://doi.org/10.1016/j.mex.2019.10.021>
6. C.B. Rudationo, B. Novianto, E. Yandri, H. Susanto, R.H. Setyobudi, A.S. Uyun, et al., *Proc. Pak. Acad. Sci.*, **58**,S: 131–139 (2021) [https://doi.org/10.53560/PPASA\(58-sp1\)750](https://doi.org/10.53560/PPASA(58-sp1)750)
7. B. Novianto, K. Abdullah, A.S. Uyun, E. Yandri, S.M. Nur, H. Susanto, et al., *E3S Web Conf.* **188**,00005: 1–11 (2020) <https://doi.org/10.1051/e3sconf/202018800005>
8. E. Kabir, P. Kumar, S. Kumar, A.A. Adelodun, K.H. Kim, *Renew. Sust. Energ. Rev.*, **82**,Part 1: 894–900 (2018) <https://doi.org/10.1016/j.rser.2017.09.094>
9. A.S. Uyun, C.B. Rudationo, T. Wahjatmo, B. Novianto, E. Yandri, M. Syukri, et al., *J. Sains Teknologi*, **12**,1: 265–274 (2022) <http://repository.unsada.ac.id/3882/>
10. B. Parrott, P.C. Zanini, A. Shehri, K. Kotsivos, I. Gereige, *Sol. Energy*, **171**: 526–533 (2018) <https://doi.org/10.1016/j.solener.2018.06.104>

11. A. Gheitasi, A. Almaliky, N. Albaqawi, *Development of an automatic cleaning system for pv plants*. 2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (Brisbane, Queensland, Australia, 2015). Conference Proceeding **3**: 7–10 (2016) <https://doi.org/10.1109/APPEEC.2015.7380938>
12. M. Mani, R. Pillai, *Renew. Sust. Energ. Rev.*, **14**,9: 3124–3131 (2010) <https://doi.org/10.1016/j.rser.2010.07.065>
13. M.J. Adinoyi, S.A.M Said, *Renew. Energy*, **60**: 633–636 (2013) <https://doi.org/10.1016/j.renene.2013.06.014>
14. D. Deb, N.L. Brahmabhatt, *Renew. Sust. Energy Rev.*, **82**,Part 3: 3306–3313 (2018) <https://doi.org/10.1016/j.rser.2017.10.014>
15. S.C.S. Costa, A.S.A.C. Diniz, L.L. Kazmerski, *Renew. Sust. Energy Rev.*, **63**: 33–61 (2016) <https://doi.org/10.1016/j.rser.2016.04.059>
16. M. Saidan, A.G. Albaali, E. Alasis, J.K. Kaldellis, *Renew. Energy*, **92**: 499–505 (2016) <https://doi.org/10.1016/j.renene.2016.02.031>
17. W. J. Jamil, H. A. Rahman, S. Shaari, Z. Salam, *Renew. Sust. Energy Rev.*, **67**: 876–891 (2017) <https://doi.org/10.1016/j.rser.2016.09.072>
18. N.M. Kumar, K. Sudhakar, M. Samykano, S. Sukumaran, *Procedia Comput. Sci.*, **133**: 746–754 (2018) <https://doi.org/10.1016/j.procs.2018.07.123>
19. S. Cai, G. Bao, X. Ma, W. Wu, G.B. Bian, J.J.P.C. Rodrigues, et al., *J. Clean. Prod.*, **217**: 724–731 (2019) <https://doi.org/10.1016/j.jclepro.2019.01.135>
20. A. Al Baloushi, M. Saeed, S. Marwan, S. Algghafri, Y. Moumouni, *Portable robot for cleaning photovoltaic system: Ensuring consistent and optimal year-round photovoltaic panel performance*. 2018 Advances in Sciences and Engineering Technology International Conferences (Dubai, Sharjah, Abu Dhabi, United Arab Emirates, 2018). Conference Proceeding. p.1–4 (2018) <https://doi.org/10.1109/ICASET.2018.8376781>
21. N. Ronnaronglit, N. Maneerat, *A cleaning robot for solar panels*. 2019 5th International Conference on Engineering, Applied Sciences and Technology (Luang Prabang, Laos, 2019). Conference Proceeding. p.1–4 (2019) <https://doi.org/10.1109/ICEAST.2019.8802521>
22. M.G. Antonelli, P.B. Zobel, A. De Marcellis, E. Palange, *Mechatronics*, **68**: 102372 (2020) <https://doi.org/10.1016/j.mechatronics.2020.102372>
23. M.U. Hassa, M.I. Nawaz, J. Iqbal, *Towards autonomous cleaning of photovoltaic modules: Design and realization of a robotic cleaner*. 2017 First International Conference on Latest Trends in Electrical Engineering and Computing Technologies (Karachi, Pakistan 2017) Conference Proceeding. p.1–6 (2018) <https://doi.org/10.1109/INTELLECT.2017.8277631>
24. N. Hashim, M.M. Mohammed, R. Al Selvarajan, S. Al-Zubaidi, S. Mohammed, *Study on solar panel cleaning robot*. 2019 IEEE International Conference on Automatic Control and Intelligent Systems (Selangor, Malaysia, 2019). Conference Proceeding. p.56–61 (2019) <https://doi.org/10.1109/I2CACIS.2019.8825028>
25. N. Khadka, A. Bista, B. Adhikari, A. Shrestha. D. Bista, *IOP Conf. Ser.: Earth Environ. Sci.*, **463**,012121: 1–8 (2020) <https://doi.org/10.1088/1755-1315/463/1/012121>
26. N.K. Memon, *Autonomous vehicles for cleaning solar panels*. 2016 International Renewable and Sustainable Energy Conference (Marrakech, Morocco, 2016). Conference Proceeding. p.633–637 (2017) <https://doi.org/10.1109/IRSEC.2016.7983975>
27. F.H.M. Noh, M.F. Yaakub, I.N.A.M. Nordin, N. Sahari, N.A. Zambri, S.S. Yi, et al., *Indones. J. Electr. Eng. Comput. Sci.*, **19**,3: 1245–1250 (2020) <http://doi.org/10.11591/ijeecs.v19.i3.pp1245-1250>
28. A. Syafiq, A.K. Pandey, N.N. Adzman, N.A. Rahim, *Sol. Energy*, **162**: 597–619 (2018) <https://doi.org/10.1016/j.solener.2017.12.023>

29. P.A. Patil, J.S. Bagi, M.M. Wagh, *A review on cleaning mechanism of solar photovoltaic panel*. 2017 International Conference on Energy, Communication, Data Analytics, and Soft Computing (Chennai, India, 2017). Conference Proceeding. p.250–256 (2018) <https://doi.org/10.1109/ICECDS.2017.8389895>